DAMS, DEVELOPMENT AND DOWNSTREAM COMMUNITIES:

IMPLICATIONS FOR RE-OPTIMISING THE OPERATIONS OF THE AKOSOMBO AND KPONG DAMS IN GHANA

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CONTENTS

Foreword vii
Acknowledgment ix
List of Figures x
List of Tables xiii
List of Plates xv
Appendix xv

PART ONE: BACKGROUND OF LOWER VOLTA:
PRE-DAM AND CURRENT CONDITIONS 1

Chapter 1 Overview of the Re-operation and
Re-optimisation of the Akosombo and
Kpong Dams Project 3
Eric A. Ofosu, Marloes Mul, Maxwell Boateng-Gyimah,
Frank Annor and Ben Y. Ampomah

Chapter 2 Re-optimisation and Re-operation Study of
Akosombo and Kpong Dams: Voices from the
Downstream Communities 27
Daniel Nukpezah, Louisa M. Sawyerr,
Richard Twum-Barimah and Yaa Ntiamo-Baidu

Chapter 3 Environmental Flow Requirements and Impacts
of the Akosombo and Kpong Dams on the Fish and
Fisheries of the Lower Volta River, Ghana 43
Hederick R. Dankwa, Solomon A. Owiredu,
Francis Amevenku and Edem Amedorme

Chapter 4 Impacts of Hydrological Changes of the
Volta River on Local Livelihoods: Lessons for
Re-Operation and Re-Optimization of
the Volta Dams 63
Jesse S. Ayivor and Benjamin D. Ofori
Chapter 5  Flow Requirements for Aquatic Biodiversity and Aquatic Weeds  
Felix J. Akpabey, Gloria Addico and Godwin Amegbe

Chapter 6  Groundwater Recharge Studies and Trends in the Lower Volta River Basin, Ghana  
William A. Agyekum, Anthony A. Duah, Collins Okrah and Evans Manu

PART TWO: CONCEPT OF DAMS RE-OPERATION AND RE-OPTIMIZATION

Chapter 7  A Review of the Benefits of Environmental and Livelihood Flows of Dam Re-operation and Re-optimisation  
Daniel Nukpezah, Opoku Pabi, Benjamin D. Ofori, Jesse S. Ayivor and Chris Gordon

Chapter 8  Analysis of Changes in Downscaled Rainfall and Temperature Projections in the Volta River Basin  
Emmanuel Obuobie, Barnabas Amisigo, Frederick Logah and Kwabena Kankam-Yeboah

Chapter 9  Defining Restoration Flow Targets to Restore Ecological Functions and Livelihoods in the Lower Volta Basin  
Marloes L. Mul, Eric A. Ofosu, Yaw Mante, Benjamin Ghansah, Frank O. Annor and Maxwell Boateng-Gyimah

Chapter 10  Trade-Offs Between Hydropower Production and Downstream Flow Requirements  
Frank O. Annor, Maxwell Boateng-Gyimah, Marloes Mul, Philip Padi, Afua Adwubi, Kwame Darkwa and Charles Addo
PART THREE: TECHNICAL AND SOCIO-ECONOMIC FEASIBILITY OF RE-OPERATION SCENARIOS

Chapter 11 Perceptions of the Effects of Re-Operation of The Akosombo and Kpong Dams on the Livelihoods of Downstream Communities
William Baah-Boateng, Richard Twum-Barimah, Louisa M. Sawyerr and Yaa Ntiamo-Baidu

Chapter 12 Re-operation and Re-optimisation of Akosombo and Kpong Dams - Engaging Downstream Communities in Re-operation Scenario Options
Fidelia Ohemeng, Narkie N. A. Nartey, Louisa M. Sawyerr, Richard Twum-Barimah and Yaa Ntiamo-Baidu

Chapter 13 The Economics of Re-operating the Akosombo and Kpong Hydropower Dams
Bedru B. Balana, Marloes L. Mul and Yaw Mante

Chapter 14 Framework for Re-operating the Large Hydropower Dams To Improve Local Livelihoods and Poverty Reduction
Marloes L. Mul, Bedru Balana, Frank O. Annor, Maxwell Boateng-Gyimah, Eric A. Ofosu and Jeffrey Dokyi

PART FOUR: MANAGING OF RE-OPERATION AND RE-OPTIMISATION SCENARIOS

Chapter 15 Institutional Capacity and Management of the Volta Lake Shores and the Lower Volta River Channel
Benjamin D. Ofori and Jesse S. Ayivor
Chapter 16  Adaptive Management Design for the Akosombo and Kpong Dams' Re-optimisation and Re-operation: The Principles and Practice  341
Opoku Pabi, Daniel Nukpezah and Christopher Gordon

Chapter 17  Public Health Impact of Dam Re-Operation and Re-Optimisation: The Case of the Lower Volta Basin  369
Dzidzo Yirenya-Tawiah, Benedicta Fosu-Mensah, Daniel Nukpezah and Christopher Gordon

PART FIVE: ALTERNATE APPROACH TO RESTORING LIVELIHOOD OF DOWNSTREAM COMMUNITIES  395

Chapter 18  Improving Access to Potable Water Supply for Downstream Communities of The Volta Lake  397
Collins Okrah, William A. Agyekum and Anthony A. Duah

Chapter 19  High Spatial Resolution Mapping and Management Options of Aquatic Weeds at the Lower Volta  419
Opoku Pabi and Felix J. Akpabey

Chapter 20  The Anti-Schistosoma Cercarial Penetration Properties and Safety of Topical Herbal Formulation for Control of Schistosomiasis  445
Dzidzo Yirenya-Tawiah, Daniel Boamah, Daniel Nukpezah, Christopher Gordon, William K. Anyan, Mark Ofosuhene and Kwabena K. Bosompem
FOREWORD

There is no gainsaying that the Akosombo and Kpong hydropower plants have contributed enormously to the socioeconomic development of Ghana. However, these hydropower dams have also contributed to the loss of livelihoods of the downstream communities and the interruption of ecosystem processes on which they depend. The re-optimisation and re-operation study of the Akosombo and Kpong dams project sought to provide solutions to reverse these trends, and, in doing so, to illuminate techniques for improving the environmental performance of these and future hydropower dams.

This publication provides valuable knowledge on several and diverse multidisciplinary, but interconnected, studies commissioned under the project. It presents in a single volume the results of in-depth investigations on defining flow targets to restore ecological functions and livelihoods by creating and evaluating operational scenarios to achieve the target flows, by constructing a model of the power generation and distribution system to evaluate technical and economic feasibility, by evaluating the operational scenarios for economic feasibility, by estimating the effects of re-operation on public health, and by identifying alternative ways of improving livelihoods of downstream communities.

Seasoned researchers and experts from leading partner institutions have contributed to these varied in-depth investigations, which are also ways of understanding and setting up pragmatic interventions to improve livelihoods, growth and sustainable management of natural resources within the downstream sections of a major dam. The publication will also inform and guide policy makers, researchers, public and private sector practitioners, and development partners in the planning, design and implementation of multi-agency collaborative schemes.

The message is that we have been offered a suite of techniques that can be widely applied to current major dams and to the next generation of dams to make them more environmentally compatible. We have been
provided with useful knowledge to improve the future of downstream riparian communities who are highly dependent on the services provided by the slowly deteriorating fresh water ecosystems. We have also been served with knowledge that contributes to the global process of shared learning.

Ben Ampomah
Executive Secretary
Water Resources Commission
ACKNOWLEDGEMENT

Considering the breadth which this book covers, its start and indeed its finish owes much to the generous support, both intellectual and practical, of many people and institutions who need special mention and commendation.

This book is a product of the Re-optimisation and Re-operation study of the Akosombo and Kpong Dams Project, supported financially by the African Water Facility (AWF) of the African Development Bank (AfDB). Special thanks goes to their staff who were directly assigned to the project. Their contribution to the success of the project and to this book is very much appreciated.

The Volta River Authority (VRA), which is the main operator of the two dams (Akosombo and Kpong), was key throughout the conception, implementation and finalization of the project. Without the consent of the VRA, the project and this book could not have materialised. We enjoyed their maximum cooperation in terms of data, information, access to facilities and support in kind.

The Water Resources Commission is grateful for the part played by the Natural Heritage Institute, especially during the conceptual and initial stages of the project. The role of the Ghana Grid Company is also highly appreciated as they joined in the middle of the implementation and contributed immensely to the studies conducted on the West Africa Power Pool (WAPP) Model.

Finally, we acknowledge the implementing partner institutions mainly, the International Water Management Institute (IWMI), CSIR-Water Research Institute (WRI), Institute for Environment and Sanitation Studies (IESS), and The Centre for African Wetlands (CAW) and their teams for their invaluable work that ensured that the project was successfully executed and that this book is published in a timely fashion, and reaches the widest possible audience.
LIST OF FIGURES

Fig. 1.1: Pre- and Post-dam flow regime in the Lower Volta 11
Fig. 1.2: Dam re-operation concept 14
Fig. 1.3: Restoration hydrograph scenarios 17
Fig. 1.4: Daily average hydropower generation over the simulation period (2016-2050) 19
Fig. 2.1: Map showing key districts in the study area 30
Fig. 2.2: Perception about potential benefits of the project 39
Fig. 3.1: The Lower Volta River Basin showing sampling sites. 47
Fig. 3.2: Catch Per Unit of Effort (number) for the sampling sites at the Lower Volta 51
Fig. 3.3: Shannon Weaver diversity Index (H') for the sampling sites at the Lower Volta 52
Fig. 3.4: Average discharge pattern of the Lower Volta before (1936-1966) and after (1968-2012) construction of the Akosombo and Kpong dams 53
Fig. 4.1: Map of the Volta Basin 67
Fig. 4.2: Lake Water Level – 1970 to 2015 (Source: VRA Records) 73
Fig. 4.3: Pre-dam Flood Recession Area of the Lower Volta Basin 75
Fig. 5.1: The Lower Volta River Basin showing sampling sites. 100
Fig. 6.1: Location map of the downstream part of the Akosombo and Kpong dams 120
Fig. 6.2: Rainfall and evaporation regime of Keta 121
Fig. 6.3: Transmissivity Variation Map of the study area 128
Fig. 6.4: Specific Capacity Distribution map of the study area 129
Fig. 6.5: Plot of Na, Cl and TDS Concentrations in Groundwater of the study area. North, Mid and South = Northern, Middle and Southern sections of the study area 130
Fig. 7.1: Sustainable Livelihoods framework, with explanatory notes 149
Fig. 8.1: Location map of the Volta Basin 162
Fig. 8.2: Schematic overview of the methods used for generating downscaled ensemble mean climate simulations for the Volta Basin (SS = synoptic station) 164
Fig. 8.3: Map of the Volta basin showing the 3 climate zones and location of 17 synoptic stations used in this study 167
Fig. 8.4: Current (1981-2010) and Future (2011-2040) mean daily temperature for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A1B scenario 174
Fig. 8.5: Current (1981-2010) and Future (2011-2040) mean daily temperature for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A2 scenario  

Fig. 8.6: Current (1981-2010) and Future (2011-2040) mean monthly rainfall for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A1B scenario  

Fig. 8.7: Current (1981-2010) and Future (2011-2040) mean monthly rainfall for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A2 scenario  

Fig. 9.1: a) Average monthly hydrograph, before and after dam construction; b) Flow duration curve, before and after dam construction (Source of data VRA, 2011)  

Fig. 9.2: Approach towards developing restoration hydrographs  

Fig. 9.3: Flood inundation map of the Lower Volta (after VRA, 2011)  

Fig. 9.4: Re-operation scenarios for Akosombo and Kpong dams  

Fig. 10.1: Dam operated for hydropower  

Fig. 10.2: Conceptual model of dam re-operation  

Fig. 10.3: Hydrographs for scenarios of re-operation and re-optimisation of Akosombo and Kpong dams  

Fig. 10.4: Schematic view of the Lower Volta WEAP model for the Akosombo and Kpong Re-operation and Re-optimisation project  

Fig. 10.5: Ghana’s Energy demand/consumption and forecasts  

Fig. 10.6: Simulated and observed Water Storage Volume at Akosombo (1981–2013)  

Fig. 10.7: Daily Hydropower Generation at Akosombo (2016-2050) for the 4 main scenarios and the reference scenario  

Fig. 10.8: Hydropower production (Daily Average from 2016-2050 at Akosombo) for S3 with 1 – 5 additional turbines  

Fig. 10.9: Daily Average Hydropower Generation at Akosombo with Climate Change Considerations  

Fig. 10.10: Average daily Downstream flow requirements delivered (2016-2050)  

Fig. 11.1: Proportions of basic and social infrastructural facilities  

Fig. 11.2: Major economic activity by district (%)  

Fig. 11.3: Current livelihood status of residents by economic status (%)  

Fig. 11.4: Relative livelihood conditions before and after construction of the dams (%)  

Fig. 11.5: Benefits associated with the construction and operation of the dams  

Fig. 11.6: Adverse effects of the construction and operation of the dams (%)  

Fig. 11.7: Net effects of the construction and operation of the dams (%)
Fig. 11.8: Suggestions to restore livelihood by type of economic activity (%) 252
Fig. 13.1: The “with and without” approach to CBA of dam re-optimisation 282
Fig. 13.2: Map of Lower Volta with key sites indicated 286
Fig. 13.3: NPV of the four flow regime (dam re-operation) scenarios 295
Fig. 14.1: Framework for assessing feasibility of re-operating dams 306
Fig. 14.2: NPV for the scenarios 2015-2050 313
Fig. 15.1: Map of the study area, the Volta Lake/River system 326
Fig. 16.1: The Lower Volta 345
Fig. 16.2: Set-up and iterative phases of adaptive management 349
Fig. 16.3: Adaptive management cycle of the Volta Dam Re-optimization 353
Fig. 16.4: A Conceptual Framework of the Volta Dams Operational Impacts on Downstream Ecology and Communities 357
Fig. 17.1: Map showing sampling area for environmental assessment 373
Fig. 17.2: Snail vector density along communities of the Lower Volta in March 2014 387
Fig. 17.3: Water salinity variation in the Lower Volta 388
Fig. 17.4: Variation in electric conductivity (EC) in the Lower Volta 388
Fig. 17.5: Heavy metal levels in water samples taken from some locations in the Lower Volta River 389
Fig. 18.1: Geological map of project site showing the location of existing boreholes 401
Fig. 18.2: Available water supply sources in the downstream communities showing [A] percentage water use in 153 communities and [B] percentage water use in 47 communities without pipe borne water 403
Fig. 18.3: Comparing resistivity tomography of quartzite terrain within Asuogyaman District showing aquifer thickness and poorly weathered hard basement rock located at Abume, Ghanakpoe, Marine and Gyakiti communities 406
Fig. 18.4: Classification of bedrock resistivity and base flow direction of Asuogyaman District 406
Fig. 18.5: Bedrock resistivity variation of the study area showing groundwater potential zones and groundwater flow direction based on variations in apparent resistivity of bedrock (negative values depict salinity) 410
Fig. 18.6: Groundwater potential categories based on bedrock resistivity assessment of Communities in the study area 410
Fig. 19.1: The Lower Volta and the Adopted Mapped Sections 423
Fig. 19.2: Aquatic weed types mapped in the study. These were distributed in distinct patterns of coverage 429
Fig. 19.3: Aquatic weed maps in at Atimpoku and Kpong Reservoir in Section A. 431
Fig. 19.4: Submerged and free floating weeds at the center of image from NDVI. Dark and light brown patches are submerged plants closer to the surface. Green patches are deeply submerged plants.

Fig. 19.5: Overview of Water hyacinth coverage at the delta of the Lower Volta. To the Left is detailed cross-section of the different classes of aquatic weed. Note the sequence of aquatic weed organization from the open waters to the banks: from the submerged, water hyacinth and Vossia sp. association.

Fig. 20.1: Effects of the aqueous and ethanol extracts of Balanites aegyptiaca stem bark on proliferation of human normal and cancer cell lines compared with effect of curcumin in vitro at 72 h using the MTT assay.

LIST OF TABLES

Table 1.1: Flow requirements for the sub-sectors
Table 1.2: Expert opinion expected impact of selected restoration hydrographs
Table 2.1: Selected communities from each district of the study area
Table 3.1: Species occurrence and distribution in the Lower Volta during the study
Table 5.1: Phytoplankton species composition, abundance and diversity identified in the Lower Volta
Table 5.2: Distribution of macro-invertebrate families and species at the various sites at the Lower Volta
Table 5.3: Shannon-Wiener Diversity Index for the macro-invertebrates
Table 5.4: Distribution of aquatic weeds at the various sites in the Lower Volta
Table 6.1: Statistical analyses on the available historical borehole data (VRWSSP, 1998)
Table 6.2: Tested boreholes and the computed aquifer characteristics (from this study)
Table 8.1: Groupings of synoptic stations by climate zones of the Volta Basin
Table 8.2: Projected changes in temperature in the Volta Basin under IPCC SRES A1B scenario
Table 8.3: Projected changes in temperatures in the Volta Basin under IPCC SRES A2 scenario
Table 8.4: Projected changes (%) in rainfall in the Volta Basin under IPCC SRES A1B scenario
Table 8.5: Projected changes (%) in rainfall in the Volta Basin under IPCC SRES A2 scenario
Table 9.1: Ecosystem services and other considerations taken into account
Table 9.2: Key ecosystem services and flow requirements during dry and wet season
Table 9.3: Flow requirements for the sub-sectors
Table 9.4: Expert opinion expected impact of selected restoration hydrographs
Table 10.1: Hydropower Production at Akosombo
Table 10.2: Percentage of time minimum hydropower production is met for the various scenarios
Table 10.3: Unmet Annual Irrigation Water Demand in the Lower Volta basin from 2016-2050
Table 11.1: Communities where Qualitative survey was carried out
Table 11.2: Sample of Communities covered in the Quantitative Survey
Table 11.3: Basic Characteristics of Households
Table 11.4: Age Distribution and unemployment and literacy rate of Household members
Table 11.5: Main Job of Household members aged 15+ and unemployment rates by age (%)
Table 13.1: Methodological approach for estimating cost and benefit for each component
Table 13.2: Assumptions for Valuation of the scenarios
Table 13.3: Total Benefits (USD) per scenario for base year 2015
Table 13.4: Total Cost (USD) per scenario for base year 2015
Table 13.5: NPV of the four flow scenarios at various discount rates (in billions of USD)
Table 14.1: Hydropower production for different re-operation scenarios
Table 14.2: Hydropower benefits based on technical and structural feasibility
Table 14.3: Net Benefit ($) per scenario for the base year 2015
Table 14.4: Total cost for expansion of the network capacity
Table 14.5: WAPP implications of the re-operation scenarios.
Table 14.6: Total investment costs, NPV (discount rate of 10%) for selected scenarios with and without investment
Table 16.1: Potential group and specific stakeholder groups
Table 16.2: Issues and Specific Problem Areas
Table 16.3: Action impact monitoring
Table 17.1: Summary of public health issues of concern in case of re-operation of the Akosombo and Kpong dams
Table 17.2: Aquatic vegetation situation in selected human contact sites
Table 19.1: NDVI Statistics for features. Water has the lowest values, with water hyacinth having the highest values.
Table 20.1: Number of snails collected during the snail survey activities and the number of infected snails.
Table 20.2: Anti-cercarial activity of aqueous extract of Balanites aegyptiaca stem bark on Schistosoma mansoni and S. haematobium
Table 20.3: Anti-cercarial activity of absolute ethanol extract of Balanites aegyptiaca stem bark on Schistosoma mansoni and S. haematobium 457

Table 20.4: Cercariae and schistosomulae recovery after 24 h ointments treatment of Balb/c mice skin 459

Table 20.5: Phytochemicals identified in the extracts of Balanites aegyptiaca stem bark 461

Table 20.6: Anti-cercarial activity of 70% ethanol extract of Balanites aegyptiaca stem bark on Schistosoma mansoni and S. haematobium 462

**PLATES**

Plate 4.1: Foreground and background arrows illustrating the extent of lake recession at Yeji (© JS Ayivor) 84

Plate 4.2: Arrow showing location of market stalls and water level at Yeji: January 2010 (© JS Ayivor) 85

Plate 4.3: Shoreline erosion at Amedika near the Kpong barricade in 2010 88

**APPENDIX**

Appendix 4.1: Names of District Government Officials And Traditional Areas Visited For Interviews 94

Appendix 5.1: Aquatic macrophytes present in the Kpong headpond and Lower Volta River 115

Appendix 18.1: Public Infrastructure (22 schools) identified for rainwater harvesting 414
PART ONE

BACKGROUND OF LOWER VOLTA:
PRE-DAM AND CURRENT CONDITIONS
CHAPTER ONE

OVERVIEW OF THE RE-OPERATION AND RE-OPTIMISATION OF THE AKOSOMBO AND KPONG DAMS PROJECT

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Keywords: Hydropower, Downstream impact, Re-operation scenarios, Downstream livelihoods, Flow target

Conceptualization of the Project

Background of the Project

Hydropower constitutes 16\% of the total electric energy produced worldwide. As the world continues to combat climate change, hydropower is widely seen as a clean energy source which helps to mitigate climate change and as such is receiving a lot of attention. Despite the huge benefits of hydropower development across the globe, its development has conventionally come at a high cost in terms of riverine livelihoods and ecosystems.

The Akosombo dam, which was completed in 1965, formed Lake Volta, the largest man-made water storage reservoir in Africa and the world.
Twenty-five kilometres downstream of the Akosombo Dam, the Kpong Dam operates as a run-of-the-river facility with minimal storage to re-generate power from the Akosombo releases. The Akosombo and Kpong dams were designed to generate an average of 6,100 GWh/yr. In addition to power generation, the Akosombo dam provides some degree of flood protection due to its very large storage capacity relative to inflow, and the Kpong dam supplies a small amount of irrigation (only about 1000 ha) for rice cultivation. Navigation and a robust lake fishery are important additional benefits of the reservoir.

Like storage reservoirs in general, the function of the Akosombo dam is to store water during seasons and years of high inflow for power generation during seasons and years of low inflow. In Ghana, the demand pattern causes the Akosombo dam to be operated to generate a relatively constant output of power daily and seasonally. Thus, the Akosombo dam alters the natural river flows by storing and releasing water in rhythm with the patterns of electricity demand in the service area rather than the seasonal patterns of rainfall and runoff in the catchment area. The effect on the downstream flow pattern is to reduce the peak flows and increase the base flows, effectively eliminating the dynamic interactions between the river and its floodplains, wetlands, deltas, estuaries, mangrove and beach environments. These are the great engines of riverine and marine biodiversity and the environmental services that they provide for the myriad of human livelihoods that are dependent upon a fully-functioning river system.

The Akosombo dam has also devastated the livelihoods of the downstream communities and the physical ecosystem processes on which they depend. The results have been a drastic reduction in floodplain agriculture, as natural flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas and an explosion in the growth of exotic weeds that have choked off the once lucrative shell fishery, increased the snail vectors for the debilitating bilharzias, and fostered the formation of a permanent sandbar at the estuary.

The shellfish have been hit particularly hard. Before the dam, there was a robust clam fishery at the Lower Volta. Clams that could only reproduce in brackish water moved up and down the river, so they had a large
habitat. Now that the front is fixed, they can only reproduce in a narrow strip. Due to the vegetation and water quality changes, clam picking, an occupation mainly dominated by women, has almost been eliminated. Many other commercially valuable species have severely declined or disappeared as well, including blue crab, shrimps, shad and herring.

The regulation of flows, the trapping of natural sediments in the reservoirs, and the formation of the sandbar have drastically changed the morphology of the river channel and the mangroves and beaches at the mouth of the river as well.

Before the dams, the shoreline erosion was estimated at 2-5 m/yr. Today, the beach is eroding at the rate of 10 m/yr. The coastal erosion also affects neighboring Togo and Benin, whose coasts are now being eaten away at a rate of 10-15 m/yr. This is because the dams trap the sediments that replenish the beaches.

The overall effect of the loss of agriculture, clam picking and fishing activities has created intense poverty and led to a dramatic shift in income generating activities. Some 80,000 people are directly adversely affected by the change in livelihood.

Project Conceptualization and Development

Following publications arising from several years of research on the downstream ecosystem and livelihoods of the downstream inhabitants with respect to the Akosombo and Kpong Dams, the Natural Heritage Institute (NHI), a Non-Governmental Organization from the United States, approached the Water Resources Commission (WRC) in 2005. NHI shared its interest in addressing the challenges imposed by the dams, and requested that WRC team up with NHI so that they could develop a project that would help address the above mentioned challenges through a dam re-operation and re-optimisation concept.

The Water Resources Commission, together with the NHI, took a period of time (between 2005 and 2007) to conduct consultative meetings with relevant stakeholders such as the Volta River Authority, the Ministry of Water Resources, Works and Housing, the Ministry of Energy, the Environmental Protection Agency, the Ministry of Environment
Science and Technology, the Ministry of Local Government as well as downstream inhabitants to introduce the project concept and seek their support and inputs into the project development.

The project development was led by the WRC and NHI. A team of local and international consultants with various experiences in the Volta Basin and related research areas of the subject were brought together to develop the project. The project development team was made up of researchers from the Water Research Institute (WRI), the International Water Management Institute (IWMI), the Natural Heritage Institute, Purdue University, Cornell University, the Centre for African Wetlands (CAW), the Volta River Authority (VRA), the Volta Basin Research Project of the University of Ghana (VBRP) which is now part of the Institute of Environment and Sanitation Studies (IESS), representatives of the traditional authorities of the downstream inhabitants and the Volta Basin Development Foundation (VBDF). The members of the project development team formed the project partners and in May 2007, organized a workshop at the Kofi Annan Centre in Accra to design the project. The workshop was used to set the objectives, impacts, outcomes and outputs of the project.

**Objectives of the Study**

The long term goal of the study is to contribute to economic growth and poverty reduction through improvement of downstream ecosystem functions and livelihoods by re-operating and re-optimizing the Akosombo and Kpong dams.

The specific objective of the study is to produce a technically and economically feasible re-operation plan which will retain existing benefits of the Akosombo and Kpong dams’ operations while improving livelihoods and ecosystem functions. Beyond this, the study is expected to demonstrate the efficacy of the resulting re-operations plan through experimental flow releases and to document and share the results of the techniques and the lessons learnt widely for application to the current inventory of major dams and to the next generation of dams to make them more environmentally compatible.
**Expected Impacts of the Project**

The expected project impact is to reintroduce, to the extent possible, downstream ecosystem functions and livelihoods and to buffer the effects of climate change, while at the same time ensuring that previous benefits are retained.

**Outcomes of the Project**

The project seeks to develop an optimization model that will be used to re-operate the dams to achieve the following outcomes:

- Improved downstream ecosystems and human livelihoods. This will include:
  - Increased flood plain agricultural production as a result of controlled downstream flooding;
  - Increased human livelihoods due to employment in agriculture, fishing and related businesses;
  - Reduced coverage of exotic aquatic weeds;
  - Groundwater availability as a result of recharge due to annual flooding;
  - Resumed shell fishing due to re-establishment of the salinity regime.

- Continued protection of the downstream communities from the larger flood events that would jeopardize human settlements while accommodating seasonal inundation of farmlands. This entails the reintroduction, to the extent possible, of the natural flow patterns. In effect, the floodplain storage would augment the reservoir in attenuating flood pulses, allowing the reservoir to be maintained at higher storage levels year around.

- Increased total electric power output of the dams, while altering the generating schedule. This would be accomplished by maximizing the hydrologic head and thus increasing electricity output through simulation of the planning model.
• Increased reliability of water supply for hydropower generation. This would be accomplished by investigating the optimum reservoir levels that will keep the reservoirs full during the early years of an extended drought, thereby reducing the potential for power shortages in later years.

• Reduced incidence of water borne disease vectors. Re-operating the Akosombo and Kpong dams will reduce the static water levels and therefore exotic weeds that are the breeding grounds of bilharzia and malaria, thus improving the health and productivity of millions of people downstream of those dams.

Expected Outputs of the Project

The project was developed to produce the following outputs:

• A computer simulation of the physical processes and infrastructure operations in the entire Volta River system;

• A power system planning model constructed for the grid system at its current state of integration with Nigeria, Benin, Burkina Faso, Cote d’Ivoire, Niger, Nigeria and Togo (West Africa Power Pool Zone A). The model also accounts for current hydro and thermal generation connected to that grid, including plants now under construction, as well as future additions to electrical supplies, which are also dynamic;

• An Economic model developed that estimates an economic incentive structure to induce users and dam operators and stakeholders to implement re-operation;

• A feasibility report prepared on the legal, institutional and political implications of re-operating dams according to the natural flow patterns;

• A report on the effects of re-operation of the Akosombo and Kpong dams on public health;

• If the model proves successful there will be the need for a follow-on study to define downstream activities that shall be necessary for improving the livelihoods of the inhabitants;
Pre-Implementation Process of the Project

Following the conceptualization of the Project and its development, the project partners developed the project proposal which they used to seek funding. The Water Resources Commission being a Government Agency, was made the implementing agent of the project, and led the partners in their search for funding. A request was sent to the African Water Facility (AWF) of the African Development Bank (ADB) in August 2008 for the financing of the project. The total budget of the Project submitted to the AWF was 2.859 Million Euros and the study was expected to be executed in 36 months.

After assessing the proposal, the AWF concluded that the project falls within the African Water Facility’s intervention areas of Water Governance and Water Resources Knowledge and Information building and dissemination. Further, it met the AWF policy that water resources should be developed and managed, among other things, to ensure ecosystem sustainability at national and transboundary levels.

The AWF embarked on a mission from 29th September to 6th October to appraise the project. Based upon a comprehensive assessment of the proposed project, and taking into consideration its relevance, effectiveness, efficiency and sustainability, and the recipient’s credibility and capacity, the AWF recommended that the project be considered.

The project received official approval from the AWF on the 2nd of August, 2010. The AWF identified the Water Resources Commission as the Executing Agency and the following as the key partners of the project:

- Centre for African Wetlands
- Institute of Environment and Sanitation Studies
- Water Research Institute
- International Water Management Institute
- Natural Heritage Institute
- Volta River Authority

On the 7th of January 2011, the AWF approved a grant not exceeding One Million Eight Hundred and Thirty Thousand, Eight Hundred and Ten Euros (Euro 1,830,810) to implement the project. The remaining
part of the budget funding was provided by the Government of Ghana (in kind).

**Project Implementation**

The commencement of the project required the fulfilment of some conditions demanded by the AWF. This included the establishment of a Project Management Unit to be headed by a Project Manager “who shall report directly to the Executive Secretary of the WRC”. Another condition required for the commencement of the project was the establishment of a Project Steering Committee (PSC) to guide the implementation of the project. A third condition required was the formation of a Scientific Advisory Committee (SAC) composed of three leading international and two reputed national scientists knowledgeable in the field to advise the PSC. The final condition was the opening of a Special Project Account by the WRC.

The WRC fulfilled these conditions in April 2012. The Project received the first disbursement on 25th May 2012 to commence the project, with the last date of disbursement given by the AWF as 31st May 2014.

The team of consultants (both local and international) who were the key project partners were pre-selected and assigned various aspects of the project. The study commenced in August 2012 and ended in June 2016 after receiving two extensions during the project implementation.

The study is a suit of activities that were executed in phases and when put together result in the achievement of the overall objective. It began with the identification of the pre-dam and the current conditions. After the first phase of activities were completed in December 2013, the project underwent a mid-term review in January 2014 which came up with findings that changed the course of the project. The key finding in the mid-term review was that due to the energy situation in Ghana and the forecasted energy challenges in the near future, the re-operation experimentation was not feasible. As such, the mid-term review recommended that the budget allocation for re-operation experimentation should be used to investigate alternate ways of improving the livelihoods of the downstream inhabitants in the
absence of re-operation. The second phase of the project involved the establishment of restoration flow objectives. The third phase considered a set of re-operation scenarios which were modelled to establish the technical, economic and socio-economic impacts. Finally, the project also looked at alternate ways of improving livelihoods in the absence of re-operation.

**Key Findings of the Project**

The key findings of the project based on the execution phases of the project are briefly outlined as follows.

**Pre-dam and current conditions**

The hydrology of the Lower Volta has been impacted significantly by the construction of the Akosombo and Kpong dams. The highly dynamic system with peak flow during the months of September and October and long dry season flows has been changed into a steady flow regime (Fig. 1.1).

![Fig. 1.1: Pre- and Post-dam flow regime in the Lower Volta](image)

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The current status of the Lower Volta River during the flood season (August-November) is close to class C (disturbed habitat and dynamics). During the dry season the flow is more than 10 times higher than the natural flow.

Floods have supported ecosystems by inundating large areas of floodplain and reconnecting creeks to the river, by offering good spawning grounds for fish, and by providing good fish yields. Low flows allowed for saltwater intrusion up to 95 km from the estuary, supporting a healthy clam industry mainly operated by women. Impoundment of the water in Lake Volta not only changed the flow regime, but also reduced flows in the Lower Volta as a result of evaporation (surface area of the formed Lake Volta at its maximum is 8,500 km²). The impoundment also traps the majority of the upstream sediments, which is the main cause of the very low sediment transport values measured in the Lower Volta. In combination with predominant sandy soil, there is high potential of scouring of river bed and banks. Due to the absence of high peak flows after the dam construction, a sandbar emerged at the mouth of the estuary, blocking saltwater intrusion and flooding upstream areas.

The pre-dam conditions provided several livelihood opportunities for downstream communities. These include fishing, farming, clam picking, petty trading, craftwork and manufacturing of nets and fish traps. The situation changed after the dam was created as a result of the dwindling resource base which has contributed to impoverishment of households. This is described in the following paragraphs.

Although there is little information on the various types of fishes found in the Lower Volta before the construction of the dam, there is anecdotal evidence that there was a good mix of freshwater, brackish water and marine water fish. The majority of the fish species now found in the Lower Volta are freshwater fish, although some few brackish water species were found some 80 km from the estuary. Fish catch has declined since the construction of the two dams, in particular due to the limited flooding of the river creeks. The West African manatee *Trichechus senegalensis*, which is listed by the IUCN as ‘Vulnerable’ since 1986, was reported by fishermen to be present in the area, albeit at much lower numbers than before. The vibrant shellfish fisheries which comprised
clams, oysters, shrimps, prawns and crabs, a livelihood activity that supported most communities during the pre-dam construction phase, are now completely lost in many places, and are mainly found within 15 km from the estuary.

Farming activities prior to the dam construction included wide-spread flood recession farming (>50,000 ha, Barry et al., 2005). Yields were relatively high due to the deposition of fertile soils in the floodplains. After the construction of the two dams, flood recession ceased, but there is a large potential for irrigation, although only a small portion of land is currently being irrigated (<10,000 ha). Overall, fewer community members are benefiting from the Lower Volta through farming activities compared to the pre-dam era.

The regulated flow due to the damming of the Volta River has promoted waterweed infestation and invasion that negatively impact on socio-economic conditions. The number of aquatic plant species in the Kpong headpond and Lower Volta River has increased from 15 in 1981 to 65 in 2015, consisting of 47 emergent, 12 free floating and 4 submerged species. Some invasive alien species (Eichhornia crassipes, Cyperus papyrus and Salvinia molesta) which were hitherto not present in the Volta River system have also invaded the headpond. The presence of the weeds has brought along various water borne and water related disease vectors, causing many problems for the people who inhabit the area. Bilharzia infection rates have increased with the aquatic weeds providing a good habitat for the snails. On the other hand, with the flooding of the Senchi rapids, onchocerciasis is no longer a public health threat in the Lower Volta. Malaria incidences have decreased with fewer shallow water bodies filled after the flooding season, but the disease still remains a threat.

With sufficient surface water available year round, groundwater is not well studied in the area. However, with the decreasing water quality of the surface water and water borne diseases, groundwater is increasingly becoming an important source for potable water.

Out of the different issues raised above, the communities identified the following key issues and concerns related to the pre- and post-dam era: unpredictable flooding; loss of natural floodplains; growth of aquatic weeds which also cause vegetation decay, kill fish and impede the smooth flow of the river; adverse effects on the fishing industry;
reduction in onchocercosis (river blindness); increase in Bilharzia; increased salinization; reduced yield from farmlands; development of sand bars and dune.

**Concept of dam re-operation**

Considering the issues raised in the previous section with regard to the current operation of the dams, dam re-operation was brought to the table to address the issues. Re-operating dams is an innovative way of addressing these challenges and can potentially increase total annual hydropower production. The concept is depicted in Fig. 1.2. For the conventional way of operating a hydropower dam, dynamic flows fill the dam and a steady flow regime is released. Due to the difference in inflow and outflow during seasons the water level in the reservoir fluctuates as well. During the dry season the water level reduces as there is less water flowing in than out. The hydropower production throughout the year is relatively steady as a function of the water level and outflow.

![Fig. 1.2: Dam re-operation concept](image)

The reoperated dam on the other hand releases flows that mimic the natural flow regime. In this scenario, as inflow and outflow are almost equal, the water level in the dam is steady. Hydropower production is
therefore more efficient (more MWh per m$^3$). However, the hydropower production fluctuates throughout the year, and during the peak flow period additional investments are required to harness the hydropower. Reduction in hydropower production during the dry season needs to be compensated for by increasing electricity generation capacity in the network.

Based on the rapid response survey conducted, 74% of the respondents foresee that re-operating the two dams could be beneficial to the communities and improve livelihoods. However, it has to come with other specific activities: removal of the sandbar at the estuary, dredging of the creeks and the lagoons, establishment of data collection stations at vantage points, promotion of cage farming and the provision of credit facilities for the communities.

**Defining Restoration Flow Targets**

The link between the flows and the ecosystem services is crucial in order to determine which type of flows could be released from the dam to restore specific Ecosystem Services (ES). For some services, the flow requirements can be determined by the amount of water the services need (e.g. irrigation or domestic water use), but for ecosystem services the relationship is more complex. Often, the ecosystem services are dependent on timing, area flooded and flood duration. After identifying the key downstream components, an ‘ideal’ flow hydrograph was constructed for each one and services combined that favour similar flows. These were put together into a selected number of restoration flow scenarios.

For fisheries (including clams and oysters), aquatic weeds removal, health and flood recession farming, the natural flow regime was found to be the most optimal flow regime (Table 1.1).
Table 1.1: Flow requirements for the sub-sectors

<table>
<thead>
<tr>
<th></th>
<th>Dry season flow</th>
<th>Wet season flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Fish - Tilapia and catfish, aquaculture, agriculture: large and small scale irrigation</td>
<td>Weeds, Fish: all except aquaculture, groundwater recharge, salinity, health: schistosomiasis</td>
</tr>
<tr>
<td>Low</td>
<td>Weeds, fish - floodplain spawning fish, clams and oysters, brackish and marine fish, agriculture: flood recession farming, health: schistosomiasis</td>
<td>Fish - Aquaculture; agriculture: large and small scale irrigation; Health: malaria</td>
</tr>
</tbody>
</table>

Seasonal flood flows provide spawning grounds in the floodplain and offer suitable land for flood recession farming, while seasonal low flows allow for salt water intrusion and larger areas suitable for clam production. Aquatic weeds are favoured by fresh water and steady flow conditions as do bilharzia snails; the natural flow regime is therefore good for managing the weeds, by washing out weeds during peak flows and increasing saltwater into the Lower Volta in the dry season. High peak flows can also contribute to breaking the sandbar.

Irrigation, aquaculture and hydropower, on the other hand are favoured by steady flow regimes with fresh water and limited fluctuations in flow velocity and water level.

Based on these preferences, two scenarios were developed, one with a steady flow regime, similar to the current day flow regime, and the other with the average pre-dam flows for the wet and dry season. Two other scenarios were developed, balancing the two scenarios, introducing the natural dynamics, while maintaining sufficient water for the users, which required the steady flow regime. These four scenarios are depicted in Fig. 1.3.
The first scenario represents the current flow regimes, the second scenario restores natural flow dynamics up to the 2010 spill level while reducing an equivalent amount during the dry season. The third scenario increases the natural dynamics while maintaining sufficient water during the dry season for irrigation. The fourth and final scenario considers average historical pre-dam flow conditions.

An initial assessment on how the components are affected by the different scenarios shows that none of the scenarios benefits all components (see Table 1.2). There is therefore a clear trade-off between the different scenarios.
Table 1.2: Expert opinion expected impact of selected restoration hydrographs

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Health</th>
<th>Fish</th>
<th>Hydropower</th>
<th>Infrastructure in floodplain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfed</td>
<td>Irrigation</td>
<td>Flood recession</td>
<td>River blindness</td>
<td>Bilharzia</td>
</tr>
<tr>
<td>S1</td>
<td>N</td>
<td>++</td>
<td>--</td>
<td>++</td>
</tr>
<tr>
<td>S2</td>
<td>N</td>
<td>+</td>
<td>N</td>
<td>++</td>
</tr>
<tr>
<td>S3</td>
<td>N</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>S4</td>
<td>N</td>
<td>--</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

++ very good; + good; N neutral; - bad; -- very bad

Modelling of Re-operation Scenarios

Climate change impact on inflows into Akosombo

Climate change (CC) is projected to have considerable impacts on both natural and human systems, including water resources. Generally, the Volta Basin is projected to become warmer and slightly wetter in the future, under both the IPPC A1B and A2 scenarios examined. The mean annual temperature is projected to increase, on average, by about 0.5°C-0.6°C by 2050. The total annual rainfall is projected to increase by about 2-8% in the basin under both scenarios, consistent with several other studies undertaken of the basin.

The impact of CC on the inflows into the Akosombo dam was assessed using the SWAT hydrological model driven by the results for the two CC projections. In general, results from the study show an increase in the mean annual streamflow into the Volta Lake by about 17% and 16% under the A1B and A2 scenarios respectively over the simulation period (2016-2050).
Water allocation

The WEAP model was used to assess the impact of the proposed restoration scenarios on hydropower production. Scenario 1 predicted an average annual hydropower generation close to the reference scenario of 5,256 GWh/yr. However, increasing more dynamic flow regimes as proposed by Scenarios 2, 3 and 4 (S2, S3, and S4) reduced hydropower generation by 45%, 58% and 74% respectively. In this case, only S1 satisfies the FIRM hydropower requirement of 4,415 GWh/yr.

S1 generates daily average hydropower steadily in the range of about 12 GWh to about 18 GWh, satisfying the daily requirement of at least 6 GWh to guarantee system stability, whereas the others fail this test (Fig. 1.4). Adding new turbines to the Akosombo dam increased daily generation by 9% per turbine (S3) during the wet season, increasing annual hydropower production by 1-2% only. This by no means offsets the reduction in hydropower. Climate change projections will affect potential hydropower production, ranging from -8% for CC scenarios with decreasing water availability to +8% for CC scenarios with increasing water availability.

For irrigation water demand, the present abstraction rate (10 m$^3$/s) will not be affected during re-operation. Increasing the abstraction rate to 38 m$^3$/s to account for the anticipated irrigation expansion, effective the year 2020, would mean that demand for some few dry years will not be fully met (however, this will lead to about 0.1% shortage).
Socio-economic analysis

Next to the current challenges faced by the communities, the 2010 spilling of the Akosombo dam provides some good insight into the effects of reintroducing natural flow regimes, in particular in relation to releasing flood peaks. The socio-economic analysis shows that the 2010 spilling had negative impact on communities, while community members expected that further spilling/flooding would lead to higher negative impacts. On the other hand, communities are inclined to perceive the pre-dam flows as more beneficial, even though reverting to such conditions would mean higher and more destructive flooding. This perception does not take into consideration the changed conditions, for example the floodplains currently being used for irrigation with the accompanying infrastructure. Damages accrued in 2010 may also be high compared to a situation where communities are aware of the dynamics and can anticipate river levels at the beginning of the season. The 2010 spilling was not anticipated well in advance and damages could have been avoided if this was clear well ahead of time (e.g. farmers planted in floodplains, and there was insufficient time to move fish cages/boats etc.). The potential destructiveness of the floods is illustrated by the fact that during the 2010 spilling, VRA increased the flow steadily to 2,650 m$^3$/s but had to reduce it to 2,300 m$^3$/s because of downstream complaints and unexpected impacts.

Economics

The economic analysis considered the cost and benefit of the four scenarios on 12 components that contribute to riparian livelihoods (Table 1.2). Two of the components listed in Table 1.2 were not considered as they were not expected to change under the scenarios; fresh water and brackish water fish were merged. The economic valuation of the ecosystem services under different scenarios used a range of market and non-market valuation approaches. The analysis showed that the current flow regime is very beneficial for the main economic components: hydropower, aquaculture and large scale irrigation, which contribute largely to the total economic benefits. However, restoring natural flow conditions contributed more towards improving rural livelihoods such as fisheries and flood recession farming. On the other hand, regular flooding affected the economic activities of large scale investors while threatening the livelihood of
riparian communities in terms of infrastructural damage, lack of access to freshwater for domestic use and potential for dry season smallholder agriculture. Introducing investments such as additional turbines and power distribution capacity, increased the economic value of the re-operation scenarios by producing more electricity, but could not off-set the investments required.

From the cost-benefit perspective, the current flow regime is the most ideal scenario, and there is more potential for further economic development, such as large scale irrigation and aquaculture. However, this should be more targeted towards benefiting the local communities.

Managing of Re-operation Scenarios

Governance and institutional framework

The Volta Basin Authority Convention binds six West African riparian countries for trans-boundary management of water resources in the Volta basin. In Ghana, the Water Resources Commission (WRC), Act 522 of 1996, subjects all water resources to state ownership, and the Commission is required by law to regulate, manage sustainably and coordinate government policies in relation to such resources. VRA’s current mandate is to generate electricity and to enhance the health and wellbeing of lake side communities. As part of its operations it is committed to minimize the impact of its operations on the environment. As re-operating the Akosombo and Kpong dams would have an impact on electricity generation as well as the environment downstream, VRA will be at the core of any re-operation. At the same time, re-operation may affect other water users and therefore any major changes in the operation of the dams will have to be approved by WRC as the regulatory body for water allocation in Ghana. Other institutions that have a stake in the re-operation study are the National Disaster Management Organisation, the Fisheries Commission and the Ghana Irrigation Development Authority.

The roles and responsibilities for water resources management are well spelled out in the national policies. However, weak institutional capacity to implement the regulatory mechanisms could negate the benefits of dam re-operation.
Gaps in institutional framework (SWOT analysis)

As mentioned in the previous section, there is a well-defined institutional framework from the international level to the locally decentralized government agencies. Additionally, there is ample qualified and competent managerial staff across scales with the opportunity for training to improve staff competencies and upgrade skills. The existence of well-structured traditional authorities and community resource management regulations is a key strength when considering the implementation of a project such as dam re-operation.

Unfortunately, there is limited budgetary allocation to state agencies, which undermines overall work output, leading to lack of logistics and equipment, which in turn limits efficient and effective work output. Poor service conditions and delays in replacement of retired staff weaken staff morale and strength. There is a general poor co-ordination between government departments resulting in several overlaps, thus waste of limited resources, and a lack of well-defined roles between traditional authorities and state agencies. Jurisdiction over resources (in particular land) in the Volta basin is generally ill-defined. There are weak implementation structures leading to total disregard of policies and regulations governing the Volta basin.

However, the existence of a network of institutions offers an excellent opportunity for education/training and monitoring of riparian activities; collaboration with research institutions provides opportunities for research; and fund raising opportunities through donor agencies and NGOs. On the other hand, there is a potential land and resource-use conflict among competing interest groups, notably local authorities and state agencies, which needs to be managed. The lack of a well-structured implementation strategy is a threat to sustainable resource management, and the lack of enforcement of sanitation bye-laws is a threat to environmental sanitation along lakeshore communities, particularly in periodic market centres.

Design of adaptive management strategy

The socio-economic and management outcomes of the construction and management of hydropower dams for downstream natural ecosystems and communities are not known with certainty. Uncertainty is due to the complex dynamics of the processes and interactions of the multiple
factors of hydrological, socio-economic and demands on power. The key area for Adaptive Management prioritisation in the Lower Volta Basin is monitoring and evaluation. The mitigating strategies were only defined for Scenario 1, as the other scenarios were deemed economically unsound.

To improve the livelihood of downstream communities, support systems such as microfinance schemes should be offered to support small-scale economic activities such as handicraft businesses to diversify the local economy. In addition, there is the need for interventions including regular dredging of the creeks and lagoons; manual and mechanical harvesting of aquatic weeds for manure; research into the use of herbicides that do not affect non target species to control aquatic weeds; removal of the sandbar at the estuary and research towards development of a medicinal product against bilharzia. These interventions should be prioritized. Finally, there is the need for a comprehensive development strategy to deal with poverty and other social problems facing the communities. It was emphasized that both adaptive management and adaptation strategies are needed to manage outcomes of hydropower dam projects for downstream natural ecosystems and communities.

**Alternate Approach to Restoring Livelihoods of Downstream Communities**

To improve riparian livelihoods in the Lower Volta basin without re-operating the Akosombo and Kpong dams, several approaches were identified. The management of aquatic weeds has the highest priority, and then avoiding the infestation of new areas by preventing further spread of water weeds and destroying aquatic weeds in areas with significant aquatic weed coverage. Community engagement in the mechanical removal of weeds showed some success in small areas; however, the communities required capacity building to transform the weeds into a marketable produce which would generate income, as they were reluctant to continue in this endeavour without incentives. Secondly, weevils were introduced in the Lower Volta as a biological control. Although the weevils managed to establish themselves, their current number is too small to counter the reproductive rate of the weeds. More weevils need to be nurtured and released to effectively control the weeds.
The proliferation of the aquatic weeds comes with health implications, as it has created perfect conditions for the snail vector of Schistosomiasis—Bulinus sp. and Biomphalaria pfeifferi. The study looked at developing medicinal products to prevent infection with bilharzia. Anti-cercarial activities of two medicinal plants (Psidium guajava leaves and Balanites aegyptiaca, stem bark) were evaluated. The Balanites aegyptiaca showed better results than the Psidium guajava. Even at low concentrations of 1,000 ppm, the extract proved able to eliminate the cercariae. An ointment based on the Balanite aegytiaca extract was developed to prevent penetration by the schistosome parasite into the human skin. Initial results are very promising, but further pre-clinical and clinical trials need to be done before the ointment will be forwarded to the Food and Drug Authority for approval. This will pave the way for commercial production and distribution to endemic areas.

Access to potable water supply is a problem in the area, with the majority turning to the Lower Volta River to collect drinking water of questionable quality. In addition, the people are unnecessarily exposed to bilharzia when collecting water. It is therefore important to improve access to potable water for these communities. One such source is groundwater, which is readily available in over 81% of the study communities downstream of Sogakope. Aquifers in this area have high groundwater potential with yielding capacity above 100 lpm to meet the required water demand for consumptive and non-consumptive purposes. However, this is limited by high salinity. The areas around Mepe, on the other hand, have relatively low groundwater potential. These areas are recommended to treat water from the Lower Volta River rather than relying on boreholes, as almost all existing boreholes are either dry or marginal-yielding. Alternatively, water can be accessed through rainwater harvesting. Although rainwater harvesting may be a potential solution at the household level, it is not suitable as a collective system, as public buildings provide inadequate amounts of water to supply an entire community.

On improving income generating activities which focused mainly on farming, key constraints were low productivity due to soil fertility and labour availability. With sufficient freshwater available in the Lower Volta, there are opportunities to develop small scale irrigation in the Lower Volta to benefit smallholder farmers. Dry season vegetable farming is identified as one promising way to improve the livelihood
of both women and men in the communities, as there is a large market nearby (Accra). However, there are constraints in the adoption of small scale irrigation technologies in the area, consisting of high investment cost, high fuel cost and transportation costs affecting access to markets. Next to improving capacity in irrigation technologies and farm management, farmers are encouraged to set-up farmer organisations to improve access to markets and to develop value added products. Access to credit for investment in irrigation technologies is crucial for improving livelihoods.

Conclusion

The results of the re-operation and re-optimisation study of the Akosombo and Kpong dams show that re-operation is technically feasible. However, system stability requirements of at least 6 GWh/day of power generation at the Akosombo dam pose a challenge. It was observed that the water level in the Akosombo dam drops steadily in the dry season, for which optimal hydropower production is not feasible using any other flow scenario apart from the current one. On economics, the Net Present Value of economic activities in the area reduces with increasing levels of re-operation, mainly due to reduction in hydropower production. Re-operation requires huge investments in alternative power supplies and transmission capacity, and proves untenable, as the economic status of the downstream communities decreases with increasing re-operation. Socially, communities have adjusted to the post-dam regime and reported negative impacts from the 2010 spilling event. Therefore they are reluctant to accept and adapt to the restoration flows. Moreover, the institutional landscape is too weak to support communities to manage the changes associated with dam re-operation.

Although re-operation of the Akosombo and Kpong dams is not feasible, the framework developed during the study can be applied to other dams, especially recently constructed dams with lower contribution to the national power grid.
CHAPTER TWO

RE-OPTIMISATION AND RE-OPERATION STUDY OF AKOSOMBO AND KPONG DAMS: VOICES FROM THE DOWNSTREAM COMMUNITIES

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Abstract

The Akosombo and Kpong dams re-optimisation and re-operation project was conceptualised to study the economic and technical feasibility of re-operating the dams for possible restoration of the natural flow and riverine ecology, as well as the livelihoods of residents of the Lower Volta Basin. As part of the study, consultations were held with the downstream communities between May 2013 and February 2014, involving a total of 426 discussants from 87 communities. One hundred and fifty-one (151) discussants participated in a follow up rapid response survey conducted to gauge preferences of the communities with respect to re-operating the dams. The findings showed that livelihood, health and environment of the downstream communities have been affected following the damming of the River Volta. Further, while some participants expressed reservations about re-operating the dams, 73.5\% of participants of the rapid response survey were in favour
CHAPTER 2

of re-operating the dams to restore livelihood opportunities. The need for a comprehensive strategy to solve the serious problems of poverty and other social ills in the study area has been emphasised.

Keywords: Community, Downstream, Pre-Dam, Livelihood, Restoration

Introduction

Rivers provide food to support livelihoods, opportunities for commerce and navigation. These roles are largely affected by river damming (Vannote et al., 1980). While there are benefits associated with dam construction in terms of hydropower generation, such development of rivers for hydropower has conventionally come at a high cost in terms of riverine livelihoods and ecosystems. The adverse environmental and social impacts of dam creation are largely unanticipated or underestimated during the design of most reservoirs. Social impacts such as displacement and resettlement of people before river damming may be considered the severest of these impacts (Terminski, 2014), with about 40 to 80 million people displaced globally due to dam creation (WCD, 2000). Hydropower dams have led to the erosion of livelihood opportunities of the downstream communities and the physical ecosystem processes on which they depend.

The damming of the Volta River at Akosombo and Kpong has resulted in a regulated flow downstream, thereby affecting the dynamic interaction of the river with its floodplains. Prior to the creation of the Akosombo dam, the major livelihood activities in riverine communities of the Lower Volta Basin were farming, fishing and clam picking (Lawson, 1963). Other activities included petty trading, native soap making, gin distillation, cotton spinning, basketwork and manufacture of nets and fish traps.

The change in the natural flow and ecology of the riverine system after the dam creation has brought about certain challenges. Major among these is the fact that flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas. In addition, the growth of exotic weeds has destroyed the once lucrative shell fishery and increased the abundance of snail vectors for schistosomiasis. The
overall effect of the loss of agriculture, clam picking, and deteriorating health due to schistosomiasis infestation is intense poverty in the area leading to a dramatic shift in income generating activities. The Akosombo and Kpong dams’ re-optimisation and re-operation study project was therefore conceived to study the economic and technical feasibility of re-operating the dams for possible restoration of livelihoods and income generating activities in the Lower Volta Basin.

The specific objectives of the community consultations were to provide a platform to create awareness of the project, document pre-dam and post-dam issues of concern to the communities, gauge the communities’ thoughts on the project, manage the expectations of the downstream communities and provide feedback from the communities to help address their key concerns. This chapter therefore reflects the thoughts of the communities on the project.

**Study area**

The study area covers eight districts in the Lower Volta Basin which constitute the downstream regions of the Akosombo and Kpong dams. The eight districts were Asuogyaman, Shai-Osudoku, Lower Manya, North Tongu, Central Tongu, South Tongu, Ada East and Keta (Fig. 2.1). The area is characterized by coastal lagoons, tidal creeks, swamps and coastal savannah lowlands with associated vegetation. The area also consists of open grassland and isolated thickets. The rainfall pattern, like most parts of the coastal basin, is bimodal with low rainfall values, averaging 740-910 mm/yr (Ayivor, 2001).
Fig. 2.1: Map showing key districts in the study area.
Methodology

Research approach

The study conducted consultative meetings with communities of the Lower Volta Basin to collect primary data. Secondary data were collected from published literature and commissioned reports. Information received from the community consultations was mostly analysed qualitatively. Descriptive statistics such as averages, percentages, frequencies as well as graphical presentations were made using Microsoft excel software.

Selection of communities

A reconnaissance visit was paid to the project area in April 2013. This visit was preceded by a preparatory phase where the project’s core team members met to discuss its execution. A map of the downstream communities was obtained and after thorough discussions, 87 out of the total of 437 communities (VRA, 2011) in the study area were selected for the consultations. The communities were chosen to ensure a geographic spread in the eight districts in the Lower Volta. Further, the selection of the 87 communities was partly influenced by their closeness to the Volta River, accessibility by vehicle, size, and the perceived vulnerability of the communities to the effects of the dam.

In selecting the communities, chiefs and opinion leaders of the area who were considered to be well versed in local geography and culture were consulted during the reconnaissance visits to confirm traditional boundaries and to generally validate the preselected communities. The reconnaissance visits confirmed the appropriateness of the 87 communities selected for the study.

Community entry

Distinct from the consultative meetings, the community entry involved interaction with key people in the community including paramount and local chiefs, opinion leaders, assembly members and municipal and district assembly officials. Such people could help propagate the objectives of the project and the selection of the community
representatives to participate in the community consultative meetings. Thus, typically, before any consultative meeting, an advance team was sent to the communities to inform the opinion leaders of the scheduled consultative meeting and ask them to invite five representatives of each community to the meeting. The key factors considered in selecting the five representatives included:

- Age: The guiding principle was that the persons selected should reflect the general demographic profile of the community and should not be skewed towards one particular age group.
- Gender: A healthy proportion of male and female was recommended, as traditionally females tended to be marginalised in such fora
- Influence: Influential people and opinion leaders were to be considered
- Knowledge: People knowledgeable about the peculiarities of the communities in relation to the damming of the River Volta
- Status: At least one of the five representatives should include persons such as chiefs, queen mothers and community elders.

**Consultative meetings**

Eight consultative meetings were held on different dates in eight districts in the Lower Volta area (Table 2.1). A maximum of five people from each of the 87 communities were invited to the meetings. The approach used for the consultation was mainly stakeholder group discussion. The consultative meetings were chaired by a traditional ruler or a community leader. A team of resource persons presented the project concept and background information on the creation of the dam. After the presentations the meetings were opened up for general discussions, during which the participants expressed their views and any concerns about the project. Notes were taken for further analysis and documentation.
Rapid response survey

At the end of each stakeholder consultative meeting, a rapid response survey was carried out to elicit feedback on participants’ perception of the project. This was based on a simple questionnaire that was designed for the purpose. The objective was to find out if, following the presentations and discussions, participants still wanted the project to proceed. A total of 151 people responded to the questionnaire. The questionnaire was in two parts. It contained questions such as “based on the background given regarding what the project is envisaged to achieve, would you want the project to come on”? The answers were then cleaned and entered into Microsoft Excel to generate descriptive data and to make graphical analyses and inference.

Table 2.1: Selected communities from each district of the study area

<table>
<thead>
<tr>
<th>District</th>
<th>No. of Towns/Communities</th>
<th>Names of Towns/Communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asuogyaman</td>
<td>7</td>
<td>Abume, Adome, Akrade, Atimpoku, Akwamufie, Mangoase, Senchi</td>
</tr>
<tr>
<td>Shai-Osudoku</td>
<td>14</td>
<td>Abuvienya, Adakope, Asuatuare, Atrobinya, Doffor, Dzorkpor, Gozatkope, Kadjanya/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dormelian, Kassunya, Kotoko, Lubuse, Natriku, Tokpo, Volivo</td>
</tr>
<tr>
<td>Lower Manya Krobo</td>
<td>3</td>
<td>Amedeka, Kpong, Lolonyo</td>
</tr>
<tr>
<td>North Tongu</td>
<td>16</td>
<td>Alabonu, Atitekope, Aveyime, Azaglokope, Battor, Daledorko, Degorme, Fodjoku, Gbadasi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kope, Gbormu, Kasa, Klamadaboe, Mepe, Nakpoe, Sokope, Torgorme</td>
</tr>
<tr>
<td>Central Tongu</td>
<td>10</td>
<td>Adidome, Amerloko, DofforAdidome, DugameMafi, Hudeko, New Bakpa, Sayiko, Titiko, Tsete</td>
</tr>
<tr>
<td></td>
<td></td>
<td>po, Volo</td>
</tr>
<tr>
<td>Ada East</td>
<td>14</td>
<td>Ada Foah, Agorkpo, Alorkpem Island, Amesikpe Island, Aiflive Island, Azizakpe Island,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Big Ada, Dikanya, Dzitrokope, Luhuese, Pediatorko Island, Tuaniko Island, Azizanya,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vidzrokope</td>
</tr>
<tr>
<td>South Tongu</td>
<td>16</td>
<td>Agave, Agbeve, Agordome, Agorme, Agorkpo, Asidowhui, Dalive, Dekporta, Gbenuako, Kpont</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e, Sogakope, Sokpoe, Tadze, Tefle, Vume, Ziwenu</td>
</tr>
<tr>
<td>Keta</td>
<td>7</td>
<td>Agortoe, Anloga, Dzita, Whuti, Keta, Kodzi, Kpordui</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>87</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 2

Validation Durbars

Following the consultative meetings, two separate durbars were organized for selected downstream communities who had participated in the community consultation sessions. The first durbar was held on Tuesday, 4th February, 2014 for selected downstream communities in the northern section of the Lower Volta Basin at Atimpoku; the second occurred on Wednesday, 5th February, 2014 at Sogakope for selected communities in the southern section. The durbars were organized to disseminate information and validate the findings obtained from representatives during interactions at the community consultation meetings. Key issues and concerns raised during the community consultation meetings were presented to invited representatives of selected communities to receive their final assent or make corrections.

Key findings and discussion

Respondents’ statistics

A total of 426 persons from 87 communities participated in the community consultations, including 326 males (73%) and 114 females (27%). One hundred and fifty-one (151) people responded to the rapid response survey. This represents 35.45% of discussants.

Pre-dam and post-dam conditions in the Lower Volta Basin

Some of the key issues raised by participants relate to the pre-dam and early post-dam era. Many of the participants said that flooding was more predictive (once a year) before the impoundment of the river and farmers were able to plan their farming activities. However, flooding became unpredictable after the dam was created and farmers are unable to determine appropriate times of the year to cultivate their crops. In North Tongu, a participant lamented how farmlands have become nutrient deficient, forcing them to stop growing some crops such as cassava.
Another concern expressed was the increased salinization of hand-dug wells - in the shallot farming area of Keta Municipality. Regulated flow from Akosombo and Kpong had resulted in over abstraction of water from the wells. Further, before the construction of the dam, the salt water at the estuary became diluted and ran into creeks that fed the shallot farms. However, with the construction of the dam, there is reduced flow compared to pre-impoundment high flows downstream. There had been little dilution effect, and the relatively little amount of water to the creeks and eventually to the farmlands is much more saline. The high salinity level does not support farming. According to a participant, “hard” water does not make the shallot thrive. This participant further submitted:

We are losing our shallot farming businesses. In the past when we had more reliable flow downstream, we had relative fresh water in the creek that fed our farms but that is not the case presently. Creeks and other tiny tributaries of the Volta River have now dried up. Salty water from the sea has now covered the whole land and farming is entirely interrupted.

The creation of the Akosombo and Kpong dams also affected the fishing industry. This is evident in the decline in lobster catch and the absence of some fish species that were abundant in the pre-dam era. Geker (1999) noted a reduction in the quantity and varieties of some fish species after the creation of the dams. The impact of the dam on fishing is profound, resulting from the prolific growth of weeds on the lake. The extensive growth of weeds which has covered a greater part of the lake has led to a decline in fish catches. The growth of weeds has also affected the hitherto lucrative oyster and crab picking business along the river. In addition, the weeds have many damaging effects, including siltation of the lake, lack of accessibility to water and hindrance to transport and fishing. In the Ada East district, a participant mentioned that salmon fish which used to be present in the river before the dam was created had disappeared. This participant made the following observation:

Fishes move in two directions, i.e., from the sea to the river and vice-versa, to reproduce, but because of the dam the movement of fishes has been compromised and we don’t get enough fish.
This observation is consistent with the fact that salmon is an anadromous species that migrates from the sea to breed in freshwater upstream. The creation of dams without suitable fish passages makes it difficult for such species to migrate upstream due to dam blockage (US, Dept. of Commerce, 2000). Similarly, catadromous species that migrate downstream to the sea also become scarce in the sea.

Another critical issue raised by participants was compensation. Most communities mentioned that they have not benefitted from the compensation schemes offered by the Volta River Authority (VRA). While over 740 villages were submerged in the lake, displacing about 80,000 people when the dam was created, only some 70,000 of these people were resettled into newly constructed settlements (Raschid-Sally et al., 2008). In spite of this, many still complained that they did not receive compensation from VRA. The issue of VRA post-dam engagement with the community remains a bone of contention for many. Indeed some of the participants mentioned that no compensation package was offered to communities affected by the construction of the dam, and some thought the VRA had been indifferent to the plight of the communities downstream of the Akosombo dam. Reacting to discussions relating to VRA’s engagement with the communities and the project under discussion, one key participant was forceful in his submissions:

...talking about dams and VRA, we feel like pointing a gun at you. VRA has not done much for farmers; even menial jobs at VRA are done by people from outside the areas; VRA should give communities scholarships. With regards to bilharzia, there are drugs; our most important need is not dam re-operation, but scholarship to communities

These sentiments reflect the frustration of a cross section of the participants who believed there was a general lack of economic progression in the lives of people of the area. To such people, the key issue is adequate compensation and an opportunity for livelihood engagement which would enable them meet their own health needs.

Many of the participants related that the incidence of schistosomiasis and malaria increased after the building of the dam while the prevalence...
of onchocerciasis became widespread in the area. This assertion is especially true of schistosomiasis. Tsikata (2006) noted that urinary and intestinal schistosomiasis in school children in some lakeside communities increased from 5% in 1960-1961 (before the lake was formed) up to 90% in 1964-1977 (after the creation of dam) and from 6% to 53.5% in downstream communities. Prior to damming, communities accessed the river for swimming, transportation, fishing and bathing. They also obtained water for domestic use without any major risks to their safety such as drowning. The community consultations revealed that recently there have been increased cases of drowning caused by efforts of community members to dredge the water. The lack of a proper drainage system in the districts was also blamed for the discharge of waste into the river which resulted in an increase in the nutrient content of the water, and subsequently the explosion of weed growth in the river.

Social-economic issues in the Lower Volta Basin

The decline in farming and fishing activities has had severe consequences on individuals engaged in these occupations. One participant in Keta expressed his frustrations and decried the lack of opportunities and the consequences of the dam creation, saying:

   *Our streams have turned into dry lands with our children playing football on what was once a stream!*

This concern highlights the effects of the regulated flow on the hydrology of the creeks and streams downstream. Participants expressed the view that their farmlands no longer got flooded with water from the creeks, resulting in a reduction in crop yield. Further, because of the drying up of the creeks, opportunities for fishing are limited. Although new economic activities such as petty trading and commerce, done mostly by women, have emerged, there is generally limited economic diversification in the study area. Some participants were of the view that because there were no more lucrative jobs, most men could not take care of their families and this has led to broken homes. Furthermore, participants expressed the view that there have been gender disparities and increased social problems such as prostitution as a result of loss of livelihoods. Several other concerns such as inadequate educational
facilities, high unemployment rate, high electricity bills, inadequate water and sanitation facilities were highlighted as problems facing the communities of the Lower Volta Basin.

Some participants in Central Tongu noted that children have dropped out of school as a result of their parents losing their livelihood. A lack of alternative economic opportunities, especially for men, has led to emigration of the youth out of the towns to other areas where they can find jobs. The changes in the fortunes of the communities have therefore had social ramifications. Migration and prostitution have been consequences of poverty and lack of economic opportunities. A participant from Mafi Dugame described the following situation:

School drop-out rate has increased because of the inability of some parents to look after their children. This has brought about teenage pregnancies and premature parenthood. Many of the children born by the teenagers are often malnourished because the parents have no gainful employment in order to cater for them.

With regards to education, it was pointed out by participants that several of the districts along the lake lack educational facilities. This has resulted in school going children travelling long distances to go to school in neighbouring communities. Some participants were of the view that impacted communities should have been compensated with at least schools and health facilities. Also, they mentioned that school going children from impacted communities should be offered scholarship opportunities.

**Perceived effects of dam re-optimisation and re-operation on livelihoods and investments**

Many participants were of the view that people have adapted to the current flow regime of the river and some people have established businesses such as resorts along the river banks. A change in the flow regime by re-operating the dams therefore may cause destruction of property and investments. Further, those engaged in fish farming indicated that their cages would be washed away during periods of high flow. Hence, they requested the authorities in charge to give early
warnings before spilling, if the dams are re-operated. While many would still favour re-operation that ensures environmental flows and restores livelihood, they were also of the view that any effect on property and investment should be compensated for. Further, the participants suggested that if there was going to be a change in the flow regime, the communities should be made aware of the periods of flooding so that those involved in aquaculture, particularly in the lake, will not suffer losses.

Participants preferences based on a rapid response survey

The findings of the rapid response survey are shown in Fig. 2.2. All the respondents answered in the affirmative to the question, *Do you want the project to come on*, and the follow-up question, *if yes, will you do everything within your power to ensure the project comes on?* The results show that respondents overwhelmingly want the project to be implemented. Further, respondents would do everything to ensure the success of the project as long as the project would be beneficial to the community. From Fig. 2.2, 73.5% of respondents strongly agree that the project would be beneficial to the community.

![Fig. 2.2: Perception about potential benefits of the project](image-url)
In spite of the concerns, reservations and uncertainties expressed by the participants during the consultative meetings, most (73.5%) participants of the rapid response survey were overwhelmingly in favour of the dams being re-operated to restore livelihoods. Those who were sceptical were mostly those who had properties close to the river. They expressed the view that spilling water will flood their farms and houses and affect them negatively.

On the other hand, the fact that many were willing to give the project a chance reflects how people yearned to, if possible, return to the old days and to have their livelihood restored, and to see a reduction in the incidence of bilharzia and the negative social consequences of building the dams. Thus, most of the participants saw the proposed project as providing them with some hope compared to the current state of hopelessness they face. From the participants’ perspectives they would support the restoration flow scenario being considered, so far as it would restore their livelihood and improve their general living conditions.

Conclusion and Recommendations

This study showed clearly that livelihood sources, health and environment of the downstream communities have been affected following the damming of the River Volta. From the communities’ perspectives, the adverse impacts of the Akosombo and Kpong dams have been profound. This has led to several conflicts between downstream communities and the institution in charge of managing the dam (VRA). Dam re-operation and re-optimisation offer hope for the future as long as the process does not worsen the situation of the communities. Key conclusions from this study are that:

- Participants would welcome the idea of dams’ re-optimisation and re-operation as long as it would not compound their problems. The key desire of the communities therefore is to improve livelihood and reduce poverty in the study area, irrespective of whether re-operation is undertaken or not.
- Many of the communities have been affected negatively from early post-dam period right to the present.
While a decision whether or not to re-operate the dam should be based on a full cost-benefit analysis, there is the need to address fundamental issues of livelihood improvement and poverty reduction in the study area.

To improve the livelihood of downstream communities, support schemes such as microfinance schemes should be offered to support small-scale economic activities such as handicraft businesses, to diversify the local economy. In addition, there is the need for interventions including regular dredging of the creeks and lagoons; manual and mechanical harvesting of aquatic weeds for manure; research into the use of herbicides that do not affect non target species to control aquatic weeds; removal of the sandbar at the estuary; and research towards the development of a medicinal product against bilharzia. These interventions should be prioritized. Finally, there is the need for a comprehensive development strategy to solve the serious problems of poverty and other social problems facing the communities.

References


CHAPTER THREE

ENVIRONMENTAL FLOW REQUIREMENTS AND IMPACTS OF THE AKOSOMBO AND KPONG DAMS ON THE FISH AND FISHERIES OF THE LOWER VOLTA RIVER, GHANA

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Abstract

Ten sites were selected along the Lower Volta River to study the fish and fisheries as well as the flow requirements of fish species in connection with the re-operation and re-optimisation of the Akosombo and Kpong dams. Fish were sampled with a battery of gill nets comprising both mono- and multi-filament nets of various mesh sizes. Fifty-one fin fishes and 5 shellfish species were recorded from the study area from both experimental and fishers’ catches. Out of these, 36 were freshwater species, 8 brackish water species and 7 marine species. The most important species to the fisheries of the Lower Volta area were the tilapias (*Tilapia zillii, Sarotherodon galilaeus* and *Oreochromis niloticus*), *Chrysichthys* species (*C. nigrodigitatus* and *C. auratus*) and the Volta clam *Galatea paradoxa*. Some marine as well as brackish water species were found some 80 km upstream from the estuary. The vibrant shellfish fisheries which comprised clams, oysters, shrimps, prawns and crabs, which provided a livelihood activity that supported many communities before the dams were built, have now been reduced or
completely lost in many places. Gill net, cast net, basket trap, hook and line harpoon/spear and hookah fishing were some of the fishing gear and methods used in the area. Considering pre-dam discharges and current developments along the banks of the River, discharges of between 2000 and 3000 m\(^3\)/s during the peak period (August to October) and between 500 and 1000 m\(^3\)/s during the low period (January to June) are recommended as reasonable flows for improving the fisheries in the Lower Volta. Pre-dam discharge data should serve as a good basis for determining flows or releases.

**Keywords:** Dams, Impacts, Flow Requirements, Fish and Fisheries

**Introduction**

The Akosombo dam was completed in 1965 and created the 8,500 km\(^2\) Lake Volta, the largest man-made water storage reservoir in Africa, and until recently the whole world, while the Kpong dam, which operates as a run-of-the-river facility situated 25 km downstream, was completed in 1981. The construction of the two dams has considerably distorted the natural flows by storing and releasing water in rhythm with the patterns of electricity demand rather than with the seasonal patterns of rainfall and runoff in the catchment area.

The effect on the downstream flow pattern is to reduce the peak flows and increase the base flows, effectively eliminating the dynamic interactions between the river and its flood plains, wetlands, deltas, and its estuary, mangrove and beach environments. The livelihoods of the downstream communities and the physical ecosystem processes on which they depend have also been devastated by the two hydropower dams. The results have been a drastic reduction in floodplain agriculture, as natural flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas, and an explosion in the growth of exotic weeds that have choked off the once lucrative shell fishery and fostered the formation of a permanent sandbar at the estuary.

Additionally, the fisheries of the Lower Volta have drastically been reduced as the wetlands and flood plains are no more sufficiently
inundated during the peak period. Inundated floodplains and wetlands play a very important role in fish production (Welcomme, 1985). The overall effect has created intense poverty and led to a dramatic shift in income generating activities.

The importance of a river’s flow regime for sustaining biodiversity and ecological integrity is well established (Poff, et al., 1997; Hart and Finelli, 1999; Bunn and Arthington, 2002). Unlike temperate rivers where much work has been done on the flow requirements for maintenance of fish populations and fisheries, only a few equivalent studies are available to serve as a basis for the management of water regimes for fish and fisheries in large river systems, particularly in the tropics, Africa and Ghana in particular. Out of 165 papers published over the last four decades which were reviewed by Poff and Zimmerman (2010), only three came from Africa.

The maintenance of viable river fish populations or assemblages can only be achieved through the management of a range of aspects of the fluvial environment which includes flow. Environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. Through implementation of environmental flows, water managers strive to achieve a flow regime or pattern that provides for human uses and maintains the essential processes required to support a healthy river ecosystem. To reintroduce ecological functions and livelihoods downstream of the dams through flow alterations, there will be the need to collect pre- and post-alteration data for a better understanding of ecological responses to flow alterations.

The objectives of this study were to find out how the construction of the two dams has affected the distribution, abundance and diversity of fish and fisheries of the Lower Volta and to determine the flow requirements that would help improve the fisheries.
Study Area

The project area is the Lower Volta River basin (Fig. 3.1), comprising the downstream part of both the Akosombo and Kpong hydro-electric dams, and it encompasses the entire section between Akosombo and the coast.

The entire area falls within two (2) main climatic regions. The northern part, which lies between Akosombo and Akuse, falls within the Wet-semi equatorial climatic zone, whilst the southern part, lying between Akuse and the coast, falls within the Dry equatorial climatic zone (Dickson and Benneh, 1988). The two climatic zones are characterized by two rainfall maxima, with the rainfall values reducing from 1,750 mm/yr in the northern section to about 1,250 mm/yr in the southern part. The major rainfall begins in March and ends in July, with the minor rainfall lasting between September and November.

The mean monthly temperature is uniform across the basin, with a mean of about 27.8 °C. The coolest month in the basin is in August, with a temperature of about 26.2 °C and the hottest month is March, with temperature of about 29.0 °C (Dickson and Benneh, 1988).

Four (4) vegetation types run across the study area. They range from moist-semi deciduous forest in the north, through Guinea savannah, coastal shrub and grassland in the mid-section to strand and mangroves in the southern part of the study area. Consequently, semi-deciduous trees, which seldom shed their leaves, are found in the northern sector.

Methods

Ten sites from the Akosombo dam to the Volta estuary were selected for sampling and interviews. These were Adomi, Kpong, Amedika, Volivo, Mepe, Big Ada, Adidome, Sopke, Agordome and Anyanui.
At each site, fish sampling was undertaken for 2 nights with a battery of mono- and multi-filament gill nets. The monofilament nets measured 25 m by 4 m each and comprised two each of mesh sizes (laterally stretched) 38, 51, 64, 76, 89, 102, 114, 127, 140, 152, 165 and 178 mm. The multifilament nets measured 25 m by 2 m and consisted of two each of meshes 15, 20, 25, 30 and 40 mm. Fishes caught were identified using identification books of Dankwa et al. (1999) and Paugy et al. (2003). Each fish was measured to the nearest 0.1 mm and weighed to the nearest 0.01 g. At each site, local fishermen were interviewed and their catches inspected to supplement experimental samples. The types of fishing gear and methods used were also noted. From the number and weight of individuals for each species, their relative abundance

Fig. 3.1: The Lower Volta River Basin showing sampling sites
and biomass were determined. The longitudinal distribution of fish species was determined using the catches at the various sites. Catch Per Unit of Effort (CPUE) was calculated using catches from the set of both mono- and multi- filament experimental gillnets as the catch, in both weight and number, per two nights. Fish biodiversity at each site was calculated using the Shannon-Weaver diversity index (H’) based on the formula:

$$H' = -\sum P_i \log P_i$$

where $P_i$ is the proportion of individuals in the $i^{th}$ species (Dahlberg and Odum, 1970).

Data on water levels or discharge for pre- and post- impoundment of the dams were compiled from the Volta River Authority (VRA) to assess how water flows have changed due to the construction of the dams and how these flows have affected the fisheries of the Lower Volta. From the historical flow pattern, suggestions are made as to the flow pattern that would help improve the fisheries of the Lower Volta.

**Results**

**Species Occurrence and Distribution**

A total of fifty-one (51) fin fishes and 5 shell fishes were recorded from the area from both experimental and fishers’ catches (Table 3.1).

Out of these, 36 were freshwater species, 8 brackish water species and 7 marine species. There were a few of them that were both freshwater and brackish water species and also marine and brackish water species. The highest number of 27 species was recorded at Kpong and the lowest number (9) at Anyanui. The species that were of most importance to the fisheries in the Lower Volta area were the tilapias (*Tilapia zillii*, *Sarotherodon galilaeus* and *Oreochromis niloticus*), *Chrysichthys* species (*C. nigrodigitatus* and *C. auratus*) and the Volta clam *Galatea paradoxa*. 
Table 3.1: Species occurrence and distribution in the Lower Volta during the study

<table>
<thead>
<tr>
<th>Species</th>
<th>Status</th>
<th>Anyani</th>
<th>Agordome</th>
<th>Big Ada</th>
<th>Sokpoe</th>
<th>Adidome</th>
<th>Mepe</th>
<th>Volivo</th>
<th>Amedika</th>
<th>Kpong</th>
<th>Adomi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ctenopoma pertherici</td>
<td>F</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
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</tr>
<tr>
<td>Hemichromis fasciatus</td>
<td>F</td>
<td>√</td>
<td>√</td>
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<td>√</td>
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<tr>
<td>Tetraodon lineatus</td>
<td>F</td>
<td></td>
<td></td>
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<td>√</td>
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<tr>
<td>Polypterus senegalus</td>
<td>F</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Astatotilapia guntherii</td>
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<td>√</td>
<td>√</td>
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<tr>
<td>Petrocephalus bovei</td>
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### CHAPTER 3

#### Species

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- Caught by experimental nets, *- Found in fishers’ catch,
  F- freshwater species, M – marine species,
  B – brackish water species.
Catch Per Unit of Effort (CPUE)

The catch per unit of effort, which reflects the relative abundance, is presented in Fig. 3.2 for the various stations. It rained heavily for the two nights that nets were set at Adomi while spillways were opened at the Kpong dam on the first night of fishing at Amedika, which is directly below the dam. These events could influence the catch at the two sites.

Fig. 3.2: Catch Per Unit of Effort (number) for the sampling sites at the Lower Volta

Diversity Index

The Shannon Weaver Index (H’) showing the diversity of fish at the various sites is presented in Fig. 3.3. This index serves as baseline information which would help evaluate what the situation would be after re-operation experiments or for future studies.
Flow pattern and determination of flow requirements

Before the construction of the dam at Akosombo there were wide fluctuations in the discharge of the Volta River as shown in Fig. 3.4 (averages from 1936 to 1966). Mean discharge data obtained from VRA from 1936 to 1966 showed a range between 36 m$^3$/s and 5128 m$^3$/s, with a peak in either September or October. After the construction of the dams however, the flow of water below them is virtually constant (Fig. 3.4), hovering around a mean of 1000 m$^3$/s throughout the year, except when the VRA spills water.
Discussion

Species Occurrence and Distribution

In a pre-impoundment study by Vanderpuye (1982) in the Kpong area, the following species which are known to be estuarine species with marine relatives were found: *Caecula cephalopeltis, Doryichthys aculeatus* and *Eleotris senegalensis*. The author also reported the presence of *Eucinostomus melanopterus* a marine element, in the area and concluded that the presence of the species about 88 km from the sea was a pointer to its extreme tolerance of a wide range of salinity. In another study by Dankwa (1982) one year after the Kpong Dam was closed, *Plectorhynchus macrolepis* a marine species, was found in the reservoir. All these species are no more found in the Kpong reservoir. However, during the current study the marine species, *Pomadasys jubelini, Trachinotus teraia* and *Lutjanus* spp. were found as far as Mepe, while the marine/brackish water species *Liza falcipinnis, Caranx hippos* and *Eleotris vittata* occurred further up at Amedika.

Fig. 3.4: Average discharge pattern of the Lower Volta before (1936-1966) and after (1968-2012) the construction of the Akosombo and Kpong dams
(Source of data VRA)
CHAPTER 3

Some freshwater species (*Oreochromis niloticus* and *Heterotis niloticus*) which used to occur lower down the estuary as far as Anyanui have, according to the fishers, either disappeared or reduced considerably in numbers because of the reduced influx of freshwater lower down the estuary.

Before the construction of the Akosombo dam, the Volta clam, *Galatea paradoxa*, was a very important species in the lower reaches of the Volta River and a major source of animal protein, and the shells especially were a source of income for the inhabitants. The shells were bought for the preparation of emulsion paints, terrazzo, and concrete for the building industry. In addition, as a source of calcium they were used as an ingredient in poultry feed. A factory for processing the shells was set up around Volivo and Asutuare, indicating that the clam could be found from Ada Foah to as far as Akuse. This is corroborated by Adjei-Boateng *et al.* (2012) who indicated that the distribution of the clams stretched all the way from the estuary to Amedika and Torgome, about 80 km from the estuary. During this study they were found at Ada Foah and have been reported to occur at Agave-Afedume (Adjei-Boateng *et al.*, 2012) and also at Agorta (pers. comm.) beyond where they were not encountered. Thus, they are now restricted to within 15 km from the estuary. One of the physical factors that influence clam distribution is substrate preference, which is sand. The reduction in flow, as a result of the two dams, facilitates deposition of silt/mud which is not suitable for clams.

At Adidome fishers interviewed indicated the presence of the West African manatee *Trichechus senegalensis* in the area. This is worth noting, as the species is listed by the IUCN as an endangered species and needs to be protected.

**Catch Per Unit of Effort (CPUE)**

Unfortunately, there are no catch statistics in the Lower Volta, but fishers in the area indicated that catches have declined drastically since the construction of the two dams. This was confirmed by the low catches made at the various sites during this study. With respect to the clam fisheries, Adjei-Boateng *et al.* (2012) also reported that landings
have drastically dwindled from 8000 tonnes per annum prior to the construction of the dam to the current 1700 tonnes per annum.

The Fisheries

The common fishing gear/methods found in the area during the study were gill net, cast net, basket trap, hook and line harpoon or spear. All these, according to the fishers, were also used to exploit the fishes before the dams were constructed. Gill net and cast net were used to exploit all types of species; basket traps were used mainly for *Chrysichthys*, tilapias, shrimps and prawns; hook and line for bottom dwelling species, e.g., *Chrysichthys*; while the harpoon or spear was used to target big-sized species.

Clams were harvested by two main methods: the traditional hand picking and the hookah fishing. The traditional hand picking was previously the only method of clam harvesting in the Lower Volta until the introduction of the hookah method in the 1990s (Adjei-Boateng *et al.*, 2012). The traditional hand picking is confined to shallow areas and mostly practised by women who wade through the water, locate the clams with their feet and pick them with their hands. The hookah method is mainly practiced by men at deeper areas of the river. They dive into the water and, with the aid of air supplied by a compressor through a long hose while they are submerged, collect the clams with their hands.

After the construction of the dams, other methods and fishing gear evolved. These include the drag net, constructed with mosquito netting material or netting material with 5 mm mesh size, and what is termed the ‘drive-in’ method. The drag net is used to exploit the West African pigmy herring *Sierrathrissa leonensis*, locally known as ‘one man thousand’, which is confined to the Kpong Dam, and *Pellonula leonensis*. The drive-in method involves cording off an area in a horse shoe shape close to vegetated fringes with a gill net and driving fish into the net by disturbing the water with sticks. This method of fishing is productive in weed infested areas where setting of nets is not feasible. Both methods are, however, illegal.
Creek fishing which was lucrative during the pre-dam era, according to fishers, also suffered a great set back after the construction of the dams, since the creeks are no more flooded sufficiently and are fully choked with weeds.

**Flow Pattern**

**Before the Construction of the Dams**

The variations in discharge before the construction of the dams ensured that during the peak period the wetlands and flood plains were sufficiently inundated. This played a very important role in fish production. The onset of floods, with its associated changes in water quality, acts as a stimulant or a cue for some species of fish to migrate upstream to spawn. Sufficient inundation of wetlands and floodplains for a reasonable length of time ensures higher recruitment success due to the availability of food as well as the refuge enjoyed by juvenile fishes in the floodplains and wetlands (Welcomme, 1985). Low discharges from December to May allowed sufficient influx of marine waters which could travel further up the River as well as marine species which were found all the way up to Kpong (Vanderpuye, 1982).

**After the Construction of the Dams**

The constant low flow after the construction of the dams has led to periodic build up of a sand bar at the mouth of the river. The formation of the sand bar reduces the volume of sea water incursions into the estuary and consequently restricts larval forms and marine fish species that may temporarily populate the estuary during high tides (Dankwa and Gordon, 2002). The limitation of sea water incursions also reduces the longitudinal distribution of clams, shrimps and marine species in the estuary. Observations and interviews conducted, as well as a previous study (Attipoe and Amoah, 1985) indicated that areas hitherto occupied by these species had been deserted by them due to high freshwater influence. This has led to a decline in the yield of these species as indicated above (Adjei-Boateng et al., 2012).
The reduced flow facilitates sedimentation which is not suitable for the establishment of clams since it interferes with their respiration activities. Thus, apart from salinity, sedimentation may be a contributing factor for the absence of this species from certain areas. Additionally, reduced flow encourages the proliferation of aquatic weeds, which interferes with fishing activities either by impeding the movement of canoes or by making actual fishing difficult. This situation has led to the evolution of various illegal fishing methods as indicated above.

**Determination of Flow Requirements**

The time frame of this study, which was six months, did not allow for such determinations to be made since a full annual cycle of flow is required to assess the ecological responses of species both during the high water and the low water periods. However, from the biology of some of the species and from traditional knowledge of the fishers in the area, it was established that the breeding period of most of the fishes in the Lower Volta basin coincided with the onset of the rains.

This supports the fact that the biology and ecology of riverine fishes are strongly influenced by flood regimes that fluctuate naturally from year to year and by the regular flooding of the associated flood plains (Welcomme, 1985; Junk et al., 1989). The typical flood regime contains five critical characteristics or components that regulate ecological processes in river ecosystems: the magnitude, duration, frequency, timing and rate of change of hydrologic conditions (Poff and Ward, 1989; Richter et al., 1996; Walker et al., 1995). These components may influence recruitment, growth and survival of individual fish species. Understanding these characteristics will help determine flow criteria for the maintenance of the floodplain fish faunas and will help design appropriate flood curves that maximize benefits from the water available.

Flood is important for most species of fish because the flooding of the lateral plains increases the area of rich habitat and shelter from predators and provides ideal sites for young fish to develop and grow. Older fish also profit from the improved feeding opportunities to build up sufficient fat to permit them to survive the stresses of the dry season and to complete reproduction. The abundance and biomass of
floodplain dependent species fluctuates from year-to-year depending on the strength of the floods. Years of better flooding ensure greater reproductive success, survival of fry and growth of both fry and adults, and the greater biomass in the system is reflected in catches of fishers, either in the same year or in subsequent years (Kolding and Zwieten, 2006; Welcomme, 2006).

Historical peak periods and low periods should guide the time of releases to coincide with natural patterns of the past. Releases at the right time will be critical for ecological responses. For example, the natural timing of high or low stream flows provides environmental cues for initiating life cycle transitions in fish, such as spawning, egg hatching, rearing, and movement on to the flood plain for feeding or reproduction, or migrating upstream or downstream (Welcomme, 1992).

Releases should be of such magnitude or amplitude that secondary channels and flood plains are sufficiently inundated for reasonable periods to allow breeding and growing of juveniles before the waters recede into the main channel. Prolonged and substantial inundation of secondary channels and the floodplains will provide food supply benefits in the main channel and also enhance food web productivity on the flood plain. Thus, the duration of flooding influences the time available for fish to grow and for them to avoid predators, resulting in bigger fish that have a greater potential to survive the following dry season and have improved reproductive potential. Studies of the effects on stream fishes of both extensive and limited floodplain inundation (Finger and Stewart, 1987) indicate that some fishes are adapted to exploiting floodplain habitats and that these species decline in abundance when floodplain use is restricted. Models indicate that catch rates and biomass of fish are influenced by both maximum and minimum wetland area (Kolding and Zwieten, 2006; Welcomme, 2006; Power et al., 1995).

Since the construction of the dams, the average discharge has been around 1000 m³/s (Fig. 3.4). In 2012 however, the discharge went up to about 1400 m³/s. Considering pre-dam discharges (Fig. 3.4) and current developments along the banks of the River, discharges of between 2000 and 3000 m³/s during the peak period (August to October) and
between 500 – 1000 m$^3$/s from January to June may be reasonable flows for improving the fisheries in the Lower Volta. Thus, where discharge data before impoundment is available, it should serve as a good basis for determining flows that would improve the fisheries after impoundment.

**Recommendations**

For the fisheries to be improved, re-operation of the dams should release more water during the peak periods, i.e., the normal wet season before the dam was built. It should be of prolonged duration and moderately high to create inundated plains for breeding, growing and refuge.

Re-operation should also be such that water release is reduced during normal dry season periods to allow more influx of sea water to travel further upstream to facilitate the production of clams and shrimps and also bring in more marine species further up the river course.

The frequency of flooding, which was once in a year, should also be taken into consideration.

**References**


CHAPTER FOUR

IMPACTS OF HYDROLOGICAL CHANGES OF THE VOLTA RIVER ON LOCAL LIVELIHOODS: LESSONS FOR RE-OPERATION AND RE-OPTIMISATION OF THE AKOSOMBO AND KPONG DAMS

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Abstract

Re-operation of dams is a means of regulating existing dams to recover many of the environmental and social benefits lost through damming. This paper examined the effects of peak and low flows of the Volta River in Ghana on the livelihoods of riparian communities with the view to drawing lessons for re-operation of the dams on the Volta. Data for the study were derived from fieldwork involving focus group discussions, interviews and on-site observations in selected riparian communities. A total of 22 towns were visited in 11 districts. Three of the districts were along the lakeshores whilst 8 were in the lower Volta basin. Within the 11 districts, 41 offices/outfits of relevant institutions were visited. In addition, 8 traditional leaders, together with 56 of their subjects (totalling 64), were contacted either through focus group discussions or interviews. The study established that though the idea of re-operation holds promise for revamping local economies, the inherent challenges experienced in headwater elevation over the past decades suggest that there is some imbalance between lake water demands and supply. The paper proposes the establishment of a development fund that would help in livelihood enhancement, particularly in the lower Volta basin where livelihoods were distorted by upstream damming.
Keywords: Local livelihood, Farming, Fishing, Volta lake shores, Lower Volta basin

Introduction

Under undisturbed conditions, the lateral exchange between the river channel and its floodplain of hydrological flows, on the one hand, and other constituents of the river system such as nutrient load and life forms, on the other, provides fundamental understanding of a functional riverine ecosystem. Junk et al. (1989) used the river channel as a transport and migration corridor to underscore the functional relationship between the main river channel and its floodplain. According to Arthington et al. (2004), flow regimes of rivers are characterized by flow quantity and temporal variables, each of which has individual and interactive regulatory influence on the biophysical structure and functioning of river and floodplain ecosystems. These processes in turn govern the ecosystems’ goods and services provided by rivers to humans. Thus, floodplains constitute important ecosystems that bring several socio-economic opportunities such as natural irrigation, transportation, recreation, habitats for plants and animals as well as the production of fish and other foods and marketable goods to riverine communities.

River damming invariably results in ecological changes that may diminish these aforementioned opportunities. According to Bunn and Arthington (2002), flow alteration can lead to disturbance of channel and floodplain habitats. Fahlund (2000) noted that apart from the fact that dams block free-flowing river systems, hindering the flow of nutrients and sediments and impeding the migration of fish and other wildlife, healthy in-stream ecosystems are also dewatered, thus impacting negatively on their functionality. The upstream areas experience inundation of large expanses of land, resulting in the loss of arable land, displacement of animal and human habitats and in marked changes in the micro-climate (Moxon, 1969; Amanor, 1994). At the downstream end of the dams, the residual river flow is artificially controlled to maintain sufficient water of requisite power generation capacity in the dam. As a result, the annual flooding which most of the rivers experienced during peak rainy periods is curtailed and the
ecological conditions of both the river water and the floodplain soils become altered (Petts, 1984).

Along floodplains that are extensively exploited agriculturally, for instance, river impoundment often depresses farming and other socio-economic activities of the riparian communities. This means that strategies adopted to mitigate the negative effects of damming are of paramount importance, particularly for the livelihoods of those who may be adversely affected. Indeed, opportunities exist through re-operation and re-optimisation of dams which could lead to successful rehabilitation of ecosystems. Dam re-operation or re-optimisation means the implementation of environmental flows designed to restore downstream ecosystem functions and services (e.g., floodplain livelihoods and food production systems) without significantly decreasing power production. According to Richter and Thomas (2007), re-operation is a means of modifying the operations of existing dams to recover many of the environmental and social benefits of healthy ecosystems that have been compromised by present modes of dam operation. In Michigan, for example, resource managers noticed a significant increase in natural fish recruitment below dams that had been altered in several rivers, from a peak flow to a more natural run of the river, which led to improvement in both water quality and habitat structure (Fahlund, 2000).

Against this background, this paper draws from the experience of local communities along the lower Volta River with respect to the effects of peak and low flows on their livelihoods. Their experiences should serve as a lesson for re-operation and re-optimisation of the Volta dams in Ghana.

The impoundment of the Volta River at Akosombo and Kpong for hydropower generation in 1965 and 1982, respectively, has resulted in drastic hydrological changes in both the Volta floodplain and the Volta lakeshore regions, thus enormously affecting the communities whose livelihoods depend on the flood regime of the river and the resources of the riverine environment. In the portions above the Akosombo dam, extensive inundation occurred, covering an area of 8,475 km² of land, resulting in the relocation of over 80,000 people (Mills-Tettey, 1989; Kalitsi, 1999). On the positive side, apart from power generation, the
damming and subsequent creation of the Volta Lake enhanced a very rapid growth in lake fishery and boosted employment in that industry (Ayivor and Vordzogbe, 2013).

The residual Volta River below the dams currently maintains a constant and regulated flow of approximately $1150 \text{ m}^3/\text{s}$. Before the construction of the dam, the unregulated flow of the Volta River attained a seasonal discharge at Ajena Gorge of between $3,540 \text{ m}^3/\text{s}$ and $11,050 \text{ m}^3/\text{s}$ in September/October each year following the rainfall pattern of the upper reaches of the catchment area. The minimum recorded flow was $30 \text{ m}^3/\text{s}$ (Halcrow and Partners, 1956, VRA, 1995). This high rate of discharge was accounted for by the extensive catchment area of 388,500 km$^2$, drained by the Volta and its major tributaries, the Black Volta, the Red Volta, the White Volta and the Oti (Petr, 1986; Hilton, 1967; Moxon, 1969) (Fig. 4.1).

Before the damming, the peak flow of the river used to be accompanied by extended flooding that regulated the calendar for farming and fishing activities in the riparian communities (Lawson, 1972). The unique farming and fishing opportunities that the floodplain provided attracted a high concentration of human population to the area (Acres, 1992). However, the impoundment has brought about several environmental as well as hydrological changes in the Lower Volta Basin. Among these are the dwindling earnings from farming due to the cessation of soil fertility recharge by seasonal flood-recession, the collapse of the fishery and oyster picking industries and the invasion of water bodies by aquatic plants (Lawson, 1972; T-Vieta, 1989; Ayivor and Kufogbe, 2001). As a result, there is loss of employment opportunities, increasing encroachment of marginal lands, over-exploitation of trees for firewood and charcoal, prevalence of water-borne diseases, malnutrition and widespread selective migration of the youth in the area (T-Vieta, 1989; Ayivor and Kufogbe, 2001).
One strategy to restore the ecological conditions of the lower Volta and to revamp the socio-economic livelihoods of the floodplain communities is the notion of re-operation and re-optimisation of the Akosombo and Kpong dams. The entire concept is premised on the notion that the penstocks and spill gates of the Akosombo dam could be manipulated during periods of peak and low flows to mimic the pre-dam flow.
regime of the Volta. If this is done, the river would assume a close to natural state and create opportunities for ecological restoration, thus enhancing food production systems and the livelihood of people in the riparian communities.

**Conceptual framework**

The study adopts the systems framework to explain the effects of water regulation through damming on floodplain areas. The systems concept, according to Tivy (1990), demonstrates a collection of components, parts or events which are linked together in such a way as to form a working unit or unified whole.

The systems theory was introduced by von Bertalanffy (1968). It has been applied by several authors including Tivy (1990) and van Dyne and Abramsky (1975), among others. According to van Dyne and Abramsky (1975), a system is characterised by the concept of wholeness and conceived as comprising functional components which are inter-connected, thus exerting some control on the system. The totality of connections in different directions in a system, according to the authors, gives the idea of structure and organization in the system. These, in turn, give the systems concept the property of stability, which is sustained by input-output mechanisms.

Tivy (1990) explained that as a unified whole with input-output devices, a system receives energy and, in turn, gives out either energy, matter or both. Such a system, according to the author, is said to be in a dynamic equilibrium. Seasonal fluctuations within its general condition of stability still maintain what is described as a steady state. On the other hand, a system in which serious imbalances occur as a result of fluctuations within its general condition of stability is said to be in disequilibrium. The author (i.e., Tivy, 1990) explained that a negative feedback mechanism within a system enables it to be self-regulatory, in which case it automatically cuts down or increases the input of energy, thus enabling it to maintain a dynamic equilibrium. A positive feedback, on the other hand, is not able to self-regulate and has the tendency of exceeding or falling below its homeostatic (ideal or set point) limits. According to Tivy (1990), there will, in this case, be a
continually increasing departure from the ideal state, in which case its equilibrium will be permanently disrupted.

Artificially controlled headwaters through dam creation would invariably result in positive feedback, particularly when more energy in the form of additional water is received without any means of escape.

In floodplain areas, river damming results in a constant flow regime and the establishment of a new equilibrium as downstream river velocity is artificially controlled. Communities adapt to the post-dam conditions by exploring new livelihood strategies, and at the same time, harnessing the opportunities created by damming.

Along the lake shores, water level is dependent on supplies from natural rainfall and demand through multiple uses such as hydropower demands and water abstraction for irrigation, industrial and domestic uses and losses through evaporation and deep seepage. There could be disequilibrium in the demand and supply equation as a result of low rainfall receipts and upstream water abstraction for irrigation and other uses. Thus, granted that demand and supply fail to balance, the system experiences disequilibrium, which affects livelihoods. Since the system is artificially controlled, any additional supply of water through excessive rainfall results in positive feedback, which is likely to cause flooding and forced spillage. In downstream areas, water spillage would eject excessive energy in the form of flash floods into the floodplain system.

**Study Area**

The study extends over the Volta lakeshore areas and the lower Volta Basin. Four major tributaries of the Volta constitute the four major arms of the lake Volta. The Black Volta, the White Volta and the Oti drain the northern areas of Ghana whereas the Afram drains the lower western part of the lake basin into the right bank of the lake. The right bank, in this context, constitutes all areas to the right side of the lake in respect of direction of flow. The lake is dendritic in shape and covers an area of approximately 165,700 km² within Ghana (Moxon, 1969; Kalitsi, 1999). Numerous opportunities offered by the lake and its adjoining
lands including fishing, farming, transportation, livestock watering, and irrigation (Acres, 1992) have attracted a large human population to the basin whose activities are contributing to de-vegetation along the lakeshores, especially in and around major fishing villages.

The Lower Volta Basin comprises the area astride the Volta River from Akuse, the location of the Kpong dam, to Ada Foah where the river empties into the Gulf of Guinea (Fig. 4.1). The approximately 80 km longitudinal stretch traverses several administrative districts of Ghana, including parts of Many Krobo District in the Eastern Region, the Shai-Osudoku District in the Greater Accra Region, North, Central and South Tongu Districts in the Volta Region, Ada East District in the Greater Accra Region and Keta Municipality in the Volta Region.

The lower Volta basin is drained by the Volta River and its tributaries. The right bank is poorly drained and has only three major streams, the Lomen, the Agbo and the Angor, which feed into the main Volta River. The area, which was prone to flooding before damming, supported a lot of drawdown farming, suggesting that hydrological changes in the present flow regime of the Volta River had a profound impact in these areas.

The relatively well-drained left bank has over six stream channels feeding into the Volta River, namely the Alabo, the Kollor, the Aklakpa, the Nyiru, the Adondzi and the Torndor streams. Although these streams contain water in their lowest reaches at all seasons, only the Aklakpa retained flowing water in its higher reaches throughout the year (Volta River Project, 1956). The Volta Estuary consists of winding channels interconnected with numerous creeks and lagoons, forming extensive coastal wetland habitats (Acres, 1992; Amatekpor, 1997; Ayivor and Kufogbe 2001).

**Methods**

Data for the study were derived from several years of work on agro-ecological and livelihood conditions of Volta basin (VBRP, 1996; VBRP, 1999; Ayivor, 1999; Ofori, 2000; Ayivor and Vordzogbe, 2013), coupled with series of rapid participatory appraisal studies carried out in 2010,
2013 and 2014. The field work involved focus group discussions with traditional leaders and their subjects in selected communities both in the lakeshore and lower Volta areas. Communities visited include Dabala, Sogakope, Adidome and Mepe (Appendix 4.1).

In addition, heads of some decentralized government departments were interviewed for views on benefits and challenges likely to be associated with re-optimisation upon implementation. The institutions included the Municipal/District Assemblies, District Agricultural Directorates, decentralized offices of the Fisheries Commission, Environmental Health Units, the National Disaster Management Organization (NADMO) and the Town and Country Planning Departments (Appendix 4.1). A total of 22 towns were visited in 11 districts. Three of the districts were along the lakeshores whilst 8 were in the lower Volta basin. Within the 11 districts, 41 offices/outfits of the institutions listed above were visited. In addition, 8 traditional leaders together with 56 of their subjects (totalling 64) were contacted either through focus group discussions or interviews. The majority of institutions were located in the district capitals (Appendix 4.1).

Three Volta lakeshore communities were also visited for a similar exercise namely the Akateng-Asesewa area in the Upper Manya Krobo District (Eastern Region) in the southern sector, the Abotoase-Nkonya Wuropong area in the Biakoye District (Volta Region) in the mid portion and the Yeji area in the Pru District (Brong-Ahafo Region) in the northern part of the Volta Lake (See Fig. 4.1). Past oscillations of the lake between extremely low and excessively high levels along the lakeshores over three decadal periods from the communities’ point of view were useful benchmarks and reference points for the assessment. The 2010 flooding experience (Caruson et al., 2014) was particularly useful. These areas were selected to ensure a fair geographical coverage of the lake region, that is, the southern section, the middle portion and the northern section. Data for the fieldwork were collected between May 2013 and April 2015. Data collected by staff of the Institute for Environment and Sanitation Studies, through a quick exploratory tour of the Volta basin during the 2010 floods, were also utilised to supplement the field data.
CHAPTER 4

Results and Discussion

Fluctuations in Lake Water Levels

Over the years, the riparian communities of the lower Volta area have readjusted to the new set of ecological conditions imposed by damming. While the majority of people in the communities that were affected by damming migrated to the lakeshore areas upstream, the remaining population farmed marginal areas of the lower Volta basin and adopted other livelihood enhancement strategies to make a living. According to respondents, the current challenge is the occasional flash floods resulting from the opening of spill ways of the dams and the low water volumes during periods of low headwater elevation in the Akosombo dam. In general, the volume of water in the basin depends solely on inflows from the main tributaries of the Volta River, namely the Black Volta, the White Volta and the Oti. The greatest threat to availability of water in the Volta basin is the poor rainfall patterns in the catchment areas which have resulted in low water inflow into the dam’s reservoir over the years. The Volta River Authority (VRA) regulates the water level in the Akosombo dam between 276 ft (81.12 m) and 235 ft (71.63 m) (National Datum Level) in 280 ft (85.3 m) contour in order to maintain sufficient water to enhance the power generation capacity of the hydroelectric power plant. After an initial peak in the 1970s, the level of water in the lower Volta area of the lake has fluctuated between low and high flows as exemplified by low headwater elevation of 235.76 ft (71.88 m) which occurred in 1984 after the 1983 drought, followed by a series of recurring low elevations of 239.48 ft (72.32 m) (1994), 336.42 ft (72.08 m) (1998), 236.42 ft (72.08 m) (2003), 236.73 ft (72.17 m) (2006) and 237.09 ft (72.28 m) (2015). It seems that the low headwater elevations in the Akosombo dam from 1994 to date may have, in part, resulted from marked rainfall variability and the construction of the Bagré Dam in neighbouring Burkina Faso.

Peak water levels have appeared to alternate with low elevations in almost a regular manner as illustrated in Fig. 4.2. Thus, from a peak elevation of 275.45 ft (83.99 m) in 1970, other peak elevations were recorded from 1979 to the present, viz: 270.02 ft (82.32 m) (1979), 275.20 ft (83.90 m) (1991), 263.90 ft (80.46 m) (1999) and 277.54 ft (84.62 m) (2010). It is evident that since 1970, the highest headwater elevation
recorded was in 2010, which explains the reason why the 2010 high flow scenario has been cited as a reference point throughout the presentation in this paper.

![Lake Water Level Graph](image)

**Fig. 4.2: Lake Water Level – 1970 to 2015 (Source: VRA Records)**

**Effects on Farming in lower Volta communities**

As noted by Lawson (1972), the peak flow of the river in the floodplain area used to be accompanied by wild floods that used to set the calendar for farming and fishing activities within the riparian communities. The combined size of the Akosombo and Kpong dams, and the resultant change in the flow regime of the residual river in the aftermath of damming, invariably altered the ecological condition of the river, with negative repercussions for floodplain dwellers. The farmers were not only practising crop farming, but also took advantage of the prevailing cyclical flooding conditions to further exploit other riverine resources like fish, oysters, crabs and shrimps. Floodplain backwaters provided important breeding refuge and habitats for aquatic fauna. These other riverine resources provided an additional incentive to the lower Volta smallholder farmers to mould their livelihood and other cultural practices according to the dictates of the biophysical environment. When, therefore, the floodplain agro-ecological conditions were disrupted by damming, not only were the farming systems interrupted, but aspects of the socio-economic activities of farmers were also altered.
During interviews, the respondents emphasized that the cessation of cyclical floods in the lower Volta floodplain after the damming has adversely affected farming, fishing and clam picking activities and impacted on their livelihoods. They indicated that farming operations in some of the riparian areas were sustained by constantly recharged soils derived from alluvial materials that accompanied the cyclical floods and natural irrigation provided by the floods. The pre-dam soils of the floodplain area, for instance, used to be more productive than those of the adjoining areas because of the availability of moisture (Ayivor and Kufogbe, 2001). Research has established that the cessation of cyclical floods and the dwindling rainfall conditions in the past few decades have made most of the post-dam soil conditions much more acidic (Amatekpor, 1997, Dogbetor, 1999; Ayivor and Kufogbe, 2001). The pH of soils, for instance, ranges between 4.5 and 4.9 throughout the 0 - 100 cm depth, a situation which came about as a result of leaching of basic cations (e.g., Ca$^{2+}$, Mg$^{2+}$, K$^+$, Na$^+$) from the alluvial soils during periods of flooding (Amatekpor, 1997). In the absence of flooding and annual replenishment of the soil through alluvial deposits, most of the soils have become impoverished and require effective management to be productive.

It was noted during fieldwork that the Volta floodplain area has emerged from an era of wild uncontrolled seasonal flooding to an era of re-regulated water flow by virtue of the artificially controlled river flow which offers a new set of economic opportunities. The flood recession area of lower Volta prior to the damming covered approximately 5 km, off portions of the river banks. The flooding of the poorly drained right bank used to be more extensive and communities such as Asutsuare, Aborvienu, Aveyime, Mepe, Tademe Vume, and Adzake were usually the most affected (Fig. 4.3). The left bank of the Volta River, which was better drained, mostly experienced limited flooding and therefore had a smaller flood recession area. Thus, except for a few areas around Vome, Morklikpo, Kledeke and Agorkpo, most of the areas were well drained. Following the cessation of annual flooding, residents in these areas have turned the low lying areas into permanent farm lands, which currently provide livelihoods for several hundreds of people.
Fig. 4.3. Pre-dam Flood Recession Area of the Lower Volta Basin
Source: Ayivor (1999)
Around Asutsuare, New Bakpa and Aveyime, for example, large scale commercial rice farms have been established with irrigation facilities to ensure all-year-round farming. At Asutsuare, a Ghana Irrigation Authority initiative has brought a large expanse of land under rice cultivation where a number of local farmers have been engaged on an out-grower scheme. Most of the other areas are occupied by smallholder farm families who are engaged in the cultivation of a wide range of crops including vegetables, maize, cassava and sweet potato. This suggests that a large number of people derive their livelihoods from farming activities. Official statistics of the South Tongu and Shai-Osudoku districts, for instance, showed that by 2010 agriculture including livestock employed 52% and 58.6% of the working population in the two districts respectively.

Residents of the lower Volta basin reported that the periodic low and high headwater elevations do not necessarily affect their operations, except in extreme events. Two of such extreme events were flash floods experienced in 1968 and 2010. Some elderly folks recounted that the 1968 flooding event was so severe that communities in the pre-dam flood-prone areas such as Kebenu, Bakpa and Tademe were completely flooded. The situation, according to the Paramount Chief of New Bapka, forced the traditional seat of Bakpa to be relocated to its current place (i.e., from Old Bakpa at the right bank to New Bakpa at the left bank of the Volta River). The relocation apparently affected livelihoods, as many of the affected people had to struggle hard to rebuild their lives. The relocation also forced residents to shift occupations from combined fishing and farming to exclusively crop farming. Most of those who could not afford to let their traditional means of livelihood go, which is fishing, migrated to the lakeshore areas up north.

The 2010 flooding was another major landmark event that residents in the (affected) communities recounted during the field work. As the headwater elevation rose to 277.54 ft above the VRA regulated level of 276 ft, the Volta River Authority was compelled to open the spill gates at both the Akosombo and Kpong dams to save the dams from potential damage. The effect of this action was not only overwhelming but also caused serious river bank erosion in areas close to the Kpong dam and, in addition, resulted in flooding in the lower reaches of the river. Essentially, most of the hitherto flood recession areas (Fig. 4.3)
got flooded, drowning several hectares of farmlands and residential areas. Smallholder farmers in most of the affected areas reported loss of their farm crops through the floods.

In the South Tongu District, which extends across much of the lower portions of the floodplain, the 2010 spillage affected farmlands and homes of communities including Alikekope, New Agbeve, Tuanyikope, Tsatsukope, Ziwenu, Agave Afedome, Avegueme, Kua, Gamenu, Kodzi, Dzetorkoe and Keseve. Though much devastation was caused to crops by the flooding, there was minimal human displacement because of intensive education of residents in the communities prior to spillage.

In the Ada East District, places most affected by the 2010 floods on main land communities as against island communities were Azizanya, Tsawetsonya and Adzim. Island communities affected include Azizakpe, Aflive, Alorkpeme, Kputsupanya, Agboka and Amekutsekope.

On the positive side, residents located close to the drawdown area such as Aborvienya and Asutsuare took advantage of the flooded areas and planted fast growing crops including maize and vegetables as the floods receded. This boosted household food production over the period. Though no agricultural production figures are available to support this claim, the District Agriculture Directorates at Kase (Ada East District), Adidome (North Tongu District) and Sogakope (South Tongu District) corroborated the claim by the residents.

**Effects on drawdown farming along the lakeshores**

The extensive drawdown area of the Volta lakeshores, as noted above, holds enormous promise for dry season agriculture. This was evident during field visits to the selected communities where large tracts of drawdown areas were under cultivation. Farmers cultivated fast growing crops such as sweet potatoes, okro, garden eggs, pepper and other vegetables. At Akateng in the Upper Manya District, for instance, residents reported that a fast growing rice variety was also cultivated along the banks as the water level receded. At Yeji, the low lying terrain in the area supports rice farming, especially close to the inlets of streams that feed into the lake. Other crops cultivated in the drawdown areas of the Pru District were mostly maize and vegetables. A major challenge
to drawdown farming was cattle-grazing which destroys crops, as herds of cattle move along the lake shores to access drinking water.

Though the Upper Manya District Agricultural Directorate engaged farmers in education and sensitization programmes to maintain a buffer of 100 m away from the lake, the drawdown practice persisted. In communities such as Batorkope, Akokoma and Akotoe, the cultivation of rice and sweet potatoes along the drawdown was a major practice, whilst vegetables and sweet potatoes dominated the Akateng area. One major concern was that most of the rice farmers operating the drawdown system applied or used weedicides at the growing stage of the crop. The Directorate had therefore been educating farmers to desist from the practice to avoid the residual effects of these chemicals and their negative repercussions on aquatic life-forms.

**Effects on Lower Volta Fishery Industry**

According to residents in the lower Volta communities, the fishery industry was the most adversely affected by the damming. The industry used to comprise estuarine fishing, fresh water fishing and creek fishing. According to Lawson (1972), the fish landing from estuarine fishery constituted an important component in the local diet. Lawson (1972) further explained that beyond the limit where estuarine conditions ceased, river fishery was of less significance except in the flooding months from September to November. The catfish (*Chrysichthys* sp.) was the most dominant catch in fresh water fishing, which was prevalent between Sogakope and Akuse. Creek fishing extended from portions of the river between Tefle and Akuse. Most residents of lower Volta regarded creek fishing as most rewarding, which prompted creek owners to enter seasonal leasehold agreements with potential fishers (Lawson, 1972). The activity was carried out in the numerous creeks adjoining the Volta River.

Respondents (or residents in communities) were also of the view that the picking of river clams (*Galatea paradoxa*) was an exclusively female activity that supported family incomes and provided for the needs of children. It was very common in the Osudoku areas on the right bank and between Adidome and Dufor on the left bank of the Volta River. According to Pople and Rogoyska (1969), during the pre-damming
era, saline sea water used to penetrate about 30 km upstream from the estuary, mostly during the dry seasons, with a maximum penetration of 40 km. The condition was very ideal for the breeding of clams, which explained why the activity extended far inland. Currently, clam breeding seems to be concentrated only a few kilometres from the estuary. Residents of Big Ada in the Ada East District reported during group discussions that the post-dam hydrological change and the current regulated flow regime of the Volta River do not encourage clam picking the traditional way, as used to be the case in the pre-dam era. In the pre-dam era, custom demanded that only one clam was picked at a time, mostly by women who used to spend a lot of time on the activity. Instead, the current system of clam picking involves the use of motorized boats accompanied by professional drivers who are mostly young men. They normally sail to the portions of the river where they suspect clams breed and spend several minutes under water picking large quantities of clams into containers which are emptied into waiting boats.

According to the Fisheries Commission office of the Keta Municipality, the damming of the Volta River has affected the marine fish catch, especially species that spawn in fresh waters. The diversity of fish species has also reduced according to their records, with the suspicion that some species might have gone extinct locally.

With the virtual collapse of the fishery industry in the lower Volta basin after damming, the socio-economic livelihoods of the majority of residents have been distorted and, in particular, women have become very vulnerable. However, individuals have taken advantage of the stable flow regime of the river and established cage aquaculture facilities as a livelihood enhancement activity. The initiative, which was quite widespread along the banks of the river, is capital intensive and out of the reach of many ordinary people in the communities.

The fieldwork also revealed that the 2010 flooding brought good memories of pre-dam conditions to the people, particularly the older ones. Some of the respondents at Fieve, Tefle and Dufor Adidome, reported that the momentary rejuvenation of the virtually ‘dead creeks’, through fresh water intrusion, brought some life back into the creeks and boosted creek fishing. With regard to fishing in the
Volta River channel, it was noted that the increased volume of water, coupled with the flooding of bushy areas along the river banks, created new spawning sites for fish, resulting in a boom in fish landing within the period. Officials of the Fisheries Commission in Ada East District, for instance, noted that fish catches during the flooding periods included species thought to have migrated from the Volta estuary. It was noted that if floods of such magnitude should occur on a regular basis, community livelihoods would be enhanced through a boost in fishing and clam picking activities. Moreover, the mangrove swamps will be revamped to enhance the development of healthy mangroves, thus creating the right conditions for fish spawning. Any re-occurrence of the extreme flood event, as experienced in 2010, would be most welcoming by the people, provided the existing institutional structures such as National Disaster Management Organization (NADMO) zonal units and the Municipal and District Assemblies are robust enough to deal with potential negative impacts.

The negative impacts of the 2010 floods on the fishery industry were also enormous. Residents reported that the floods destroyed aquaculture facilities, especially the established fish cages in the river channel; stalled the activities of clam shell pickers; and destroyed fishing nets. River transport became very risky and virtually grounded to a halt due to high flow velocity which then affected fishing activities. For example, at Dufor Adidome close to the Kpong dam in the North Tongu District, fishermen were prevented by the Paramount Chief from going to the river to fish as a precautionary measure due to the high water current. This denied people the opportunity to benefit from fishing. There was also the aquatic weeds menace in areas such as Pediatorkope islands, Agordomi and Mepe, which obstructed navigation and fishing activities. The weeds were washed down from upstream areas and deposited in several downstream locations.

Effects on Lake Fishing

The Volta Lake is the most important national resource for fresh water fishery. By 2002, about 85% of total inland fish production which stood at about 88,000 metric tons came from the Volta Lake (Diei-Ouadi and Mensah, 2005). Since the formation of the lake, it has attracted a huge fishermen population which increased from 18,358 in 1970 to about
71,862 in 2000. Fishing effort on the lake has also risen from 9,113 canoes in 1971 to 24,035 by 2000 and average yield of the fishery decreased from 46.8 kg/ha in 1976 to 32.6 kg/ha in 1998, giving an annual decline of 0.255 kg/boat/day (Braimah, 2001). These figures suggest pressure on the lakeshore fishery which has not been well managed over the years and is now affecting livelihoods.

At Yeji in the Pru District of the Brong Ahafo Region, the Artisanal Fisheries Station under the Fisheries Commission recounted the 2009 and 2010 flooding experience and noted that more water in the lake would always result in more conducive space for spawning. Similar to the lower Volta experience, the Pru District Office of the Fisheries Commission reported that fishing activities in the lakeshores received a major boost during the 2010 flooding events, as adjoining ‘bushy’ areas that were inundated became spawning grounds for a lot of species, thus improving fish landings dramatically during the period.

High flows, according to officials at the Fisheries Commission in Yeji, have the tendency to reduce fish size because fishes will have to exert more energy in swimming against the tide at the expense of growth. It was noted also that the development of cage aquaculture along the lakeshores usually suffers serious setbacks during periods of high flows. This affects investment capital and the livelihoods of people employed to manage aquaculture facilities.

During periods of low headwater elevation, as experienced in the years 1984, 1994, 1998, 2003, 2006 and 2015, fish catches and landings were low. According to the Fisheries Commission office at Yeji, when this happens, fishermen resort to all kinds of illegal fishing methods which go by various local names such as ‘bamboo traps’, ‘atidza system’, ‘adra’, ‘nifanifa’ and ‘wangari’ among others; also Bamboo fishing which is known to target catfish (Cristisia oretus), appears to be on the ascendency. This system of fishing, according to the findings, affects the catch of other species, fishermen are unable to access these because

The bamboo traps, according to field findings, constitute a system of fishing where pieces of bamboo, about two meters long with an opening at one end, are stuck into the mud to mimic natural openings where gravid Cristisia oretus spawn. Once the fishes enter the bamboo holes, they get trapped and are later harvested by the fishermen. One piece of bamboo is able to trap several fishes, a situation which constitutes a threat to the fish species since the pregnant ones are the most affected.
the fishes are thought to hide under left-over or discarded bamboos on
the lake.

Officials at the Fisheries Commission at Yeji further noted that due
to the increasing pressure on the fishery resources, recruitment level
of juvenile fishes is very low. On the whole, the dwindling fortunes
of most fisher folks in the Yeji area have compelled many fishermen
and their families to migrate to areas upstream of the Bui dam, which
provides a new set of opportunities for fishing.

Effects on Other Livelihood Activities in the lower Volta Basin

Several other livelihood activities in the lower Volta area were affected
either positively or negatively by the 2010 floods. Public health issues
were of major concern, especially when flooding events are associated
with some waterborne diseases. The findings of the study suggest
that after the 2010 flooding, the aquatic weed menace intensified in
downstream areas close to the estuary, as weeds washed from upstream
areas were deposited in the downstream areas. This resulted in increased
incidence of bilharzia among residents of the communities. The snail
intermediate host of Schistosoma, finds water bodies overgrown with
aquatic weeds to be conducive habitats. Infected snails release Cercaria,
which swim in the water to find a human host on contact (Waddy, 1962).
Since the activities of most of the riparian communities of lower Volta
bring them constantly into contact with infected water, the incidence of
bilharzia is very common in the area. Additionally, pools of water that
collected in low-lying areas after flooding became breeding grounds
for mosquitoes, which resulted in an upsurge in malaria cases.

In the upper sections of the lower Volta in the Dufor Adidome area,
the high velocity of water discharge from the reservoir(s) resulted in
bank erosion and washing away of many floating aquatic weeds. The
research findings suggest that the flood waters cleared the weeds and
temporarily led to a reduction in incidences of bilharzia in the area. It
was also reported that the high flood waters mainly flushed floating
aquatic weeds downstream leaving submerged weeds unaffected,
which probably explains the finding that the impact of the 2010 floods
on incidence of bilharzia was only temporary.
Effects on Other Livelihood Activities along the Lakeshores

Hydrological changes along the lakeshores affect several other activities. During periods of low flows, haulage of goods (and services) on the lake becomes difficult and sometimes risky. Boats are unable to dock at the usual landing bays and have to find other convenient places. Tree stumps, which hitherto might be buried under water during normal times and pose no danger to navigation, tend to emerge at low level elevation and pose serious threat to navigation. During periods of high lake levels, these tree stumps are covered by water. Boat operators are unable to notice the presence of such trees, and most often run into them, resulting in fatal lake accidents.

Domestic Water Supply

The majority of lakeshore communities rely on untreated water from the lake for domestic use. Water abstraction through head potage by women and children during low flow regimes becomes a problem, as walking distance may increase due to water recession. In low lying areas such as Akateng, the shoreline receded up to about 400 m. Elsewhere, as in the case of Abotoase, the flood recession area, which is more or less an inlet of the lake, was about 1km in length. Field observations in the major lakeshore communities further revealed that during periods of low lake levels, large quantities of solid waste, generated through marketing activities, were dumped along the shoreline. This waste eventually finds its way into the lake and has the tendency of compromising water quality (Plates 4.1 and 4.2). In Akateng, it was observed that during the dry season, livestock, notably cattle, are watered directly from the lake and in the process, they defecate in the water and along the coastline, which affects the quality of the water (Dibakar, 2012).
Lessons for Re-Operation and Re-Optimization of the Volta Dams

The fluctuations in Volta lake headwater elevation and the accompanying impacts on shoreline and riverine activities, together with local community responses to such changes and impacts, hold useful lessons for re-operation and re-optimisation of the Volta Dams. Essentially, re-optimisation will provide opportunities for revamping dried up creeks and watering floodplain areas to bring back their ecological functions. It also holds great promise for creek fishery and drawdown farming to boost livelihoods. This notwithstanding, the feasibility of re-optimisation improving reliability and access to water and electric power supply was noted as a major concern. Other issues noted include the possibility of disrupting post-dam initiatives and survival strategies adopted by communities, shoreline erosion in upper sections of the lower Volta floodplain (Plate 4.2) and the inability of re-optimisation to remove aquatic weeds and curb the menace of bilharzia.
in the lower Volta area, as evident from the 2010 floods scenario. The effects of flooding on aquatic weeds will, however, require further studies, probably using biophysical models.

Essentially, re-optimisation will provide opportunities for revamping dried up creeks and re-watering floodplain areas to bring back their ecological functions. In the event of high water discharges in the lower Volta during re-operation, the drawdown farming system could be revived. In that regard, fast growing crop varieties could be introduced to ensure food security and strengthen rural economies. The benefits of re-operation to farmers will, however, depend on effective information flow between the water regulator, notably the Volta River Authority, and the farmers. Such effective communication will ensure proper timing of the cropping seasons to avoid flooding of farms. Along the lakeshores, the low headwater level is likely to fall further when water is released for re-operation and would boost drawdown farming. However, such low headwater levels risk plunging the Akosombo
and Kpong power plants into a crisis as their respective capacities to generate power would be compromised.

With regard to fishing, re-optimisation, as noted in the preceding sections, would restore the ecological functions of the lower Volta River and boost fishing and clam picking activities among riparian communities. It will also rejuvenate dry creeks and revive creek fishing for local livelihood enhancement. In the event of re-optimisation, however, the repercussions on Volta Lake fishing, lake transport and water abstraction may be serious for local communities and the hydropower generating plants at Akosombo and Kpong if unanticipated dry spells follow.

From the discussion so far, it is obvious that the fundamental question about the feasibility of re-optimisation of the Volta dams relates to water demand against supply. Andreini et al. (2000) observed over a decade ago that demand for water in the Volta basin has approached supply and that the trade-offs between various water uses are likely to intensify, thus posing challenges for future water supply. Though Andreini et al. (2000) used a ‘crude model’ which makes their conclusions disputable, there is overwhelming evidence to suggest that water demand in the lake is exceeding supply. Frank et al. (2005), for instance, observed that water losses through evaporation on the lake Volta are 1.5 times higher than ETp, or 14.6 km³/yr, which is only partially offset by rainfall on the lake. Land use and land cover within the basin, which according to Andreini et al. (2000), was to play a pivotal role in determining future water balance, seem to have changed over the years. This is evident in the high rate of population growth in the country (from approximately 21 million in 2000 to 25 million in 2011) and the research findings by Braimoh (2004) which suggest that conversion of natural vegetation to cropland is occurring at the rate of 5% annually in the lakeshores. Other evidence which suggests high water demand over supply include:

- climate change and its negative impacts on the lake Volta (Bekoe and Logah, 2013),
- siltation of the lake, resulting in reduced water volumes (VRA, 1996), and
current challenges with headwater levels due to rainfall variability and the fact that pressure is on the VRA (the hydro-power Producers) to produce more electric power to curb the country’s power crisis. This has compelled the Volta River Authority (VRA) to operate at minimum lake elevation levels with the hope that subsequent rainy seasons will replenish the lake.

If this trend continues, re-optimisation will not be feasible, as any such undertaking would reduce headwater levels and affect the power generation capacity of the lake. It is, therefore, agreeable that Ghana’s dependence on hydropower for over half of her energy needs makes the re-operation and re-optimisation a challenging issue. However, if the West Africa Power Pool comes on stream and if, in addition, the country increases its alternative sources of energy, re-optimisation may become feasible.

Furthermore, the ability of re-optimisation to reduce water weeds and curb bilharzia has come under scrutiny. As noted in the findings, water weeds flushed out from upstream areas will normally flow downstream to choke the lower reaches of the river and create problems. The flushing of the weeds, according to Officials of the Wildlife Division, Ada East District, will also result in habitat change for some species, with negative implications for biodiversity. Reptiles such as pythons which find sanctuary in the weeds are also likely to get stranded, and thus pose a threat to humans.

Additionally, re-optimisation is likely to disrupt post-dam initiatives and survival strategies adopted by local people. For example, cage aquaculture projects and the holiday resorts that have emerged in the aftermath of damming will be affected.

Finally, in the event of re-optimisation and re-operation, increased flow velocity in the upper portions of the lower Volta (that is, just below the Akosombo and Kpong dams) is likely to result in river bank erosion as was experienced in 2010 (Plate 4.3). Such a re-occurrence will not encourage navigation and fishing due to the risk associated with the high flow velocity of the water. This observation, however, will need further studies, as the 2010 discharge may not be the optimal flow in the re-optimisation.
Conclusion

The idea of modifying the operations of the Akosombo and Kpong dams to recover many of the environmental and social benefits of healthy ecosystems that have been compromised by present modes of dam operation appears very commendable. However, the inherent water balance challenges being experienced in the Volta Lake or the reservoir over the past two decades seem to suggest that water demand is currently crossing the critical threshold where supply through natural rainfall is unable to effectively sustain demand. It is obvious that a release of water in the event of re-optimisation is only possible when headwater elevation is very high at the Akosombo barricade. Owing to issues of fluctuating lake levels, it will be in the best interest of hydropower managers (i.e. the Volta River Authority) to maintain high elevation levels that would ensure the power generation capacity of the
dams. The observed cyclical fluctuations in the headwater elevation and the problems of power generation suggest that re-operation and re-optimisation of the Volta dams may face challenges unless retrofitting of the dams is done, which could most likely compromise the power generation capacity of the dams. This might not be the best option for a country which has been experiencing energy crises over the past two decades. The proposed establishment of the Lower Volta Development Fund announced by the president of the Republic of Ghana in April, 2016 appears to be in response to what residents in communities of the lower Volta, led by the Paramount Chief of Tefle Traditional Area, have been advocating for years. The fund is supposed to accelerate development and help restore hope among people of the lower Volta basin.

Constant de-silting of the sand bar that clogs the estuary through long-shore drift was also recommended by the local people to ensure regular sea water intrusion into the lower Volta River. This, according to the people, will reduce the growth of aquatic weeds, at least within the limits where sea water could reach and likely reduce incidences of bilharzia.

Along the lakeshore areas, greater law enforcement regarding undesirable human activities that trigger deforestation, on the one hand, and undermine proper environmental sanitation standards, on the other, is imperative to save the viability of the Volta Lake.

Finally, it is worthwhile to note that increased power production from other sources rather than over-reliance on the Akosombo and Kpong hydro power plants would make re-operation and re-optimisation of the dams possible without affecting overall power supply.

References


### Appendix 4.1: Names Of District Government Officials and Traditional Areas Visited For Interviews

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<th>Town/Community</th>
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CHAPTER FIVE

FLOW REQUIREMENTS FOR AQUATIC BIODIVERSITY AND AQUATIC WEEDS

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Abstract

The diversity of phytoplankton in the Lower Volta River was low with a total of 22 species. These comprised three classes of phytoplankton, namely green algae (eight genera), blue-green algae (nine genera) and diatoms (five genera). The blue green algae (cyanobacteria) had the highest total counts at all the sites, forming between 70% and 90% of the total count. There is proliferation of all types of aquatic weeds – emergent, free floating, submerged and sudd formers - in the Lower Volta. The number of species in the Kpong headpond and the Lower Volta River increased from 15 in 1981 to 65 in the current study (2015), consisting of 47 emergent, 12 free floating and 4 submerged species. Alien invasive species such as Eichhornia crassipes, Cyperus papyrus and Salvinia molesta have also invaded the headpond. Eight orders of macro-invertebrates were present (Annelida, Diptera, Ephemeroptera, Gastropoda, Mysidaceae, Odonata, Pelecypoda and Trichoptera) at the study sites, each order represented by one taxa but with between 1 and 300 individuals per taxa.

Keywords: Alien invasive species, Anthropogenic, Cyanobacteria, Macro-invertebrates
 CHAPTER 5

Introduction

Natural flow regimes in rivers are determined by the climate, run-off, catchment size and geomorphology without the impacts of dams, weirs, extraction and river management. Hydropower projects that are operated to store water disrupt the natural variability in the flows that sustain floodplain agriculture, animal grazing, fisheries and replenish groundwater, riparian lands and coastal beaches. The Akosombo and Kpong dams and their effects on the downstream food production systems are a prime example of alteration to the natural flow regimes of rivers and streams and their impact on floodplains and wetlands. While hydropower development is a cleaner source of energy than burning fossil fuels, dams can transform river ecosystems through changes to water levels, sedimentation, water chemistry, and temperature, and associated diversions can drastically reduce natural flows in diverted rivers (Morris et al., 2007).

These changes are recognised as a major factor contributing to loss of biological diversity and ecological function in aquatic ecosystems. Alteration of natural flow regimes can occur through reducing or increasing flows; altering seasonality of flows; changing the frequency, duration, magnitude, timing, predictability and variability of flow events; altering surface and subsurface water levels; and changing the rate of rise or fall of water levels (Walker, 1985; Cadwallader and Lawrence, 1990; Gehrke et al., 1995; Kingsford, 1995; Maheshwari et al., 1995; Poff et al., 1997; Boulton and Brock, 1999; Robertson et al., 1999, 2001).

It is now well established that an unaltered river has a natural flow regime; that human activities alter river flow in diverse ways; and that channel shape, habitat for the biota and ecological integrity can suffer due to a variety of human activities (Poff et al., 1997). As a consequence, efforts to restore a river’s flow to more closely resemble its natural condition have become a cornerstone of river restorations. Ultimately, re-establishing more natural flow regimes in the Lower Volta River is a core element of a larger strategy to protect and restore the ecosystem health of waters of the Lower Volta River, leading to improvements in the physical environment and restoration of previous functions. By identifying the flow regime for the aquatic biodiversity and aquatic
weeds in the Lower Volta River, this report contributes to on-going efforts to improve water management for humans and for ecosystems of the Lower Volta River.

Aquatic plants provide ideal habitat for macro-invertebrate colonisation (Sharitz and Batzer, 1999; Masifwa et al., 2001). The structure provided by the roots and leaves create habitat for macro-invertebrates, especially for epiphytic macro-invertebrates such as snails, arachnids (Brendonck et al., 2003) and amphipods (Toft et al., 2003; Rocha-Ramirez et al., 2007). Several studies have documented a positive correlation between epiphytic macro-invertebrate densities and the surface area of floating aquatic vegetation, including water hyacinth (Crowder et al., 1982; Schramm et al., 1987). The presence of aquatic weeds along the shores of the lake and within the tributaries has resulted in the prevalence of water borne and water related diseases to the detriment of local inhabitants. The weeds provide the necessary habitat for black-fly, mosquitoes and snails, which are the vectors of water-borne illnesses such as bilharzia, river blindness and malaria (Gyau Boakye, 2001). Since the construction of the dam, the incidence of these diseases has increased remarkably and a village’s likelihood of infection corresponds to its proximity to the lake (Zakhary, 1997). Children and fishermen have been especially hard hit by this rise in disease prevalence. For example, the prevalence of schistosomiasis in children in the Lower Volta River basin in south eastern Ghana ranges from 2-21% with the most vulnerable age groups being 6-11 and 12-17 years (Nkegbe, 2010).

The aim of this study is to contribute to the necessary data, create the necessary analytical tools and use them to explore how the Akosombo and Kpong dams could be re-operated. The objectives are to:

i. Determine the current status of aquatic biodiversity (aquatic weeds, algae and macro-invertebrates) with respect to their composition, distribution, and abundance

ii. Determine the flow requirements necessary for maintaining aquatic biodiversity which will guide the re-operation exercise and consequently ensure the restoration of livelihoods
Study Site

Ten sites were selected for sampling during the study. These were: Anyanui, Agodome, Sokpoe, Adidome, Big Ada, Mepe, Volivo/Avakpo, Amedika, Kpong and Adomi. Sampling covered phytoplankton, macro-invertebrates, and aquatic weeds. The geographical locations of all sampling stations were taken with a GPS, model GARMIN GPSmap 76CSx, and are indicated in Fig. 5.1.

Fig. 5.1: The Lower Volta River Basin showing sampling sites.
Methods

Phytoplankton (Algae)

Water samples were taken twice during the study period from the 10 sites and preserved with Lugol’s solution (to which a few drops of detergent had been added to separate diatom cells) immediately after collection. In the laboratory, the samples were well shaken and aliquots of 25 ml transferred into counting chambers for analysis. Identification (using the keys of Prescott, 1978 and McGregor and Fabbio, 2001) and enumeration of algae were done using a Carl Zeiss inverted microscope.

Macro-invertebrates

Three samples were randomly collected from each of the sites using a pond net and an Eckman grab sampler where necessary. The pond net was used to collect kick samples of benthic fauna and also fauna associated with vegetation that either grew or trailed into the water, and the Eckman grab was used to take bottom or sediment samples. Small rocks were washed into buckets and the collected water washed through a sieve (BS-410 Standard 72 mesh which is 212 micrometre mesh). The samples were then preserved in 70% ethanol and taken to the laboratory for further processing. Samples were examined under a dissecting microscope in the laboratory and all macro-invertebrates sorted out and enumerated. The individuals were identified as far as possible with the aid of available taxonomic keys (Dejoux et al., 1982; Brown and Kristensen, 1993; Needham and Needham, 1969).

Aquatic weeds (Aquatic macrophytes)

Sampling of macrophytes was undertaken twice within 6 months at each of the 10 sampling sites. The choice of the sites was based on ease of accessibility and the extent of coverage of the aquatic macrophytes present. The sites were surveyed from a boat and on foot and the vegetation recorded. Records were made of the habit and growth/life-form of plants, substrate type, presence of ‘sudd’ or rooted vegetation and cover of individual species. At each of the sites, a 0.25 m² quadrat was located at random over an area of about 10 m x 20 m using a table of random numbers (Fisher and Yates, 1963). There were 10 quadrats per
site. The plant samples were obtained by hand-cutting the 10-quadrat samples from each site, during each sampling session, and they were then transported to the laboratory for identification.

Results

Phytoplankton (Algae)

The diversity of phytoplankton at the ten sampling stations within the Lower Volta was low, with a total number of 22 genera (Table 5.1). This comprises the three major classes of phytoplankton, namely green algae (8 genera), blue-green algae (9 genera) and diatoms (5 genera).

Table 5.1: Phytoplankton species composition, abundance and diversity identified in the Lower Volta

<table>
<thead>
<tr>
<th>Species of phytoplankton</th>
<th>Big Ada</th>
<th>Anyanui</th>
<th>Agodome</th>
<th>Sokpoe</th>
<th>Adidome</th>
<th>Mepe</th>
<th>Volivo/Avakpo</th>
<th>Amedeka</th>
<th>Kpong</th>
<th>Adomi</th>
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<td>42</td>
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</table>
Macro-invertebrates

The results (Table 5.2) show that there were 8 families of macro-invertebrates present at the sampling sites at the time of the study. All families had only one taxon, indicating low diversity with Shannon Wiener Diversity index, $H = 0.9474$ (Table 5.3). A total of 662 individuals were encountered. Annelida, Diptera, Ephemeroptera, Gastropoda, Mysidacea, Odonata, Pelecypoda and Trichoptera all had a taxon each, with individuals ranging from 1 to 300 species.

Table 5.2: Distribution of macro-invertebrate families and species at the various sites at the Lower Volta

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Anyanui</th>
<th>Agordome</th>
<th>Big Ada</th>
<th>Sokpo</th>
<th>Adidome</th>
<th>Mepe</th>
<th>Ayako</th>
<th>Amedeka</th>
<th>Kpong</th>
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<td>10</td>
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### Taxa Sampling Sites

<table>
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<tr>
<th>Taxa</th>
<th>Anyanui</th>
<th>Agordome</th>
<th>Big Ada</th>
<th>Sokpoe</th>
<th>Adidome</th>
<th>Mepe</th>
<th>Avakpo</th>
<th>Mepe</th>
<th>Adidome</th>
<th>Mepe</th>
<th>Kpong</th>
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### MYSIDACEAE

- **Mysidae**
  - *Mysis* sp. 1

### ODONATA

- **Coenagiidae**
  - *Bradinopyga strachani* 1

### PELECYPODA

- *Pelecypoda* sp. 2

### TRICHOPTERA

- *Cheumatopsyche* sp. 1

Mepe had 1 family and 44 individuals, Adidome, Avakpo and Amedeka had 2 families each with 4, 21 and 31 respectively, Anyanui, Agodome, Big Ada and Sokpoe all had 3 families each with 51, 48 individuals, 18 and 41 individuals respectively. Kpong had 4 families and 120 individuals while Adomi had 5 families and 284 individuals.
Table 5.3: Shannon-Wiener Diversity Index for the macro-invertebrates

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<th>Life form</th>
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<th>lnPi</th>
<th>Piln(Pi)</th>
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</table>

From the table, $H = -(-0.9474)$, therefore Shannon-Wiener Diversity Index $H = 0.9474$

All values recorded during the study period were near 0, which means that the life-forms of the macro-invertebrates were not evenly distributed in the Kpong headpond and the Lower Volta River due to the dominance of Diptera, Gastropoda and Annelida.

Aquatic Macrophytes

The current study recorded 65 species, an indication that the number of species and their diversity is increasing in the Kpong Headpond and the Lower Volta River. The newly identified species are made up of five rooted emergent plants including *Cyperus papyrus* and seven free-floating species including *Nymphaea lotus* and *Eichhornia crassipes* (see Appendix 5.1). The study revealed that the Kpong headpond and the Lower Volta River have mats of mixed vegetation which grow around the banks and islands, and over shallow areas including the intake point of the Kpong head works of the Ghana Water Company Limited (GWCL) and parts of the landing sites. The current study identified 49 emergent, 12 free floating and 4 submerged species (see Appendix 5.1). The distribution of weeds at the other sites apart from Kpong which had all the 65 species is shown in Table 5.4.
Table 5.4: Distribution of aquatic weeds at the various sites in the Lower Volta

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Anyanui</th>
<th>Agordome</th>
<th>Sokpoe</th>
<th>Adidome</th>
<th>Big Ada</th>
<th>Mepe</th>
<th>Avako</th>
<th>Amedeka</th>
<th>Adomi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emergents</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Aponogeton pectinatus</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Commelina diffusa</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclosorus striatus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyperus sp.</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Echinocloa pyramidalis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Eleocharis acutangula</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>Leersia hexandra</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ludwigia sp.</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Marsilea sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Neptunia oleracea</td>
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<td></td>
<td></td>
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<td>Typha domingensis</td>
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<td></td>
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<td>Vossia cuspisata</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Free Floating</strong></td>
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<td>Azolla sp.</td>
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<td></td>
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<td>Eichhornia crassipes</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
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<td>Pistia stratiotes</td>
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<td></td>
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<tr>
<td>Salvinia sp.</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Spirodella polyrrhyiza</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Nymphaea sp.</td>
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<td>x</td>
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<td></td>
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</tr>
<tr>
<td><strong>Submerged</strong></td>
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<td></td>
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<tr>
<td>Ceratophyllum demersum</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>Potamogeton octandrus</td>
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<tr>
<td>Vallisneria aethiopica</td>
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<td>x</td>
<td>x</td>
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</tr>
</tbody>
</table>
Discussion

The blue green algae (cyanobacteria) had the highest total composition at all the ten sites from Anyanui, the sea end of the Lower Volta River to Adomi village, the riverine end.

The high algal counts in these areas can be attributed to the high human activity such as free range defaecation, fertiliser run-offs from nearby farms and siting of refuse dumps along the banks of the river which could lead to nutrient pollution of the river. With regard to species dominance, the blue-green algae dominated in the samples throughout the Lower Volta, forming between 70% and 90% of the total counts. Diatoms and green algae were scanty, with the diatoms especially contributing below 10% of the total counts. Diatoms are known to be predominantly affected by the geochemical characteristics including pH and mineralization level, especially silicon (Tolotti, 2001). Diatoms are also known to thrive under low nutrient conditions and higher water velocity (Sabater, 1990). Some of the prominent green algal species encountered were Ankistrodesmus, Pediastrum, Scenedesmus, Staurastrum and Ulothrix. Out of these genera, Scenedesmus and Ulothrix were found to be present at all the stations. The presence of Scenedesmus is a strong sign of eutrophication (Rosen, 1981); however, their low biomass makes this assertion inconsistent with our results from the Lower Volta. Cyanobacteria species composition was dominated by Anabaena, Merismopedia, Microcystis and Planktothrix (Table 5.1). Out of these four species of cyanobacteria, Merismopedia is the only nontoxic one. Navicula, Synedra and Nitzschia sp. were common within the diatoms. Navicula, a species known to thrive well in estuarine conditions (Riaux and Germain, 1980), was present at all the stations with the exception of Kpong and Adomi.

The dominance of cyanobacteria in Ghanaian waters has been reported in earlier studies (Frempon and Addico, 2004; Addico et al., 2006; Addico et al., 2009). The Lower Volta serves as a source of drinking water, either treated or untreated. The presence of cyanobacteria in these waters presents serious water quality problems such as taste, odour and colour, as well as fish kills due to oxygen depletion and the release of ammonia from dead and decaying cyanobacteria (Chorus et al., 2000). Cyanobacteria are not a good source of food for zooplankton and fishes.
CHAPTER 5

due to their low nutrient value and unpalatability. Cyanobacteria are also known to irritate the gills of fishes and to release toxic compounds into the surrounding waters, leading to stunting of growth.

Macro-invertebrates are sensitive to different chemical and physical conditions. If there is a change in the water quality or in the flow regime due to environmental modifications, e.g., building of a dam, the macro-invertebrate community structure may also change. Therefore, the richness of the macro-invertebrate community composition in a water body can be used to provide an estimate of the health of the water body.

The disappearance of clams and oysters from most parts of the Lower Volta has been blamed on the change in the flow pattern of the river after the construction of the dam. The reduction of flow after the dam construction has led to the deposition of silt on the river bed, a situation which does not support the growth of macro-invertebrates since their respiratory activities are interfered with. Clams and oysters are known to prefer sandy bottoms. Sandy bottoms can be created by increasing the flow rate to as close as possible to the pre-dam condition, which is about 2000 m$^3$/s.

Salinity is a major problem facing lagoon macro-invertebrates, as some macro-invertebrate communities have varying degrees of tolerance to different levels of salinities. A decrease in the number of individual macro-invertebrate species has been attributed to the increase of salinity in the coastal waters. However, studies have shown that generally, crustaceans are more tolerant to rising salinity than insects. It can be seen that the macro-invertebrate diversity of the Lower Volta is very poor and it is only the gastropods and diptera that are prevalent in the river.

Some macro-invertebrates are able to take advantage (opportunistic) of altered conditions and exploit the excess of food supply. For example, the red midge larvae (Chironomids) are very tolerant to low levels of dissolved oxygen and therefore take advantage of such situations to establish themselves. Macro-invertebrates and phytoplankton are very important in the food chain of aquatic ecosystems. In fact, they form an important component of the food items of the two most important species (i.e., the Tilapias and *Chrysichthys* sp.) in the Lower Volta. The tilapias are known herbivores feeding extensively on phytoplankton,
while *Chrysichthys* sp. are benthic omnivores feeding extensively on macro-invertebrates (Dankwa *et al*., 2009). Thus, the presence of both macro-invertebrates and phytoplankton is important for the fisheries at the Lower Volta.

Distribution of aquatic plants is, to a large extent, influenced by environmental factors, of which flow and salinity play a major role. During the pre-dam situation, aquatic weeds were not a problem at the Lower Volta. This was because the flow of water, especially during the floods, was fast enough to flush away the weeds. After the construction of the dam the flow has considerably reduced, enabling the weeds to get established. Additionally, the influx of sufficient sea water which could travel further up the channel prevented aquatic weeds from getting established because they could not tolerate saline waters. Currently, aquatic weeds are posing a big threat in the Lower Volta. The re-operation of the dams should be such that the flow is considerably increased to about 2000 m$^3$/s to flush away the weeds and also ensure that there is enough intrusion of sea water to kill the weeds. An absence of weeds will drastically reduce the incidence of water borne and water related diseases and ensure more fish catch since the weeds impede fishing activities.

According to deGraft-Johnson (1999), when the Kpong Headpond was closed for filling in 1981, there were only 15 species of aquatic macrophytes present (3 submerged, 3 free floating, 5 emergents and 4 sudd-formers), but the number increased rapidly, and by 1988 there were 53 aquatic plants (7 free floating, 43 emergent and 3 submerged) (Gyimah-Amoako, 1988; de-Graft Johnson, 1999). The current study recorded 65 species, an indication that the number of species and their diversity are increasing in the Kpong Headpond and the Lower Volta River. The newly identified species are made up of five rooted emergent plants including *Cyperus papyrus* and seven free-floating species including *Nymphaea lotus* and *Eichhornia crassipes*. This means that the increase in new plant species invading the headpond is across all the life-forms, but there were more free-floating species than emergent and submerged species. Some invasive alien species (e.g., *Eichhornia crassipes*, *Cyperus papyrus* and *Salvinia molesta*), have also invaded the headpond. All the plant species found in the headpond at the time it was closed for filling were indigenous species.
In 1988, there was a huge increase in the number of aquatic plants from 15 to 53, and by 2015, the number of aquatic plants had increased to 65. The absence of aquatic weeds from Anyanui (except the mangroves) is also expected because of the saline nature of the water at that site.

**Conclusion**

The construction of the two dams has led to the proliferation of all types of aquatic weeds – emergent, free floating, submerged and sudd former in the Lower Volta, especially in the Kpong Headpond. The number of species in the headpond has increased from 15 in 1981 to 65 in the current study, consisting of 47 emergent, 12 free floating and 4 submerged species. The presence of the weeds has not only brought along with them various water borne diseases, the vectors of which are associated with the weeds, but they also impede fishing activities.

However, the weeds, especially the free-floating ones, cannot survive in fast flowing waters, and also in saline conditions. The flow rate and regime is likely to change with the re-operation exercise. With an increase in the flow rate, the weeds will be flushed away, and with the intrusion of more saline waters most of them will perish. This project identifies hypothetical restoration flow regimes, but recognizes that the most reliable method for developing a restoration flow regime is through a long-term adaptive management programme including a series of trials that test the effectiveness of various flow prescriptions.

**Recommendation**

There will be the need to develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and to identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.
References


**Sustainable Integrated Development of the Volta Basin** (pp 55–62)  
Volta Basin Research Project, Legon, Accra.


Appendix 5.1: Aquatic macrophytes present in the Kpong headpond and Lower Volta River.

<table>
<thead>
<tr>
<th>Name</th>
<th>Family</th>
<th>1981</th>
<th>1988</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emergent species</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acroceras zizanoides</em> (Kunth) Dandy</td>
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<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><em>Aeschynomena elaphroxylon</em> Guill. and Perr.</td>
<td>Fabaceae</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><em>Aeschynomena indica</em> L.</td>
<td>Fabaceae</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><em>Alternanthera sessilis</em> L. R. Br. Ex Roth</td>
<td>Amaranthaceae</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><em>Aponogeton pectinatus</em> L.</td>
<td>Asteraceae</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><em>Brachiara mutica</em> (Forssk.) Stapf</td>
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<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><em>Burnatia enneandra</em> (P.Micheli)</td>
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<tr>
<td><em>Ceratopteris cornuta</em> (P. Beauv.)</td>
<td>Parkeriaceae</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td><em>Chasmapodium caudatum</em> (Hack) Stapf</td>
<td>Poaceae</td>
<td>x</td>
<td></td>
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</tr>
<tr>
<td><em>Chloris robusta</em> Stapf</td>
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<td>x</td>
<td></td>
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<td></td>
<td></td>
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<td><em>Cyperus nudicaulis</em> (Poir)</td>
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<td></td>
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<td><em>Cyperus papyrus</em> L.</td>
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<tr>
<td><em>Echinochloa pyramidalis</em> (Lam.) Hitchc. and Chase</td>
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<tr>
<td><em>Eichhornia natans</em> (P. Beauv.) Solms-Laub</td>
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<td><em>Eleocharis acutangula</em> (Roxb.)</td>
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<td><em>Hydrolea glabra</em> Schumach and Thonn.</td>
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<td><em>Ipomoea asarifolia</em> (Desr.) Roem and Schult.</td>
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<tr>
<td><em>Ipomoea fluviana</em> Sw.</td>
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<td><em>Leersia hexandra</em> Sw.</td>
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<td>x</td>
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<tr>
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<td><em>Ludwigia leptocarpa</em> (Nutt.) Hara</td>
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</tr>
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<td>x</td>
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<tr>
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<td>x</td>
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<tr>
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<td>x</td>
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<tr>
<td><em>Typha domingensis</em> (Persoon) Steud</td>
<td>Poaceae</td>
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<td><em>Spirodella polyrrhyiza</em> L. Schleid</td>
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<td><em>Wolffia arrhiza</em> L. Horkel. Ex. Wimm.</td>
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**Total** | 15 | 53 | 65
Abstract

Trends of groundwater recharge of the Akosombo and Kpong hydro-electric dams of the Lower Volta river area have been estimated as part of studies to help re-optimize and re-operate both dams with the view to restoring lost bio-diversity and livelihoods. This has been done by assessing existing hydrogeological data to establish the general groundwater availability and for general aquifer and groundwater recharge characterization. Historical hydrogeological data on boreholes suggest that only about 5.8% of communities in the area depend on groundwater for domestic and other uses due to the close proximity of the communities to the Volta river. Modelled pumping test results from some existing boreholes suggest increasing borehole yield, transmissivity as well as specific capacity variations from the northern section of the study area towards the southern section. Using the chloride-mass balance estimation method, groundwater recharge rates for the Lower Volta river area, relative to the total annual rainfall, were computed to range from 10% in the northern section to 33% towards the coast. The increasing hydraulic characteristics and the relatively high groundwater recharge trends from the northern section towards the coast could be attributed to the nature and structural characteristics of the underlying rock formations, which tend to
decrease in consolidation towards the southern section. Total dissolved solids, chloride and sodium contents in borehole water increased from the northern section towards the coast; iron and turbidity contents decreased in the same direction. Because no groundwater monitoring study has been carried out in the area, the results obtained from the current study could effectively serve as baseline data and information for future hydrogeological work in the Lower Volta Basin.

Keywords: Akosombo, Biodiversity, Groundwater recharge, Re-optimisation, Transmissivity

Introduction

Construction of dams worldwide is often associated with changes in original river flow regimes, especially at their downstream sections. The dams have direct and extensive impact on the ecological conditions, leading to huge environmental degradation and loss of biodiversity and livelihoods (Dai and Liu, 2013). In many parts of the world, the construction of dams have led to the disruption of many traditional production systems, including flood recession on agriculture through changing the availability of surface and shallow groundwater, and by changes in the distribution of fertile sediments and fishery production (Thomas and Adams, 1977). Flooding of downstream sections often results in storage of water in shallow aquifers, which inadvertently serves as freshwater buffers during low flow periods. Such recharge have proven to be reliable sources of water to support all-season irrigation.

Even though the construction of the Akosombo and Kpong hydro-electric dams on the Volta River in 1965 and 1981 respectively, have greatly benefited Ghanaians in hydro-electric power generation and provision of domestic and agricultural water requirements, the damming of the river has led to devastating ecological changes downstream. Several indigenes lost fertile agricultural lands through forced relocation, primary economic activities and livelihoods from artisanal fishing to agriculture, homes, community stability and important socio-cultural values (Gyau-Boakye, 2001).
Hydro-geologically, an increase in groundwater storage within downstream parts of the dams gives rise to increasing water levels in shallow wells, and this impacts positively on agricultural activities within the downstream area (Gyau-Boakye, 2001). It may therefore be necessary to determine levels of recharge into the groundwater system in the downstream parts of the dams, especially after their construction, to provide information or data to help re-optimize and re-operate the dams to restore the original hydrodynamic and ecological flow conditions.

Even though there have been several studies in the past to estimate groundwater recharge in the northern part of the Volta Basin, little or no comprehensive work has been done in the southern part of the basin. Alfa et al. (2011), and Gumma and Pavelic (2012) predicted recharge rates of between 15% and 22% of the annual rainfall in the Lower Volta Basin. Again, using run-off coefficient estimation, Anayah et al. (2013) computed the recharge rate for the Lower Volta Basin to range between 11% and 15% of the annual rainfall.

**Study area**

The study area is the Lower Volta River basin, comprising the downstream part of both the Akosombo and Kpong hydro-electric dams. The drainage area of both dams initially traversed six (6) administrative districts. However, with government’s re-demarcation policy to create additional districts in 2011, the study area now traverses nine (9) administrative districts, i.e. Ada-East, Ada-West, Shai-Osudoku, Asuogyaman, Lower Manya, North Tongu, Central Tongu, South Tongu and Keta Municipal (Ghana Statistical Service, 2005). The southern part of the study area is marked by sand bars, deltas and lagoons (Fig. 6.1).
CHAPTER 6

The study area falls within two (2) climatic regions. The northern part, which lies between Akosombo and Akuse, falls within the Wet semi-equatorial climatic zone whilst the southern part falls within the Dry equatorial climatic zone (Dickson and Benneh, 1980). The two climatic zones are characterized by two rainfall maxima with rainfall values reducing from 1,750 mm/yr in the northern section to about 1,250 mm/yr in the southern part. The major rainfall begins in March to July and the minor rainfall from September to November (Dickson and Benneh, 1980). Available 15-year rainfall records (1990-2004) show that the mean

Fig. 6.1: Location map of the downstream part of the Akosombo and Kpong dams
annual rainfall is about 937 mm/yr at Akatsi and about 830 mm/yr at the Keta meteorological stations (Gyau-Boakye and Timbulto, 2000). Fig. 6.2 shows the rainfall and evaporation regimes at the meteorological stations at Keta in the southern section of the project area.

Fig 6.2: Rainfall and evaporation regime of Keta
(Source, Gyau-Boakye P, 2001)

The mean annual potential evapo-transpiration is about 1,340 mm/yr and 1,582 mm/yr for the Akatsi and Keta stations, respectively. The mean monthly potential evapo-transpiration rates exceed mean monthly rainfalls for most part of the year. The mean monthly temperature is uniform across the basin, with a mean of about 27.8 °C. The coolest month in the basin is August, with a temperature of about 26.2 °C and March is the hottest month with a temperature of about 29 °C (Kankam-Yeboah and Gyau-Boakye, unpublished).

Generally, three (3) main geological formations underlie the entire area. The northern section near Akosombo is underlain by rocks of the Togo Series, which form the Akwapim-Togo mountain range that borders the Accra Plains on the west and trends through Kpong in the south-western direction (Kesse, 1985). Predominant rocks of the Series comprise quartzite, quartz-schist, sandstone, sericite-schist, shale and phyllite. The mid-section of the project area around Kpong, Osudoku and Akuse is underlain by the Dahomeyan, which occurs as alternating
belts of acidic and basic gneisses (Kesse, 1985). The Acidic Dahomeyan consists mainly of muscovite-biotite gneiss, quartz-feldspar gneiss, augen gneiss and minor amphibolites, which decompose to slightly permeable calcareous clays. The basic Dahomeyan is very uniform, coarse-grained and usually of well-foliated garnet hornblende gneiss, with minor layers of biotite schist. When decomposed, the basic Dahomeyan rocks become grey, calcareous clay and silt which, when wet, become plastic, but shrink and crack when dry.

The geology of the southern section, including parts of North Tongu, and the entire South Tongu Districts and Keta Municipal area comprises Recent and Tertiary marine sediments of unconsolidated rocks and soils which overlie varying thicknesses of Eocene/Cretaceous limestone beds. Kesse (1985) indicated that the stratigraphy of the basin is made up of alternating beds of loose sand and clays (100-215 m thick) and limestone with black clays (45-120 m thick). In his studies on the structural evolution of the Keta Basin, Akpati (1998) used results from Bouguer gravity anomalies to indicate that the southern part of the project area is dominated by two major northeast-trending anomalies.

Hydrogeologically, the underlying basement rock of the northern and mid-sections of the project area, between Akosombo and Akuse-Osudoku, is massive with few fractures. Darko et al. (2003) indicated that porosity and permeability of the rocks are very low, and this has given rise to low groundwater potential in the sections underlain by this rock formation. Accordingly, groundwater only occurs in porous fractured media with yielding capacity in the range of 0.2-8.2 m$^3$/hr. The aquifer system of the southern section comprises mainly unconsolidated sands and some minor clays, and therefore has a fast recharge rate from rainfall. Consequently, borehole yields in the southern section are generally high, ranging between 75 and 540 litre/min (Dapaah-Siakwan and Gyau-Boakye, 2000). Water quality is generally good except for fairly high contents of chloride, alkalinity and iron. Further from the coast within the basin, the topsoil is made up of mixed unconsolidated sandy soil, slightly acidic lateritic sandy soil, basic sandy-clay soil and sandstone. These overlie acidic/basic Dahomeyan gneiss rocks, which weather to form layers of clay which eventually impede water infiltration into the ground, leading to waterlogging, especially in the wet season (Dapaah-Siakwan and Gyau-Boakye, 2000).
Methods

The methodology adopted for the study consisted of desk study, reconnaissance survey, historical groundwater data analysis and pumping tests on selected boreholes within the study area. The desk study involved acquisition and study of topographic, geological and aerial photographs, as well as available data and information on boreholes within the study area from the mapping section of Ghana Survey Department. Inventory and documentation of previous hydrogeological work done within the entire downstream part of the dam were also acquired and reviewed. The purpose of the desk study was to establish the state or level of current knowledge about the underlying aquifers, their thicknesses, mean depths and the water table. Data on groundwater from the Volta Regional Community Water and Sanitation Agency (CWSA) were also analysed to provide background information on the expected groundwater availability and quality in the project area.

In addition, a fracture-trace analytical study from available topographic sheets obtained from the Survey Department, which covered the study area and were prepared from aerial photos taken in 1974, indicated that there are several lineaments mostly trending in the north-south and northeast-southwest directions (Kesse, 1985). Two sets of topographic sheets developed from aerial photos taken in 1974 and earlier ones on a scale of 1:62,000 sheets developed from aerial photos around the 1950s were acquired from Ghana Survey Department and studied. The lineaments indicate incise hills and mountains that border the eastern side of the Volta Region and extend towards the coast and these may have served as pathways for many streams and rivers flowing into the Volta and Tordzie Rivers (Geological Survey of Ghana, 2009).

An aquifer test was conducted on selected boreholes to help establish hydrogeological characteristics of the underlying aquifer system in the project area. Twenty-four (24) boreholes were selected from the communities within the study area and pump-tested on the basis of geology. The Cooper-Jacob semi-log straight line method was used to estimate the transmissivity coefficient and specific capacity values of the underlying aquifer system. The transmissivity coefficient of an aquifer refers to the rate at which water flows through a vertical
strip of the aquifer 1m wide and extends through the full saturated thickness under a unit hydraulic gradient (Driscoll, 1995). The specific capacity of an aquifer refers to the amount of water that is required to be pumped out of a borehole in order to cause a unit drawdown (MacDonald et al., 2008). In other words, it represents the volume of water released from storage per unit change in head (Driscoll, 1995). In addition, the chloride mass balance method was used to estimate groundwater recharge in the study area by comparing the chloride content in rainwater and groundwater samples by using the relation:

\[ R = \frac{PC_p}{C_{gw}} \]

where, \( R \) is annual groundwater recharge (mm); \( P \) is annual rainfall (mm), \( C_p \) is concentration of chloride in precipitation (mg/l); and \( C_{gw} \) is concentration of chloride in groundwater (mg/l).

Physico-chemical analyses were carried out on the twenty-four (24) borehole water samples to determine the water quality trend within the study area. In addition, simple statistical analyses were carried out on the water quality results to obtain the mean and range of the various parameters.

**Results**

**Historical hydrogeological data**

Available hydrogeological information of the Lower Volta Basin indicates that due to the abundance of lake water, very little attention is paid to groundwater exploitation (VRWSSP, 1998 and WRRI, 1993). This is supported by the assertion made by Amoah et al. (2008) that water supply through boreholes in the Lower Volta Basin averages 5.8%. The few boreholes and hand-dug wells that have been drilled in the study area have been for private domestic uses, and no pumping test was carried out on them (WRRI, 1993). Historical data were obtained on two hundred and eighty (280) boreholes that were drilled between 1970 and 1998 in the Asuogyaman, Adidome, Sogakope, Keta and Ketu Districts within the study area, though they were drilled some few years after the construction of the dam (VRWSSP, 1998). The data comprise borehole depth, aquifer sections, drilling yield and static
water level (Table 6.1). They represent borehole data from the upper, middle and southern sections of the study area. Simple Statistical analyses conducted on the 280 boreholes (Table 6.1) show that the depth of boreholes within the South Tongu, North Tongu and Asuogyaman Districts, which are underlain by hard rocks, ranges between 11m and 85 m with an average depth of 47 m. Average borehole yield is 30 lpm, ranging between 2 lpm and 270 lpm, with an average static water level of 5.59 m below the ground level. However, in the Keta district, which is underlain by unconsolidated formation, borehole depths are relatively higher, ranging between 8 m and 617 m, with relatively higher borehole yields ranging from 9 lpm to 750 lpm.

Table 6.1: Statistical analyses on the available historical borehole data (VRWSSP, 1998)

<table>
<thead>
<tr>
<th>District</th>
<th>No of BHs</th>
<th>Statistic</th>
<th>Depth (m)</th>
<th>Yield (lpm)</th>
<th>SWL (m)</th>
<th>Date of Drilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sogakope/Adidome/</td>
<td>89</td>
<td>Mean</td>
<td>47</td>
<td>29.8</td>
<td>5.59</td>
<td>1970 - 1998</td>
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<tr>
<td>Asuogyaman</td>
<td></td>
<td>Range</td>
<td>11 - 85</td>
<td>2 - 270</td>
<td>0.3 - 50.8</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev</td>
<td>15.1</td>
<td>45.5</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>154</td>
<td>260.5</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Keta</td>
<td>32</td>
<td>Mean</td>
<td>8 - 617</td>
<td>9 – 674</td>
<td>0.3 – 25.6</td>
<td>1952 - 1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>122.5</td>
<td>223.1</td>
<td>6.4</td>
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<tr>
<td></td>
<td></td>
<td>Std. Dev</td>
<td>66.1</td>
<td>105</td>
<td>20.1</td>
<td></td>
</tr>
<tr>
<td>Ketu</td>
<td>159</td>
<td>Range</td>
<td>9 – 304</td>
<td>15 – 750</td>
<td>1.55 – 40</td>
<td>1949 - 2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Std. Dev</td>
<td>47.1</td>
<td>141.8</td>
<td>11.3</td>
<td></td>
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</table>

Borehole and Aquifer Characteristics

Results of pumping tests conducted on the selected boreholes to assess existing hydrogeological characteristics of the underlying aquifer system are presented in Table 6.2. The pumping yield results showed yield values ranging between 0.6 and 6.6 m³/hr. The low pumping yield values, which averaged 2.5 m³/hr and ranged from 0.6 - 4.5m³/hr, were recorded in the northern section of the study area in the Asuogyaman District. The highest pumping yield values were recorded in the southern section of the study area at Battor, Mepe, Sogakope, Dabala, Vume, Kpotame, as well as Keta and Anyako in the North and South Tongu Districts and in the Keta Municipality with mean pumping rate of 4.5 m³/hr (range 0.6-52.6 m³/hr).
<table>
<thead>
<tr>
<th>No.</th>
<th>Community /borehole</th>
<th>District Assembly/ Municipality</th>
<th>GPS location Elevation (m, amsl)</th>
<th>BH Depth (m)</th>
<th>SWL(m)</th>
<th>Discharge Rate (m³/hr)</th>
<th>Max Drawdown (m)</th>
<th>Trans-missivity (m²/d)</th>
<th>Specific Capacity (m³/d/m)</th>
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<tr>
<td>1</td>
<td>Atimpoku District Ass</td>
<td>Asuogyaman</td>
<td>N6.24324°, E0.09076°</td>
<td>57</td>
<td>85</td>
<td>7.49</td>
<td>1.8</td>
<td>57.2</td>
<td>0.18</td>
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<td>2</td>
<td>Ayermesu</td>
<td></td>
<td>N6.21745°, E0.03255°</td>
<td>137</td>
<td>54</td>
<td>7.48</td>
<td>2.4</td>
<td>9.63</td>
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<td>N6.24649°, E0.02141°</td>
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<td>9.75</td>
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<td>13.62</td>
<td>2.63</td>
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<td>Odorkorm</td>
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<td>N6.24703°, E0.04662°</td>
<td>276</td>
<td>71</td>
<td>7.04</td>
<td>1.2</td>
<td>54.1</td>
<td>0.116</td>
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<td>Old Akrade</td>
<td></td>
<td>N6.20301°, E0.10209°</td>
<td>27</td>
<td>35</td>
<td>6.48</td>
<td>1.2</td>
<td>6.18</td>
<td>1.32</td>
</tr>
<tr>
<td>6</td>
<td>Volivo</td>
<td></td>
<td>N6.09977°, E0.25159°</td>
<td>19</td>
<td>12</td>
<td>7.69</td>
<td>1.5</td>
<td>1.10</td>
<td>32.9</td>
</tr>
<tr>
<td>7</td>
<td>Atrobinya</td>
<td>Shai-Osidoku</td>
<td>N6.09399°, E0.22680°</td>
<td>18</td>
<td>21</td>
<td>6.36</td>
<td>0.9</td>
<td>11.89</td>
<td>0.56</td>
</tr>
<tr>
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<td>Kewum</td>
<td></td>
<td>N6.09677°, E0.22648°</td>
<td>25</td>
<td>19</td>
<td>5.66</td>
<td>4.5</td>
<td>3.22</td>
<td>198.0</td>
</tr>
<tr>
<td>9</td>
<td>Manya Battor (Nurses qtrs)</td>
<td></td>
<td>N6.06318°, E0.40444°</td>
<td>16</td>
<td>11</td>
<td>5.46</td>
<td>5.1</td>
<td>0.58</td>
<td>90</td>
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<tr>
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<td>Manya Battor (Methodist)</td>
<td>North Tongu</td>
<td>N6.06055°, E0.39775°</td>
<td>14</td>
<td>11</td>
<td>4.8</td>
<td>5.1</td>
<td>2.41</td>
<td>112</td>
</tr>
<tr>
<td>11</td>
<td>Manya Battor (Atsu’s hse)</td>
<td></td>
<td>N6.05811°, E0.39801°</td>
<td>15</td>
<td>12</td>
<td>6.25</td>
<td>0.6</td>
<td>3.27</td>
<td>1.1</td>
</tr>
<tr>
<td>12</td>
<td>Mepe (St Kizito SHS)</td>
<td></td>
<td>N6.07547°, E0.43070°</td>
<td>16</td>
<td>15</td>
<td>3.78</td>
<td>6.0</td>
<td>2.26</td>
<td>88.0</td>
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<td>Mepe (Presby Church)</td>
<td></td>
<td>N6.07869°, E0.43101°</td>
<td>19</td>
<td>15</td>
<td>7.20</td>
<td>6.0</td>
<td>0.78</td>
<td>105.4</td>
</tr>
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<td>Ada-West</td>
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<td>40</td>
<td>48</td>
<td>5.65</td>
<td>1.5</td>
<td>26.57</td>
<td>0.3</td>
</tr>
<tr>
<td>15</td>
<td>Afiadenyigba (Dogorbom)</td>
<td></td>
<td>N5.96312°, E0.50071°</td>
<td>14</td>
<td>51</td>
<td>16.35</td>
<td>3.6</td>
<td>5.55</td>
<td>7.9</td>
</tr>
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<td>No.</td>
<td>Community/borehole</td>
<td>District Assembly/Municipality</td>
<td>GPS location</td>
<td>Elevation (m, amsl)</td>
<td>BH Depth (m)</td>
<td>SWL(m)</td>
<td>Discharge Rate (m$^3$/hr)</td>
<td>Max Drawdown (m)</td>
<td>Transmissivity (m$^2$/d)</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------------</td>
<td>--------------------------------</td>
<td>--------------------------------</td>
<td>---------------------</td>
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Discussion

Transmissivity Variation

Analyses of the pumping test results revealed that borehole yields in the upper section of the study area, near Akosombo, were very low, whilst those close to the coast in the southern section were fairly high. Computed transmissivity values of the major underlying aquifer varied widely from the north to the south of the study area. In the northern section, transmissivity values varied from 0.12 - 8.4 m²/d in the Asuogyaman and Ada-West Districts. They ranged between 0.3 and 198 m²/d in the mid-section. On the other hand, transmissivity values ranging from 0.13 to 264 m²/d with a mean of 12m²/d were recorded in the North and South Tongu Districts and Keta Municipal area of the southern section of the study area. Fig. 6.3 is the modeled transmissivity variation map across the entire study area. The high values may be due to the high porosity and hydraulic conductivity characteristics of the underlying sandy formation in the North and South Tongu Districts and Keta metropolis, which allows fast rainwater percolation to recharge the unconsolidated sandy aquifers.

Fig. 6.3: Transmissivity Variation Map of the study area
Specific Capacity Distribution

Modelled specific capacity values of the Lower Volta River Basin (Fig. 6.4) ranged between 0.53 m$^3$/d/m and 211.6 m$^3$/d/m. Higher values were recorded in the mid-sections and the south-eastern sections in the North-Tongu (Mepe, Battor) areas, through Central Tongu, to South Tongu areas at Vume, Sogakope and Dabala to the coast around Keta in the south-eastern portion of the study area, with values of 1.09 - 211.6 m$^3$/d/m. Specific capacity values obtained in the Asuogyaman and Ada-West Districts were low. The low hydraulic characteristics obtained for the northern section of the study area conform to Darko and Krasny’s (2003) results on the Regional Transmissivity distribution and groundwater potential in hard rock of Ghana.

![Specific Capacity Distribution map of the study area](image.jpg)
Groundwater Quality Assessment

Physico-chemical assessments were conducted on water samples from the pump-tested boreholes, and the results indicate decreased turbidity values from the northern section, (Asuogyaman District) of the study area to the southern section with average values of 192 NTU in the north, through 72.1 NTU in the mid-section, to a mean of 14 NTU towards the coast. The colour of the borehole water, as obtained from the analytical results also followed a similar trend as the turbidity variation. This suggests that boreholes in the southern section are less turbid in terms of their colour than those in the northern section, and this may be attributed to the high porosity and permeability properties of the overburdened sandy soils and the relatively low clay content of the underlying geological formation of the southern section of the study area (Dapaah-Siakwan and Gyau-Boakye, 2000). Mean chloride concentrations of 103.3 mg/l, 121 mg/l and 2,405 mg/l for the northern, middle and southern sections respectively, indicate a gradual increase from the northern section to the southern section. Total Dissolved Solids (TDS) of borehole water ranged from 421 mg/l in the north to 4,980 mg/l in the south. The concentrations of sodium showed an increasing trend from the northern to the southern section. The results suggest that the concentrations of sodium, chloride and TDS constitute the major water quality problems in the study area, as displayed by the plotted values in Fig. 6.5.

Fig. 6.5: Plot of Na, Cl and TDS Concentrations in Groundwater of the study area. North, Mid and South = Northern, Middle and Southern sections of the study area.
Groundwater recharge estimation

Groundwater recharge is governed by an intricate balance between several components of the hydrologic cycle. These include rainfall, evaporative losses, discharge losses, catchment dynamics, geology, fracture networks and the occurrence of structural features (Beekman and Xu, 2003). In the current study, a simple estimate of groundwater recharge was made using chloride concentration in rainfall and in groundwater samples. The results obtained were between 5% and 15% for the northern section of the basin in the Akosombo area, and 10% to 33% near the coast between Battor and Keta.

Conclusion

Pumping test results on selected existing boreholes yielded varying hydraulic characteristics for the upper, middle and lower sections of the Lower Volta River basin. Results from analyses of pumping test data were used to prepare transmissivity, yield and specific capacity maps for the upper, middle and southern section of the study area. The results suggest a higher increase in groundwater availability in the southern section than the northern sector of the study area.

Using the chloride-mass balance method, the groundwater recharge rates were estimated up to 11% and 15% of the annual rainfall in the northern section of the basin, reaching up to 33% in the southern section towards the coast. Relatively higher contents or levels of TDS, sodium and chloride were recorded in the southern section of the study area than the northern section.

Recommendations

i. Due to the absence of previous hydrogeological studies of the project area, it is envisaged that the results obtained from this study will form important baseline information for any future work in the Lower Volta River Basin area.

ii. Despite the close proximity of the project area to the Volta River, alternative sources of safe and reliable drinking water
should be provided for the inhabitants to reduce infestation of water-related diseases that result from their dependence on raw water from the Volta River.

References


PART TWO

CONCEPT OF DAMS RE-OPERATION AND RE-OPTIMIZATION
CHAPTER SEVEN

A REVIEW OF THE BENEFITS OF ENVIRONMENTAL AND LIVELIHOOD FLOWS OF DAM RE-OPERATION AND RE-OPTIMISATION

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Abstract

The damming of rivers for irrigation, electricity generation etc., contributes to the growth of an economy as a result of the multiplier effects created by providing power for industry and for domestic use, among others. However, dams also result in the erosion of the quality of the standard of living of downstream communities. This occurs because damming impairs the functions, processes and services of ecosystems downstream, thereby affecting the livelihoods of downstream communities that depend on these ecosystems such as rivers and the associated floodplains. The damming of the Volta River at Akosombo resulted in the drastic reduction of floodplain agriculture as natural flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas. In addition, the damming has disturbed the natural flow of the Volta River, thereby changing its natural ecology, promoting the growth of exotic weeds that have choked off the once lucrative shell fishery and increased the snail vectors of the schistosome parasite. The overall effect of the loss of agriculture, clam picking and the deteriorating health of the communities due to bilharzia
infestation, have created intense poverty in the Lower Volta basin and led to a dramatic shift in income generating activities. The Akosombo and Kpong dams’ re-operation and re-optimisation study project was conceived to assess how mimicking natural flows could help optimise livelihood opportunities of communities living downstream of the dams. The logic of re-operation is that since damming constraints optimal benefits derived from rivers, a situation of close to natural flow downstream would improve the dynamic interaction of the river with its floodplain and thereby restore livelihood losses that were suffered as a result of the construction of the dams. This chapter reviews the benefits of environmental and livelihood flows and provides an indication of the benefits to be derived when dams are re-operated and re-optimised, with particular reference to the Akosombo and Kpong dams.

**Keywords:** Environmental flows, Livelihood flows, Benefits, Livelihood Assets, Lower Volta

**Introduction**

The damming of rivers to generate electricity contributes to the growth of an economy, considering the positive cascading effects it has for the development of any nation. However, the development of rivers for hydropower has conventionally come at a high cost in terms of riverine livelihoods and ecosystems. In spite of the clearly documented benefits that hydropower generation from the damming of rivers contribute to any economy, hydropower dams have also devastated the livelihoods of the downstream communities and the physical ecosystem processes on which they depend.

The damming of the Volta River at Akosombo has resulted in a drastic reduction in floodplain agriculture as natural flooding no longer left the rich alluvial deposits that improve soil fertility in the floodplain areas. In addition, stakeholders have realized that the damming of the Volta River has distracted its natural flow and ecology. It has also brought about certain challenges like the growth of exotic weeds that have choked off the once lucrative shell fishery and increased the snail vectors responsible for the debilitating bilharzia. Furthermore, the
sediments trapped behind the dam result in a sediment deficit in the coastal current which has an increased capacity for coastal erosion. Coastal erosion along some transects near the Ada estuary and on the east of the Keta Sea defence site reached as high as 16m/year compared to an estimate of 2-5 m/yr before the Akosombo and Kpong dams were built (Appeaning Addo et al., 2011).

The overall effect of the loss of agriculture, reduced clam picking, deteriorating health due to bilharzia infestation and reduced fishing activities is intense poverty in the lower Volta and a dramatic shift in income generating activities. The goal of the Akosombo and Kpong dams’ re-operation and re-optimisation study project is to contribute to economic growth and poverty reduction through restoration of downstream ecosystems, food systems and livelihoods by re-operating the Akosombo and Kpong dams. In this chapter, the authors review the concepts of environmental and livelihood flows and the benefits associated with these flows.

**Methodology**

The authors conducted a systematic literature review using key terms like ‘environmental flows’, ‘livelihood and livelihood flows’ and the ‘integrative model of environmental and livelihood flows’ on appropriate Internet search engines such as Google Scholar, Yahoo search and ask.com as well as printed documents and journal articles. The articles were then read, analysed and the key points reviewed. Sources of the literature search included the Internet, the electronic resources of the Balme Library, University of Ghana and the Institute for Environment and Sanitation Studies (IESS) at the University of Ghana.
Key findings of the review

Environmental flows

Concept of environmental flows

Increasingly, concerns over environmental sustainability and maintaining ecosystem integrity in rivers have persuaded water resources managers to recognize the need to allow a certain amount of flow with an acceptable level of quality in rivers, which is often regarded as environmental flow (EF) (Tharme, 2003). The origins of the environmental flows concept can be traced to work undertaken in the 1940s in the western USA, following the recognition that a loss of flow in rivers was responsible for reduced numbers of game-fish species. Subsequently, the concept of environmental flows has advanced considerably in the last 20 years from a focus on individual aquatic species (although there are circumstances where this continues to be relevant) to a much broader concern about aquatic ecosystem protection or restoration (King et al., 1999; Hirji and Davis, 2009; Moore, 2004). In the literature, the three most common terms, environmental flow, minimum flow and in-stream flow, showed relatively equal frequencies, and other common terms included natural flow regime, ecological reserve and environmental water allocation. Brown and King (2003), however, point to an important distinction between in-stream flows and environmental flows. They were of the view that in addition to releases for environmental needs, in-stream flows encompass all releases for non-environmental purposes, including hydropower, irrigation, navigation, dilution of pollution and inter basin transfers. These releases do not constitute environmental flows, as they do not take into account the natural variability of the flow regime.

The environmental flows concept recognizes that there is the need for freshwater systems to maintain their ecological integrity and to continue to provide goods and services to society (Moore, 2004). This implies that rivers, wetlands, aquifers and other water systems require a certain fraction of water in sufficient quantities and at regular times to ensure that their integrity is not undermined. It is unrealistic and undesirable in many cases to return modified rivers, wetlands and estuaries to their natural state or pristine condition.
The environmental flows concept now serves to enhance informed, equitable and sustainable decision making in water management (Dyson et al., 2003).

Stewardson and Gippel (1997, pp. 92–93) provide a definition for environmental flows as: ‘a set of operational rules for water resource schemes to limit adverse ecological impacts to acceptable levels’ which ‘may be designed for a river, subject to a new water resource development or more commonly, a historical development for which insufficient consideration has been given to the ecological impacts’. Dyson et al. (2008) posit that the goal of environmental flows is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the health of the rivers and other aquatic ecosystems. This description is in line with the International Union for the Conservation of Nature’s (IUCN) definition that it is the water regime provided within a river, wetland or estuary to maintain ecosystems and their benefits where there are competing water demands/uses and where flows are regulated (IUCN 2000). The Nature Conservancy (2006) defines the term along similar lines, as the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people.

Several features of these definitions have a universal appeal. The descriptions signal that the ‘quality’ of water is an important dimension alongside water quantity and temporal flow patterns, and it also highlights the continuity of rivers and estuaries and their dependence on freshwater flows. Furthermore, it explicitly links environmental flows, river and estuarine ecosystems and the livelihoods and well-being of people and societies.

Environmental flows have been shown to be important in restoring downstream ecosystem processes and functions. For example, Lamouroux et al. (2006) reported that the Pierre-Bénite, a reach of the Rhone River in France, has a natural minimum flow rate of 10 m$^3$/s in the month of August. However, increment in the minimum flow due to alteration of the natural mean discharge also affected the average velocity of the river’s minimum flow. This artificial change induced by dams caused a significant change in the fish community within the
river. This finding confirms that changes in flow can have a significant impact on an ecosystem’s structure and function. This may well imply a threshold flow for optimal ecosystem function, making the concept of flow significant for ecosystem sustainability of the Lower Volta River.

**Flow as a driver of aquatic ecosystems functions and processes**

There are four distinct principles that demonstrate how the flow regime is the key driver of processes that sustain river and floodplain biodiversity (Bunn and Arthington, 2002; Korsgaard, 2006).

*Principle 1:* Flow is a major determinant of physical habitat availability, which in turn is a major determinant of biotic composition.

*Principle 2:* Aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes.

*Principle 3:* The maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species.

*Principle 4:* The invasion and success of exotic and introduced species in rivers are facilitated by the alterations of flow regimes.

The flow regime is often the driving variable in these systems, strongly affecting other aspects of the riverine environment such as fluvial processes (e.g., channel widening, meandering) and alluvial groundwater dynamics (Shafroth and Beauchamp, 2006). These factors, overlaid on the geologic and climatic setting, form the physical ‘stage’ on which vegetation dynamics play out. All major processes that sustain river functions, such as flooding, moderation of salt water intrusion, sediment transport etc., are dependent on certain aspects of the discharge characteristics of the river (Marchand, 2003). For river and wetland ecosystems, the flow regime is the most important determinant of ecosystem function and services. Flow features are determined by river size, geology, climate variation, topography and vegetation cover.
Environmental flow regime and component

Although biotic interactions take place and influence species composition and abundance, it is now commonly understood that flow regime is the overriding factor governing the nature and stability of communities along a river (King et al., 2000; Marchland, 2003). The flow regime is the pattern or variation of flow needed throughout the year to maintain essential ecosystem functions and processes. Many factors, such as water quality, sediments, food-supply and biotic interactions, are important determinants of riverine ecosystems. However, the overarching master variable is the river’s flow regime, that is the natural flow paradigm (Poff et al., 1997).

The flows in many rivers may vary throughout a year and between years. This pattern of flow (termed the flow regime) typically consists of low flows during the drier months, small peaks (freshets) when rains return, and occasional high floods in unregulated rivers (Hirji and Davis, 2009). River flow regimes and their relevant events can be described by hydrological indices derived from these components, which must adequately represent the main facets of the regime and the events that determine the biological functioning, geomorphologic processes, and the transportation of nutrients and sediment (Poff and Ward, 1989; Richter et al., 1996; Olden and Poff, 2003).

The environmental flow regime influences not only water quality and energy cycles, but also biotic interactions and habitat of rivers (Naiman et al., 2002). There are five elements of the flow regime which support specific ecological functions (Matthews and Richter, 2007):

- **Extreme low flows** which occur during drought; these are associated with reduced connectivity and limited species migration. During a period of natural extreme low flows, native species are likely to out-compete exotic species that have not adapted to these very low flows. Maintaining extreme low flows at their natural level can increase the abundance and survival rate of native species, improve habitat during drought, and increase vegetation.

- **Low flows**, sometimes referred to as base flows, occur for the most part of the year. Low flows maintain adequate habitat,
temperature, dissolved oxygen, and chemistry for aquatic organisms; drinking water for terrestrial animals; and soil moisture for plants. Stable low flows support feeding and spawning activities of fish, offering both recreational and ecological benefits.

- **High flow pulses** occur after periods of precipitation and are contained within the natural banks of the river. High flows generally lead to decreased water temperature and increased dissolved oxygen. These events also prevent vegetation from invading river channels and can wash out plants, delivering large amounts of sediment and organic matter downstream in the process. High flows also move and scour gravels for native and recreational fish spawning and suppress non-native fish populations, algae, (and beaver dams).

- **Small floods** which occur every two to ten years; these events enable migration to flood plains, wetlands, and other habitats that act as breeding grounds and provide resources to many species. Small floods also aid the reproduction process of native riparian plants and can decrease the density of non-native species. Increases in native waterfowl, livestock grazing, rice cultivation, and fishery production have also been linked to small floods.

- **Large floods** take place infrequently; they can change the path of the river, form new habitat, and move large amounts of sediment and plant matter. Large floods also disperse plant seeds and provide seedlings with prolonged access to soil moisture. Importantly, large floods inundate connected floodplains, providing safe, warm, nutrient-rich nursery areas for juvenile fish.

It is important, however, to note that the different components of an environmental flow regime contribute significantly to different ecological processes. In addition to elements of the flow regime, five components are recognized that regulate physical and biological processes in fluvial ecosystems (Moore, 2004). These five components include:

- Rate of Change of flow,
- Flow Frequency,
- Flow Duration,
Timing of flows and
Quantity (magnitude) of water flows.

The five components, according to Poff et al. (1997), comprise the elements of the natural flow regime that draw attention to the fundamental scientific principle behind the ecological integrity of flowing water systems. As mentioned earlier, these components regulate physical and biological processes in fluvial ecosystems. Thus maintaining or restoring the natural range of variation of hydrological regimes is a fundamental element for protecting fluvial ecosystem integrity (Poff et al., 1997).

Hirji and Davis (2009) noted that there are two broad methods for providing environmental flow regimes. On regulated rivers, those with water storages in their headwaters, the agreed environmental flows can be delivered through specific releases of water from the storages at the right times to mimic some of the natural patterns of flows. Further, on all rivers - regulated and unregulated - and in all groundwater systems, controls over abstractions can also be used to retain certain components of flows (Hirji and Davies, 2009). For example, cease-to-pump rules during dry periods are widely used to ensure that low flows are protected. A wide variety of instruments are used to provide these flows, including separate entitlements for environmental water, conditions on abstraction licenses, and dam operating rules (Hirji and Davies, 2009). However, it has been observed that the recognition of the importance of the flow regime in maintaining a healthy ecosystem has been virtually ignored in a management context (Poff et al., 1997).

Livelihood and livelihood flows

Categories of livelihood assets

Livelihood may be defined as adequate stocks and flows of food and funds to meet basic needs. It comprises the capabilities, assets (including both material and social resources) and activities required for a means of living (Chambers and Conway, 1992).
The livelihoods approach is about people and seeks to gain an accurate and realistic understanding of people’s strengths (assets or capital endowments) and how they endeavour to convert these into positive livelihood outcomes. The approach is founded on a belief that people require a range of assets to achieve positive livelihood outcomes and that no single category of assets on its own is sufficient to yield all the many and varied livelihood outcomes that people seek. This is particularly true for poor people whose access to any given category of assets tends to be very limited. As a result, they have to seek ways of nurturing and combining what assets they have in innovative ways to ensure survival (DFID, 1999).

Five categories of livelihood assets, which development workers draw on to explore the various dimensions of well-being and the means for achieving it, have been identified. These are natural capital, social capital, human capital, financial capital and physical capital (DFID, 1999; FAO, 2006). According to FAO (2006):

- Natural capital relates to access to land and resources, including air, water, living organisms and all formations of the earth’s biosphere that provide humans with ecosystem goods and services.

- Social capital refers to the institutions, relationships, and norms that shape the quality and quantity of a society’s social interactions.

- Human capital is the stock of competencies, knowledge, social and personality attributes, including creativity, embodied in the ability to perform labour so as to produce economic value.

- Financial capital relates to assets that are considered to be liquid in nature, which can be used to make purchases of various goods and services or to acquire other types of assets.

- Physical capital is the collection of the tangible items that are used for actual production of the good or service.

A single physical asset can generate multiple benefits. People with secure access to land (natural capital) may also be well-endowed with financial capital, as they are able to use the land not only for
direct productive activities but also as collateral for loans. Similarly, livestock may generate social capital (prestige and connectedness to the community) for owners while at the same time being used as productive physical capital (think of animal traction) and remaining, in itself, as natural capital. In order to develop an understanding of these complex relationships it is necessary to look beyond the assets themselves, to think about prevailing cultural practices and the types of structures and processes that ‘transform’ assets into livelihood outcomes (DFID, 1999).

Livelihood flows

Livelihood flows are processes that enable livelihoods to function. A range of dynamic flows and processes, referred to as elements of livelihood flows, enable livelihoods to function. These include energy, food, water, information, motivation, social connectedness and income (FAO, 2006).

The Sustainable livelihoods framework

The sustainable livelihoods framework attempts to establish a link between the policy environment and access to resources such as forestry and water, besides the impact of such access on the strategies adopted by the rural population (Hobley and Shields 2000).

Since the 1990s governments and development agencies have increasingly been employing the sustainable livelihood approach (SLA) as a tool for tackling poverty reduction. This followed the expansion of the concept of sustainable livelihood at the 1992 United Nations Conference on Environment and Development that, among other things, advocated for the eradication of poverty (Krantz, 2001). The issue of sustainable livelihood borders on poverty-focussed development activities which aim at building the capacities of groups of people to improve upon their living status (DFID, 1999). Thus, the promotion of sustainable livelihoods seeks to address the conditions of vulnerable groups by taking into consideration the factors and processes that create and perpetuate poverty.
According to the Department for International Development (DFID), SLA ‘provides an analytical framework that promotes systematic analysis of the underlying processes and causes of poverty’ (DFID, 1999: pp. 2). It draws on the main factors that affect poor people’s livelihoods and the typical relationships between these factors. It focusses on the strengths within the group and takes advantage of the knowledge, skills and abilities as well as the structures that are needed to take people out of poverty (DFID, 1999). Though the SLA framework is used variously by different agencies, the main focus is on poverty reduction on a sustainable basis by dealing with the underlying resources and capacities – it is a capacity building model. It provides a holistic way of thinking through complex issues at various levels for designing programmes and evaluating the strategies (DFID, 1999).

The model highlights the variety of assets at the disposal of the group which support their livelihood (Fig. 7.1). The vulnerability context is understood as the factors that create and perpetuate poverty which is conceived at the level of the individual and in the broader social context. An understanding of the context–specific processes is necessary for the design of appropriate policies and strategies to enhance progress towards poverty reduction and elimination. The strategies adopted are expected to transform existing structures and processes that create the conditions of poverty. The structures and conditions include institutional arrangements and power relations that define access to livelihood assets, help shape individual creativity to cope with stresses, build trust and confidence among people and ensure mutual support and cooperation. These human organizational systems define the strategies that are adopted to develop the assets in order to achieve certain outcomes to support human livelihoods. The SLA is viewed as versatile and can be used under different circumstances and at different levels. At the lowest level, it lends itself to the adoption of participatory approaches in understanding the causes and dimensions of poverty, thereby enabling people to examine their circumstances and provide their own definition of poverty. When employed at the level of programme planning and policy analysis, it unravels the impacts of different policy and institutional arrangements upon households and the dimensions of poverty. Within the context of the Akosombo and Kpong dams re-operation and re-optimisation study project, improving the flow dynamics is expected to increase livelihood assets.
as a result of enhancement of the natural capital, thereby influencing the livelihood strategies and resulting in better outcomes such as reduced vulnerabilities to bilharzia, increased income, increased well-being and food security (Fig. 7.1).

**Fig. 7.1: Sustainable Livelihoods framework, with explanatory notes**
*Source: Nhantumbo et al. (2003). (SUNR refers to sustainable use of natural resources).*

**Environmental flow and sustainable livelihood: An integrative model**

Riverine ecosystems (and riparian communities) are sustained by environment flows, in this case water, which ensures ecological balance and maintains healthy aquatic ecosystems that support human livelihoods. The natural seasonal flows dictate the rising and falling water levels necessary for maintaining aquatic life and other life-forms that depend on riverine ecosystems and riparian habitats.
Environmental flows are however modified by dam construction across river channels to impound water and regulate water flow for whatever purpose. According to the World Commission on Dams (WCD), dam construction increased after the 1950s, particularly in developing countries, and by the end of the 20th century, there were over 45,000 dams in over 150 countries (WCD, 2000).

Dam construction has a long lasting and profound impact on the environment, and the total economic, social and environmental cost is enormous. Many people, including displaced populations, host communities and downstream riverine communities are affected by dams, particularly large scale ones. It is estimated that 472 million people located downstream of the 7,000 largest dams in the world have been affected (Richter et al., 2010). Dam construction alters the natural flow pattern of rivers and changes downstream ecological conditions, which has implications for livelihood support. It blocks movements of fish and other aquatic animals and disrupts flood-recession agriculture upon which riparian communities depend. Altogether, dam construction dramatically changes the established response of downstream communities to natural seasonal flow regimes that define their livelihoods.

Very often dam-affected downstream populations are given little attention by dam development authorities and governments and this worsens their livelihood conditions, even though they may benefit from flood protection, irrigation and other opportunities provided by the dam (Richter et al., 2010). The nature, severity and duration of the adverse impacts of damming on downstream communities vary from one dammed river to the other.

The alteration of downstream ecological conditions means that the riparian communities have to adjust to post-dam conditions and redefine their livelihood strategies, and this continues to be a major challenge. The adaptation responses to dam-induced alterations of downstream ecosystems are also expected to vary depending upon a variety of reasons. Apart from specific intervention programmes to improve upon the livelihoods of riparian populations, the idea has been mooted that dams can be re-operated to allow for ecological gains and social benefits (Richter et al., 2010). This could be achieved
through controlled environmental releases that would try to mimic the natural condition of rivers and thus be capable of restoring downstream river ecosystems (The Nature Conservancy, 2010) to some extent. ‘The challenge is determining the quantity and timing of water flows required to maintain the components, functions, processes and resilience of aquatic ecosystems and sustain the goods and services they provide to people’ (The Nature Conservancy, 2010).

**Conclusion**

Rivers have great influence on the landform, physiography, livelihood as well as flora and fauna. Given the present degraded condition, environmental flow requirement would be most useful for many rivers (Bari and Marchand, 2006). Environmental flows are essential for freshwater ecosystem health and human well-being. The overarching reason why there is the need for flow requirements for the Lower Volta River is that the creation of the dams has impacted negatively on ecosystem functioning, services and livelihoods downstream of the dam. Defining flow requirements for key species and processes is an important step towards restoration of downstream ecosystem functions and livelihoods. Key components of flow variables such as magnitude, frequency, duration, timing and rate of change of flow are important flow requirements for downstream ecosystem services restoration.

This chapter has established that there is a relationship between environmental flows and sustainable livelihood. Environmental flows tend to maintain important ecological processes and functions that restore livelihood flows downstream. Thus if adequate flows are established, some livelihood activities could be restored. As mentioned earlier, within the context of re-operation and re-optimisation of the Akosombo and Kpong dams, improving the flow dynamics is envisaged to increase livelihood assets such as natural and financial capitals, thereby influencing the livelihood strategies and resulting in better outcomes such as reduced vulnerabilities to bilharzia, increased income, increased well-being and improved food security. Environmental flows can therefore serve as an important link between environmental conservation and poverty alleviation for riparian communities of the Volta basin.
References


CHAPTER EIGHT

ANALYSIS OF CHANGES IN DOWNSCALED RAINFALL AND TEMPERATURE PROJECTIONS IN THE VOLTA RIVER BASIN

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Abstract

This study analysed changes in future (2011-2040) rainfall and temperature, relative to the current period (1981-2010), in the three main climate zones (Guinean, Sudanno-Sahelian and Sudannian) of the Volta Basin. Rainfall and temperature data from two Global Climate Models (MPEH5 and HADCM3) (forced) driven with two of the IPCC emission scenarios (A1B and A2) used in the fourth assessment report were obtained from the data portal of the World Climate Research Programme’s Coupled Model Inter-comparison Project phase 3 and statistically downscaled using the Long Ashton Research Station-Weather Generator. The projected changes in rainfall and temperature were determined by computing the mean values of the downscaled projections of MPEH5 and HADCM3 and comparing them to the rainfall and temperature values of the current climate. Relative to the current climate, the Volta Basin as a whole is projected to become warmer and wetter in the future, under both the A1B and A2 scenarios. However, some areas within the basin will become warmer and dryer in the same period. The mean annual temperature is projected to increase, on average, by about 0.5 - 0.7 °C across the basin under both the A1B and A2 scenarios. Generally, warming of the basin is most rapid in the
Sudanno-Sahelian zone (northern inlands) and least in the Guinean zone (southern areas). Total annual rainfall is projected to increase marginally by about 3-4% and 3-5% across the three climate zones of the basin under the A1B and A2 scenarios, respectively. Generally, the biggest increase is in the Sudannian zone and the smallest in the Sudanno-Sahelian zone. Projected changes in rainfall computed in this study are largely in agreement with changes projected by many past studies in Ghana, in the Volta Basin and in West Africa that used scenarios similar to the IPCC scenarios used in this study.

**Keywords:** Climate change, Climate zone, Statistical downscaling, Volta basin

**Introduction**

Climate change (CC) has been described as ‘unequivocal’ (IPCC, 2007) and is projected to have considerable impacts on both natural and human systems. The phenomenon will have adverse impacts on water resources in particular, with dire consequences for vulnerable regions such as Africa (Boko et al., 2007; Chinowsky et al., 2011; Kankam-Yeboah et al., 2013). Thus, several studies have been carried out in river basins in Africa including the Volta Basin, to ascertain the likely changes in future climate of these basins.

Some past studies in the Volta Basin such as CSIR-WRI (2000), Kasei (2010), McCartney et al. (2012) and Kankam-Yeboah et al. (2013) predicted a warmer and drier future climate in the basin. Several other studies of climate change in Ghana and the Volta Basin (Andah et al., 2003; Kunstmann and Jung, 2005; Jung, 2006; McSweeney et al., 2010; Obuobie and Asante-Sasu, 2013; Tachie-Obeng et al., 2014; Obuobie, 2014) and the larger West African region (Paeth et al., 2011; Sylla et al., 2012; IPCC, 2013), however, predict a warmer but wetter climate in future.

Generally, temperatures in West Africa are expected to rise by 3-6 °C by the end of the 21st century under a range of scenarios, and most global and regional climate models are in agreement on this (IPCC, 2013). Unlike temperature, the future signal of rainfall in West Africa
is less certain, even though many global models project a wetter main rainy season with a slight delay in the onset of the rainy season by the end of the 21st century (CDKN, 2014).

Tachie-Obeng et al. (2012; 2014) note that improvement in the annual rainfall of the current climate in Ghana (and possibly the West African region) from the late 1990s to the 2000s may continue into the near future. Thus future climate in the Volta Basin is anticipated to be wetter than for the second half of the 1970s, 1980s and early 1990s.

This study was done as a contribution to the re-optimisation and re-operation study of the Akosombo and Kpong Dams Project led by the Water Resources Commission of Ghana. The objectives of the re-optimisation and re-operation project were to: restore downstream ecosystems and human livelihoods; continue to protect the downstream communities from the larger flood events that would jeopardize human settlements while accommodating seasonal inundation of farmlands; increase the total electric power output of the dams while altering the generating schedule; and increase the reliability of water supply for hydropower generation.

The main goal of this study was to determine the projected changes in future climate (temperature and rainfall) over the Volta Basin for use in impact assessment of future stream flow into the Volta Lake for dam re-operation scenarios. The specific objectives were to: (i) downscale future climate projections from two Global Climate Models forced (driven) by two IPCC Emission Scenarios (A1B and A2) using statistical downscaling technique; (ii) summarize results of the downscaled future projections to provide an understanding of the changes to the future climate, relative to the current climate; and (iii) provide data on current climate and downscaled future climate to other work components of the re-operation and re-optimisation project as input to an assessment of Climate Change impacts on stream flow into the Volta Lake.
The Study area

The study covered the entire Volta Basin, which is located in the semi-arid and sub-humid zones of West Africa (Fig. 8.1) and lies between latitudes 5° 30’N and 14°30’N and longitudes 2° 00’E and 5° 30’W. The Basin occupies about 28% of the total West Coast (FAO, 1997), has a total surface area of about 400,000 km² and is shared by the six riparian countries: Burkina Faso (42.65%), Ghana (40.18%), Togo (6.4%), Benin (4.10%), Mali (3.69%), and Côte d’Ivoire (2.99%) (Rodgers et al., 2007). The Volta Basin has a predominantly flat topography. Over half of the basin lies within 200-300 m above mean sea level, with a mean elevation of 257 m (Barry et al., 2005).

Climate in the basin is controlled by the movement of the Inter-Tropical Convergence Zone (ITCZ) that dominates the climate of West Africa. The ITCZ is the inter-phase of the hot, dry and dusty northeast trade winds that blow from the Sahara in the north of the region and the cool and moist southwest trade winds that blow over the sea from the south Atlantic. The ITCZ moves across the Volta Basin in a complex manner, resulting in a mono-modal rainfall pattern in areas that it crosses once and a bi-modal rainfall pattern in areas that it crosses twice. The movement of the ITCZ is associated with vigorous frontal activities which influence the amount and duration of rainfall over the basin (Amisigo, 2005; Andah et al., 2003).

Two major climatic zones can be identified in the Volta Basin: the humid south with two distinct seasons of rainfall that peak in June and September and the tropic north with one rainfall season that peaks in August/September. Most areas of the Basin fall within the tropic north zone. Rainfall in the tropic north zone is poorly distributed and very much skewed towards the months of June to September, during which over 70% of the total annual rainfall occurs (Amisigo, 2005). In the humid south zone, rainfall is evenly distributed throughout the year.

Annual mean rainfall in the Volta Basin ranges from 600 mm/yr in the extreme north in Mali and Burkina Faso to about 1,600 mm/yr in the humid south in Ghana (VBRP, 2002). Rainfall in the Basin is characterized by high spatial and temporal variability. However, compared to runoff, the annual mean rainfall over the entire basin
suggests a fairly even temporal distribution with a lower coefficient of variation (Andreini et al., 2000). Temperatures in the basin increase in a south-north direction, although the variation is not high. Mean monthly temperatures vary from 36 °C in March to 27 °C in August in the northern parts of the basin, and from 30 °C in March to 24 °C in August in the south (Oguntunde, 2004). Daily maximum temperatures vary from 32 to 44 °C (recorded in March to April) while daily minimum temperatures are recorded in December to February and can be as low as about 14 °C in January (FAO, 1997).

Evapo-transpiration is the most significant component of the water balance in the Volta Basin. The annual mean potential evapo-transpiration varies from 2,500 mm/yr in the north to 1,800 mm/yr in the coastal zone (Amisigo, 2005). Potential evapo-transpiration exceeds rainfall for most part of the year, usually from 6 to 9 months. Actual evapo-transpiration in the Basin is estimated at about 91% of total rainfall (Andreini et al., 2000).

The Basin is drained by 3 main river systems – the Black and the White Volta and the Oti river systems (Fig. 8.1). A major landmark of the Basin is the Volta Lake formed from the hydropower dam on the main Volta River at Akosombo in south-eastern Ghana. The Lower Volta is that region of the Basin below the Akosombo dam and the smaller Kpong dam just downstream. The mean annual stream flows in the Volta Basin are estimated at 7.8 km³ for the Black Volta River, 8.0 km³ for the White Volta, 12.7 km³ for the Oti and up to 38.2 km³ for the Lower Volta River (Amisigo, 2005). Flows in the Lower Volta River are essentially from dam releases and are thus controlled by the dam operations at the Akosombo and Kpong hydropower facilities.

Table 8.1: Groupings of synoptic stations by climate zones of the Volta Basin

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Synoptic stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guinean savanna</td>
<td>Abetifi, Bole, Ho, Wenchi, Kete Krachi, Koforidua, Sunyani, Yendi</td>
</tr>
<tr>
<td>Sudanian savanna</td>
<td>Wa, Akuse, Navrongo, Tamale, Po</td>
</tr>
<tr>
<td>Sudano-Sahelian</td>
<td>Boromo, Dedougou, Ouagadougou, Ouahigouya</td>
</tr>
</tbody>
</table>
Fig. 8.1: Location map of the Volta Basin
Source: Mul et al. (2015)
Methods and Data

Climate downscaling and assessment of climate change

Fig. 8.2 shows the general methodology used in this study to generate two sets of downscaled climate projections for describing changes in the future climate of the Volta Basin. The two sets of simulations (A1B and A2 ensemble mean for climate zones) are the mean of statistically downscaled simulations from two selected Global Climate Models (MPEH and HADCM3) forced by two selected emission scenarios (A1B and A2). For each emission scenario, projection data for the MPEH and HADCM3 global climate models were obtained for seventeen (17) synoptic stations used in the study. This resulted in each station having a total of four (4) projections (A1B-MPEH, A2-MPEH, A1B-HADCM3, and A2-HADCM3). Each projection was downscaled using the Long Ashton Research Station-Weather Generator (Semenov et al., 1998; Semenov and Barrow, 2002), after which projections for each station were averaged into ensemble mean values for the two emission scenarios. Lastly, ensemble mean values for stations within the same climate zones were averaged to obtain ensemble mean values for each climate zone. Details of the choices made under each section of the approach used are described below.
Fig. 8.2: Schematic overview of the methods used for generating downscaled ensemble mean climate simulations for the Volta Basin (SS = synoptic station)
Choice of IPCC Emission Scenarios

Two emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) documented in the IPCC Fourth Assessment Report – AR4 (IPCC, 2007) were used in this study. These were the A1B and A2 scenarios. The IPCC’s newly reported emission scenarios, named Representative Concentration Pathways (RCPs) in its Fifth Assessment Report – AR5 (IPCC, 2013), were not used in this work because they were not available at the time of the study. The A1B and A2 scenarios were chosen from 6 plausible scenarios of the AR4 for a number of reasons. The A1B scenario lies between the extremes produced by other IPCC scenarios (McCartney et al., 2012). As such, it is a relatively conservative, but not overly cautious, scenario. The A2 scenario, which paints a picture of a very heterogeneous world with emphasis on family values and local tradition, was selected because it is one of the extreme (high greenhouse gas emission) scenarios that can be expected in the future, as it depicts extensive use of fossil fuel and a very slow technological change (IPCC, 2007).

Choice of Global Climate Model Simulations

Nearly all the GCMs used in the IPCC AR4 are consistent in projecting rise in temperature over West Africa, though the magnitude of change varies among models (IPCC, 2007). The same cannot be said for precipitation. The projections for precipitation show significant uncertainty about the magnitude and direction of change. The uncertainty in the projections can be attributed to uncertainty in both future emissions of greenhouse gases (e.g. carbon dioxide) and in the representation of key processes within models. As a result, estimates of climatic risk are best made through integrations of models in which the uncertainties are explicitly incorporated by using different models and exploring different emission scenarios. This is often referred to as a multi-model ensemble experiment (Diallo et al., 2012). In this way, an ‘ensemble’ of results is produced which can be used to quantify the uncertainty in the climate projections.

The ensemble of GCM used in this study consisted of a two-member model, namely, the HADCM3 model (Johns et al., 2003) developed by the UK Met Office, UK, and the MPEH5 (or ECHAM5/MPI-OM)
model (Roeckner et al., 2003) developed by the Max Planck Institute for Meteorology, Germany. The two models were chosen because of their capacity to quantify the current climate of the Volta basin and the West African region as a whole. Past studies (Diallo et al., 2012; McCartney et al., 2012; Sylla et al., 2012) have shown that the HADCM3 and MPEH5 models are two of the few GCMs that realistically simulate most of the features of the West African Monsoon and best quantify the current climate of the wider West African region.

**Climate Data and Sources**

Daily observed and modeled data on rainfall, minimum and maximum air temperatures used in this study were acquired for seventeen (17) synoptic stations in the Volta Basin (Fig. 8.3). Based on data obtained from the National Meteorological Departments in Ghana and Burkina Faso, there are over 30 climate stations in the Volta Basin. However, many of them have several years of missing records in their data. Therefore, the analysis was limited to synoptic stations on the Ghanaian and Burkinabe portions of the Basin for which data were readily available for further analysis. The data were obtained from the national meteorological agencies in the two countries and span a 30-year period (1981-2010) considered as the current or baseline climate. This period was chosen because it is the time horizon for which many of the climate stations used in this study had only few missing records. Missing temperature records were filled using long-term average values of the station while missing rainfall records were filled either using linear regression between the station with missing records and the nearest best correlated station or interpolation with Inverse Distance Weighting (IDW) technique as described in Wagner et al. (2012).
Fig. 8.3: Map of the Volta basin showing the 3 climate zones and location of 17 synoptic stations used in this study.
(Data Source: National Meteorological Services in Ghana and Burkina Faso)
Four modelled data comprising HADCM3 and MPEH5 simulations of the A1B and A2 scenarios (i.e. HADCM3-A1B, HADCM3-A2, MPEH5-A1B and MPEH5-A2) were obtained for the 17 synoptic stations for the current (1981-2010) and future or projected (2011-2040) climates. The modelled data were obtained from the data portal of the World Climate Research Programme’s (WCRP’s) Coupled Model Inter-comparison Project phase 3 - CMIP3 (Meehl et al., 2007). The period (2011-2040) was used as the future time horizon for this study because it ties in well with one of the major activities of the re-optimisation and re-operation project, which was to monitor the impacts of different hydrographs on hydropower generation and livelihoods under climate change considerations in the short to medium terms.

**Statistical Downscaling**

Spatial resolution of GCM/RCM is often too coarse for direct application in impact studies such as hydrological modelling at a local scale due to the fact that local scale climate is greatly influenced by atmospheric processes, topography, and land-sea distribution which are not well represented in global models because of their coarse resolution (von Storch et al., 1993). This challenge is often overcome through dynamic or statistical downscaling techniques. Each of the downscaling techniques has its advantages and disadvantages. The modelled datasets (HADCM3-A1B, HADCM3-A2, MPEH5-A1B and MPEH5-A2) were statistically downscaled to obtain station-specific climate scenarios for the 17 synoptic stations. The downscaling was done using the Long Ashton Research Station Weather Generator - LARS-WG (Semenov and Barrow, 2002; Semenov et al., 1998) which is a stochastic weather generator for simulating daily climate data at a single site under current and future climate conditions.

Key assumptions associated with LARS-WG are stationarity (statistical distribution associated with each climate variable remains the same; the statistical relationships between predictors and predictands do not change) and availability of long-term good quality data for calibration. The impacts of the assumption of stationarity on the resulting downscaled projections, as well as impacts on projected stream flow in the Volta basin, driven by the downscaled projections of this study, are not yet known. An ongoing follow up study seeks to establish the
impacts. The assumption of availability of long-term good quality observed data for calibrating LARS-WG resulted in the use of only the synoptic climate stations in the basin, as only these stations have long-term good quality data (30 years daily data with a maximum of 3% missing records). The superior performance of LARS-WG as a downscaling tool is well documented in many studies including the authors’ past climate change studies in Ghana and the Volta Basin (e.g. Obuobie et al., 2012; Kankam-Yeboah et al., 2013; Etemadi et al., 2013; Irwin et al., 2012; Semenov et al., 1998).

Three distinct steps were followed to achieve the desired downscaling. These were:

(i) LARS-WG adapted to the 17 synoptic stations in a ‘Site Analysis’ process using the 30 years’ (1981-2010) observed climate data for the stations. The site analysis resulted in the generation of key files containing important statistics (e.g. mean, median, etc.) that describe the climate of individual stations.

(ii) LARS-WG validated in a ‘Q-Test’ by generating 100 years of synthetic climate data based on the statistics of the stations and comparing the synthetic data to the observed (by computing the p-value for statistical significance) to determine the performance of LARS-WG in reproducing the current climate of the stations.

(iii) The adapted LARS-WG driven by changes in rainfall, minimum and maximum temperatures between the future (2011-2040) and current (1981-2010) climates as simulated by HADCM3 and MPEH5 for the A1B and A2 scenarios to produce 4 sets of station-specific downscaled climate data for each of the 17 synoptic stations.

Estimation of Change in Climate

Changes in future climate relative to the current were analysed using mean values of the ensemble (ensemble mean) of climate simulations from the HADCM3 and MPEH5 for the A1B and A2 emission scenarios computed from equation (8.1) below and on the basis of the 3 main
climate zones identified in the Basin, namely the Guinean zone, the Sudannian zone, and the Sudanno-Sahelian zone (Fig. 8.3). The ensemble mean approach was used because it has been shown in past studies to give a better representation of the current climate than the output from individual models (e.g. Diallo et al., 2012). The 17 synoptic stations were grouped into the 3 main climate zones indicated above (Table 8.1 and Fig. 8.3). Data for the current and future climates for stations within each climate zone were averaged to obtain climate output for the zone. Basic statistics of mean annual and monthly rainfall, minimum and maximum temperature values were computed for each of the 3 climate zones for the current climate, the A1B-driven future climate and the A2-driven future climate.

\[
P_{\text{mean}}_{\text{ENSEMBLE}} = \left( \frac{P_{\text{HADCM3}} + P_{\text{MPEH5}}}{2} \right) \quad \text{......... (8.1)}
\]

where, \( P_{\text{mean}}_{\text{ENSEMBLE}} \) is the ensemble mean value, \( P_{\text{HADCM3}} \) is the rainfall, minimum temperature or maximum temperature value from the HADCM3 model, and \( P_{\text{MPEH5}} \) is the rainfall, minimum temperature or maximum temperature value from the MPEH5 model.

Changes in the future temperature and rainfall values, relative to the current, were calculated using equation (8.2) for temperature and equation (8.3) for rainfall, after Salack et al. (2011).

\[
ADB_{\text{ccs}} = \bar{T}_{\text{future}} - \bar{T}_{\text{current}} \quad \text{.......................... (8.2)}
\]

where, \( ADB_{\text{ccs}} \) is absolute change in temperature (°C), \( \bar{T}_{\text{future}} \) is the mean daily temperature over the future period, and \( \bar{T}_{\text{current}} \) is the mean daily temperature over the baseline period.

\[
RPD_{\text{ccs}} = \left( \frac{\bar{P}_{\text{future}} - \bar{P}_{\text{current}}}{\bar{P}_{\text{current}}} \right) \times 100 \quad \text{............... (8.3)}
\]

where, \( RPD_{\text{ccs}} \) is the relative change in rainfall (%), \( \bar{P}_{\text{future}} \) is the mean annual rainfall for the future and \( \bar{P}_{\text{current}} \) is the mean annual rainfall for the baseline period.
Results and Discussion

Projected changes in mean annual and seasonal temperatures of future climate

Temperature projections under both the A1B and A2 scenarios show increases in the mean annual values of the future climate, relative to the current, in all three climate zones of the Volta Basin (Tables 8.2 and 8.3). In addition to the average projected values, Tables 8.2 and 8.3 also show the spatial variability of the projected changes across the climate stations in each of the climate zones. Under the A1B scenario, the mean annual temperature is projected to increase, on average, by about 0.5 °C in the 30-year period (2011-2040) in the Guinean climate zone, 0.6 °C in the Sudannian zone and 0.7 °C in the Sudano-Sahelian zone (Table 8.2). The range of increases projected by the two models used in this study for the A1B scenario is 0.4 °C - 0.6 °C for the Guinean zone, 0.4 °C - 0.7 °C for the Sudannian zone and 0.6 °C - 0.8 °C for the Sudano-Sahelian zone. For the A2 scenario, the mean annual temperature projections of the future climate show average increases of about 0.6 °C in the Sudannian and Sudano-Sahelian zones and about 0.5 °C in the Guinean zone, relative to the values of the current climate (Table 8.3). The A2 scenario-driven range of projected annual changes across the two models is 0.4 °C - 0.6 °C for the Guinean zone and 0.5 °C - 0.7 °C for the Sudannian and Sudano-Sahelian zones. Generally, increase in mean annual temperature for both the A1B and A2 scenarios is most rapid in the Sudano-Sahelian zone and least rapid in the Guinean zone. This suggests that the inland northern portions of the Basin, which are currently the warmest areas in the Basin, will likely continue to warm faster than the middle and southern coastal areas towards the middle of the 21st century. The projected increases in mean temperature in the Guinean and Sudannian zones are slightly higher under the A1B scenario, compared to projected increases under the A2 scenario.
### Table 8.2: Projected changes in temperature in the Volta Basin under IPCC SRES A1B scenario

<table>
<thead>
<tr>
<th>TIME SCALE</th>
<th>GUINEAN ZONE</th>
<th>SUDANNIAN ZONE</th>
<th>SUDANNO-SAHELIAN ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed mean (°C)</td>
<td>Projected Changes (°C)</td>
<td>Observed mean (°C)</td>
</tr>
<tr>
<td>Annual</td>
<td>27.0 0.5 0.5 0.6</td>
<td>28.4 0.5 0.6 0.6</td>
<td>28.9 0.6 0.7 0.7</td>
</tr>
<tr>
<td>JFM</td>
<td>28.4 0.5 0.6 0.6</td>
<td>29.6 0.5 0.5 0.6</td>
<td>28.2 0.5 0.5 0.6</td>
</tr>
<tr>
<td>AMJ</td>
<td>27.5 0.5 0.6 0.7</td>
<td>29.6 0.5 0.6 0.7</td>
<td>32.1 0.7 0.8 0.9</td>
</tr>
<tr>
<td>JAS</td>
<td>25.3 0.4 0.4 0.5</td>
<td>26.5 0.4 0.4 0.5</td>
<td>27.5 0.5 0.5 0.6</td>
</tr>
<tr>
<td>OND</td>
<td>26.7 0.5 0.6 0.7</td>
<td>28.0 0.4 0.6 0.7</td>
<td>27.9 0.7 0.7 0.7</td>
</tr>
</tbody>
</table>

NB: projected change = Downscaled projected mean temperature (2011-2040) minus the observed mean (1981-2010). The min and max projected changes refer to the least and most projected changes at the synoptic stations within the climate zone.

### Table 8.3: Projected changes in temperatures in the Volta Basin under IPCC SRES A2 scenario

<table>
<thead>
<tr>
<th>TIME SCALE</th>
<th>GUINEAN ZONE</th>
<th>SUDANNIAN ZONE</th>
<th>SUDANNO-SAHELIAN ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed mean (°C)</td>
<td>Projected Changes (°C)</td>
<td>Observed mean (°C)</td>
</tr>
<tr>
<td>Annual</td>
<td>27.0 0.5 0.5 0.6</td>
<td>28.4 0.4 0.6 0.6</td>
<td>28.9 0.5 0.6 0.6</td>
</tr>
<tr>
<td>JFM</td>
<td>28.4 0.5 0.7 1.0</td>
<td>29.6 0.4 1.1 1.4</td>
<td>28.2 1.7 1.9 2.1</td>
</tr>
<tr>
<td>AMJ</td>
<td>27.5 -0.1 0.0 0.2</td>
<td>29.6 -0.3 -0.2 0.1</td>
<td>32.1 -0.2 -0.1 0.1</td>
</tr>
<tr>
<td>JAS</td>
<td>25.3 0.6 0.6 0.7</td>
<td>26.5 0.6 0.7 0.7</td>
<td>27.5 0.7 0.8 0.8</td>
</tr>
<tr>
<td>OND</td>
<td>26.7 0.6 0.7 0.8</td>
<td>28.0 0.2 0.5 0.7</td>
<td>27.9 -0.5 -0.2 -0.1</td>
</tr>
</tbody>
</table>

NB: projected change = Downscaled projected mean temperature (2011-2040) minus the observed mean (1981-2010). The min and max projected changes refer to the least and most projected changes at the synoptic stations within the climate zone.
Seasonally, temperature projections in the Volta Basin under the A1B scenario show significant increases in mean values of the future climate in all the 4 seasons (January to March - JFM; April to June-AMJ; July to September-JAS; and October to December-OND) (Table 8.2). Projected increases in the Sudanno-Sahelian zone are most rapid in AMJ, with a mean value of about 0.8 °C, and least rapid in JAS, with a mean value of about 0.5 °C. Increases in mean seasonal temperature in the Guinean climate zone are most rapid (0.6 °C) in JFM, AMJ and OND, and least (0.4 °C) in JAS. In the Sudannian zone, warming is most rapid in AMJ and OND (each with a mean value of 0.6 °C) and least in JAS (0.4 °C). Under the A2 scenario, projected temperatures also show significant increases in mean values of future climate in all the three climate zones for all seasons of the year, except for the AMJ season where projections show no change in mean temperatures in the Guinean zone but decreases in the Sudanno-Sahelian zone (seasonal average of -0.1 °C) and the Sudannian zone (-0.2 °C) (Table 8.3). In the Guinean zone, the temperature is projected to increase most rapidly in JFM and OND. No change is projected for the season of AMJ. For the Sudanno-Sahelian and Sudannian zones, the increases are expected to be most rapid in JFM.

The warmest months in the current climate for each of the climate zones (March for the Guinean and Sudannian zones and April for the Sudanno-Sahelian zone) are projected to remain the same under both the A1B and A2 scenarios (Figures 8.4 and 8.5). Under the A1B scenario, the biggest change in monthly temperature (+0.9 °C) is projected to occur in January for the Guinean and Sudannian zones but in June for the Sudanno-Sahelian zone. For the A2 scenario, the biggest change in monthly temperature is projected to be +1.5 °C in January for the Guinean zone, +1.7 °C in January for Sudannian zone, and +2 °C in January and February for the Sudanno-Sahelian zone (Fig. 8.5).
Fig. 8.4: Current (1981-2010) and Future (2011-2040) mean daily temperature for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A1B scenario

Fig. 8.5: Current (1981-2010) and Future (2011-2040) mean daily temperature for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A2 scenario
Projected changes in mean annual and seasonal rainfall of future climate

The projected changes in mean annual and seasonal rainfall of the future climate, relative to the current climate, in the different climate zones of the Volta Basin are depicted in Table 8.4 for the A1B scenario and Table 8.5 for the A2 scenario. In general, the mean annual rainfall is projected to increase slightly across the three climate zones for both the A1B and A2 scenarios. The extent of spatial variability in the projected increases is captured in the minimum and maximum projected changes depicted in Tables 8.4 and 8.5.

Table 8.4: Projected changes (%) in rainfall in the Volta Basin under IPCC SRES A1B scenario

<table>
<thead>
<tr>
<th>TIME SCALE</th>
<th>GUINEAN ZONE</th>
<th>SUDANNIAN ZONE</th>
<th>SUDANNO-SAHELIAN ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed mean (mm)</td>
<td>Projected Changes (%)</td>
<td>Observed mean (mm)</td>
</tr>
<tr>
<td>Annual</td>
<td>1241.4</td>
<td>-3.3 3.2 12.3</td>
<td>1018.6</td>
</tr>
<tr>
<td>JFM</td>
<td>126.4</td>
<td>-6.2 15.3 53.7</td>
<td>46.9</td>
</tr>
<tr>
<td>AMJ</td>
<td>450.7</td>
<td>-2.8 1.6 6.8</td>
<td>344.5</td>
</tr>
<tr>
<td>JAS</td>
<td>464.6</td>
<td>-8.6 4.1 12.5</td>
<td>524.6</td>
</tr>
<tr>
<td>OND</td>
<td>199.8</td>
<td>-21.6 -3.1 10.9</td>
<td>102.7</td>
</tr>
</tbody>
</table>

Table 8.5: Projected changes (%) in rainfall in the Volta Basin under IPCC SRES A2 scenario

<table>
<thead>
<tr>
<th>TIME SCALE</th>
<th>GUINEAN ZONE</th>
<th>SUDANNIAN ZONE</th>
<th>SUDANNO-SAHELIAN ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed mean (mm)</td>
<td>Projected Changes (%)</td>
<td>Observed mean (mm)</td>
</tr>
<tr>
<td>Annual</td>
<td>1241.4</td>
<td>-3.1 3.5 13.2</td>
<td>1018.6</td>
</tr>
<tr>
<td>JFM</td>
<td>126.4</td>
<td>-7.9 11.8 51.9</td>
<td>46.9</td>
</tr>
<tr>
<td>AMJ</td>
<td>450.7</td>
<td>-3.2 1.3 6.5</td>
<td>344.5</td>
</tr>
<tr>
<td>JAS</td>
<td>464.6</td>
<td>-8.2 5.0 13.1</td>
<td>524.6</td>
</tr>
<tr>
<td>OND</td>
<td>199.8</td>
<td>-18.6 -0.1 18.2</td>
<td>102.7</td>
</tr>
</tbody>
</table>
Under the A1B scenario, the projected mean annual rainfall shows, on average, slight increases of about 3%, 4% and 3% over the values of the current climate in the Sudanno-Sahelian, Sudannian, and Guinean zones, respectively (Table 8.4). The range of projected increase in rainfall between the two models used is 2-4%, 3-5% and 2-5%, for the Guinean, Sudannian and Sudanno-Sahelian zones, respectively. Similarly, the projected changes under the A2 scenario are small for all three zones (Sudanno-Sahelian - 3%, Sudannian - 5% and Guinean - 4%) (Table 8.5). The associated range of projected changes is 2-4%, 3-7% and 3-5%, for the Sudanno, Sudannian, and Guinean zones, respectively. There appear to be no significant differences in the projected changes in annual rainfall for the three zones under both the A1B and A2 scenarios, even though the change is generally biggest in the Sudannian zone and smallest in the Sudano-Sahelian zone.

Analysis of rainfall projections on a seasonal basis under both the A1B and A2 scenarios (Tables 8.4 and 8.5) suggests increases in mean values of the future rainfall in all the seasons in the Sudano-Sahelian zone and three of the four seasons in the Guinean (JFM, AMJ, JAS) and Sudannian (JFM, JAS, and OND) zones. Under the A1B scenario, the biggest change (increase) in mean seasonal rainfall is projected for the JFM season in all the three zones (Sudano-Sahelian – 77%; Sudannian – 40%; and Guinean – 15%), while the smallest change is projected for the AMJ season in the Guinean (about 2%) and Sudannian (about 0%) zones and the JAS season in the Sudano-Sahelian zone (about 1%). Similarly, under the A2 scenario, the biggest change in mean seasonal rainfall is projected for the JFM season (Sudano-Sahelian – 59%; Sudannian – 35%; and Guinean – 12%) while the smallest is projected for the AMJ for the Sudano-Sahelian zone (about 1%) and OND for the Sudannian (1%) and Guinean (0%).

Fig. 8.6 and Fig. 8.7 are plots of monthly rainfall for the current and future climates in the three climate zones of the Volta Basin for the A1B and A2 scenarios respectively. The bi-modal rainfall pattern observed in the current climate of the Guinean zone and the mono-modal rainfall pattern observed in the Sudanno-Sahelian and Sudannian zones are projected to remain unchanged in the future climate under both the A1B and A2 scenarios. Also, the peak rainfall months for the Guinean zone (June and September) as well as the Sudanno-Sahelian/Sudannian
zones (August) appear to remain unchanged under the two scenarios. The projected increase in rainfall appears to be biggest in JFM in all three climate zones, followed by JAS in the Guinean and Sudannian zones and OND in the sudano-Sahelien zone.

Fig. 6. Current (1981-2010) and Future (2011-2040) mean monthly rainfall for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A1B scenario

Fig. 7. Current (1981-2010) and Future (2011-2040) mean monthly rainfall for the 3 climate zones of the Volta Basin (Guinean Zone - GZ, Sudannian Zone - SZ, and Sudanno-Sahelian Zone - SSZ), driven by SRES A2 scenario
In this study, the projected trend of increases in daily mean temperature and mean annual rainfall in the near-future may be consistent with results reported in previous studies of climate change in Ghana and the Volta Basin (Andah et al., 2003; Kunstmann and Jung, 2005; Jung, 2006; McSweeney et al., 2010; Obuobie and Asante-Sasu, 2013; Tachie-Obeng et al., 2014; Obuobie, 2014) and the larger West African region (Paeth, et al., 2011; Sylla et al., 2012; IPCC, 2013). In particular, the results of this study appear to corroborate the findings of Tachie-Obeng et al. (2012, 2014) who noted that improvement in annual rainfall of the current climate (in Ghana and possibly the West African region) from the late 1990s to the 2000s may continue into the near-future. It is important, however, to note that the net effect of an increase (or positive signals) in mean annual rainfall in all the climate zones does not necessarily mean that the future rainfall will increase everywhere in the Basin. Within each climate zone, the projected mean change varies from one synoptic station to the other. While the projections for some stations within a climate zone show increases in rainfall or temperature, other stations within the same climate zone show decreases in temperature and rainfall amount. This is evident from the minimum and maximum values depicted in Tables 8.4 and 8.5.

However, the projected increase in mean annual rainfall over the Volta Basin obtained in this study contrasts with previous work undertaken by Opoku-Ankomah et al. (2000), Kasei (2010) and McCartney et al. (2012), all of whom suggested decreases in future mean annual rainfall in the Basin. It is important to note that the reference climate (called current climate in our study) used in the three studies above (see Opoku-Ankomah et al., 2000; Kasei, 2010 and McCartney et al., 2012) spanned the 1960s and 1970s when annual rainfall in Ghana was very high (McSweeney et al., 2010; Owusu and Waylen, 2009).
Conclusion and Recommendations

Conclusion

Downscaled climate change data from 2 IPCC emission scenarios have been generated and used to understand projected changes in future climate in the basin. The results of this study suggest that, in general, the Volta Basin may become warmer and slightly wetter across all the climate zones in the near-future (2011-2040) relative to the current (1981-2010) climate under the IPCC A1B and A2 scenarios. However, some areas within the climate zones will most likely experience a warmer and dryer climate in the same period. Under the A1B scenario, the mean annual temperature is projected to increase, on average, by about 0.5 °C in the Guinean, 0.6 °C in the Sudannian and 0.7 °C in the Sudano-Sahelian zones of the basin. Under the A2 scenario, mean annual temperature is projected to increase by about 0.6 °C in the Sudannian and Sudanno-Sahelian climate zones and by about 0.5 °C in the Guinean climate zones. Generally, the warming of the Basin is more rapid in the JFM and OND seasons. Also, the warming is fastest in the Sudanno-Sahelian zone (northern inlands) and slowest in the Guinean zone (southern forest areas) under the two scenarios.

Projected changes in rainfall in the 3 climate zones are relatively small. Under the A1B scenario, the total annual rainfall is projected to increase, on average, by about 3% in the Guinean and Sudanno-Sahelian zones and by about 4% in the Sudannian zone. For the A2 scenario, the projected increases are about 4% in the Guinean zone, 5% in the Sudannian zone and 3% in the Sudano-Sahelian zone. Projected increase in seasonal rainfall is biggest in JFM under both the A1B and A2 scenarios. The pattern of rainfall in the current climate is projected to remain the same in the future climate. The projected changes in rainfall and temperature over the basin appear consistent with changes projected in many previous studies in Ghana, the Volta Basin and West Africa. However, the projection of increase in future rainfall is in disagreement with a few other studies in Ghana and the Volta Basin, and this could be attributed largely to differences in the reference periods and the IPCC emission scenarios used.
CHAPTER 8

Recommendations

The following are recommendations for future studies in the basin:

i. Since the baseline (current climate) period over which climate change projections are made affect the results of the projections in addition to the choice of model projection, we recommend a kind of ‘standardization’ of the baseline period at national and basin levels, going forward. At the national level in Ghana, the process can be led by the Environmental Protection Agency, which is the UNFCCC focal point for climate change. Similar institutions in the Volta Basin riparian countries can lead the process in their respective countries. At the level of the Volta Basin, the process can be led by the Volta Basin Authority.

ii. As the new IPCC scenarios, the RCPs, are fast becoming available to the climate and hydrology communities at large, it would be worthwhile to use the new scenarios in future climate change studies in the basin, as these scenarios provide more accurate climate projections and are more objective, compared to the SRES scenarios used in the present study (IPCC, 2015). Further, since direction of rainfall in climate change, particularly in Africa, is uncertain, we recommend the use of a multi-model ensemble approach that consists of more than two global or regional climate models for analyzing changes in climate over the basin, as this approach is expected to yield more robust downscaled projections for climate change impact assessments and adaptation.

References


CHAPTER NINE

DEFINING RESTORATION FLOW TARGETS TO RESTORE ECOLOGICAL FUNCTIONS AND LIVELIHOODS IN THE LOWER VOLTA BASIN

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Abstract

The construction of the Akosombo and Kpong dams in the 1960s and 1980s changed the downstream flow regime significantly and affected downstream livelihoods. The re-optimisation and re-operation study of the Akosombo and Kpong dams aims to assess the feasibility of improving downstream livelihoods through re-operation of these two dams. To restore these livelihoods, first, the key components influencing the downstream livelihoods affected by the changed flow regime were identified. These included fisheries, agriculture, aquatic weeds, sediments, groundwater, domestic water use and hydropower.
Water requirements for each of the components were assessed through a workshop with key project partners and key experts in the field of the identified key components. The components were grouped in their preferences for high-dry season flows, low-dry season flows, high-wet season flows and low-wet season flows. The results indicated that peak flows favour fisheries and aquatic weeds control, while a steady flow regime favours aquaculture, irrigation and domestic water use.

Through a combination of statistical analyses, field visits, and stakeholder engagement, in combination with the water requirements for the individual components, four flow scenarios were developed. The first scenario represents the current steady flow regimes; the second scenario restores natural flow dynamics up to the 2010 spill level, while reducing by an equivalent amount of flow during the dry season. The third scenario releases higher wet season flows than scenario 2, but up to a level whereby sufficient water is available during the dry season for irrigation. The fourth and final scenario considers average historical pre-dam flow conditions.

An initial assessment on how the components are affected by the different scenarios shows that none of the scenarios benefits all components. Scenario 1 supports irrigated agriculture, hydropower generation and aquaculture; however, this has had an impact on the natural ecosystem and its services, such as fisheries, managing aquatic weeds and water related diseases. On the other hand, Scenario 4 will bring back some of the natural ecosystem services; however, this comes at a cost for irrigation and hydropower production and will flood infrastructure which has been developed in the floodplains after the construction of the dam. A detailed economic analysis is required to get a more in-depth assessment of the impact of the scenarios on the downstream livelihood and socio-economic conditions.

Keywords: Environmental flow requirement, Ecosystems, Re-operating dams, Akosombo, Kpong dams
Introduction

Dams are constructed for various purposes to boost national and regional economic development. At the same time, dams impact local livelihoods surrounding them, displacing people when impoundment takes place and affecting downstream ecosystems by changing flow regimes. Globally an estimated 40-80 million people have been displaced due to the construction of dams (WCD, 2000). The number of people affected by dams is much higher than those directly displaced due to impoundment, but this is often not well documented. This is also the case for downstream communities who are often highly dependent on the natural environment for their livelihoods and for whom changing flow regimes can have major negative impacts. Dams constructed for consumptive water uses such as irrigation and domestic use create an overall deficit in the downstream river sections, often affecting dry season flows. Incidentally, water demand is high and natural water availability is low during this period. On the other hand, hydropower dams do not consume large quantities of water but do influence the flow regime, aiming for a steady release from the dam to maintain hydropower production. This generally means a reduction in peak flows during the wet season and an increase in low flows during the dry season. Reduction in peak flows is often considered a positive side effect of dam construction, reducing downstream floods that may affect downstream livelihoods. However, seasonal flooding supports a range of ecosystem services such as providing spawning grounds that support fisheries and supporting agricultural production in the floodplains by depositing fertile soils. Maintaining a minimum flow is important for weed control, water quality maintenance and water supply to local communities.

Communities living downstream of the Akosombo and Kpong dams in Ghana face similar challenges. Hydropower production by the two dams has changed the highly dynamic flow regime into a steady one. The loss of the strong seasonality has affected important ecological functions of the system that used to create a source of livelihood for the people living in the Lower Volta (Tsikata, 2006). Historical benefits from flood recession farming and a highly productive clam industry have been replaced by challenges such as the proliferation of aquatic weeds that block access to the river and the building up of a
sandbar at the estuary, reducing saltwater intrusion that supports clam production and helps to control aquatic weeds. The re-operation and re-optimisation study of the Akosombo and Kpong dams assessed the feasibility of re-operating dams to restore downstream ecosystems and livelihoods. One key element for successful re-operation of dams is to establish critical flows that will help restore downstream ecosystems and support downstream users.

There are various ways of determining environmental flow requirements, such as using hydrological statistics or comprehensive methods (Acreman and Dunbar, 2004). Comprehensive methods often require substantial field work to understand the relationship between flows and components of a freshwater ecosystem. These methods are often resource intensive, require a multi-disciplinary team and provide very detailed information for a particular site (King et al., 2003; Tharme and King, 1998). Simpler approaches can be used for quick estimates of environmental flows and are more appropriate as basin wide planning tools (Richter et al., 1996; Smakhtin and Eriyagama, 2008; Mul and Gao, 2016). In this chapter we present a combination of statistical approaches complemented by expert judgement, based on research done on different components of this volume (Ayivor and Ofori, 2017; Dankwa et al., 2017; Akpabey et al., 2017). This information is compiled into 4 restoration hydrographs which feed into the economic valuation (Balana et al., 2017).

**Background**

The historical hydrograph is used as a benchmark for the natural flow dynamics and the pre-dam conditions serve as a reference for natural ecosystem services. The current flow regime resulting from the releases from the two dams serves as a comparison between the natural and highly modified system. Fig. 9.1a shows the average monthly flow for the natural flow regime (before the construction of the Akosombo dam) and the current flow regime (after the construction of the Akosombo dam). It is clear that the construction of the dam has drastically changed the flow regime downstream of the dam. Seasonal peak flows (5,000 – 8,000 m³/s) no longer occur; instead, a steady flow regime (1,000 m³/s +/-50%) has been put in place (VRA, 2010). The peak floods in the
months of September and October were a response to rainfall in the upper part of the Volta basin; low flows occurred between the months of December and May and reflected the dry season condition with very little rainfall.

Fig. 9.1b shows the Flow Duration Curve for the two time periods and reflects similar trends as Fig. 9.1a, with a reduction of high flows and an increase in low flows. The total flow towards the Lower Volta has reduced as a result of evaporation from the impounded water (surface area of the formed Lake Volta is at its’ maximum 8,502 km² (VRA, undated)). With estimated average potential evaporation of 1,500 mm/yr and at maximum capacity, this roughly accounts for a reduction in flow of around 404 m³/s. On the other hand, rainfall on Lake Volta increases the water availability as well. Annual rainfall ranges between 1,000 and 1,200 mm/yr increases the flow between 269 and 232 m³/s.

Fig. 9.1: a) Average monthly hydrograph, before and after dam construction
Fig. 9.1: b) Flow duration curve, before and after dam construction (Source of data VRA, 2011).

Methodology

The link between the flows and the downstream (ecosystem) services is crucial in order to determine which type of flows (magnitude, frequency and timing) should be released from the dam. For some services, the flow requirements can be determined by the amount of water the services need (e.g., irrigation or domestic water use/urban water supply), but for others, such as ecosystem services, the relationship is more complex. Often, the ecosystem services are dependent on elements such as timing, area flooded, flood duration or salt water intrusion length. Fig. 9.2 shows the flood extent for different discharge rates (after VRA, 2011).
Fig. 9.2: Approach towards developing restoration hydrographs
The first step was to identify key (ecosystem) components in the Lower Volta basin which are affected by changes in the flow regime (Table 9.1). Second, for each of these components the flow requirements were determined in close consultation with key experts, and combined into restoration hydrographs (Fig. 9.3).

**Table 9.1: Ecosystem services and other considerations taken into account**

<table>
<thead>
<tr>
<th>Ecosystem services considered</th>
<th>Other consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fisheries</td>
<td>• Affected Infrastructure</td>
</tr>
<tr>
<td>o Freshwater fish</td>
<td>o Aquaculture</td>
</tr>
<tr>
<td>o Marine and brackish water fish</td>
<td>o Flood plain developments</td>
</tr>
<tr>
<td>o Clams</td>
<td>o Irrigation</td>
</tr>
<tr>
<td>• Aquatic weeds</td>
<td>• Community consultation</td>
</tr>
<tr>
<td>• Flood recession agriculture</td>
<td></td>
</tr>
<tr>
<td>• Sediment transport</td>
<td></td>
</tr>
<tr>
<td>• Groundwater replenishment</td>
<td></td>
</tr>
<tr>
<td>• Health</td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 9.3: Flood inundation map of the Lower Volta (after VRA, 2011)*
The following section describes the key components and how they relate to the flow regime of the Lower Volta River. Table 9.2 provides an overview of key flow requirements for each of these components.

Table 9.2: Key ecosystem services and flow requirements during dry and wet season.

<table>
<thead>
<tr>
<th>Key issues</th>
<th>Dry season flow</th>
<th>Wet season flow</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish (fresh water)</strong></td>
<td>Requires minimum level of salt water intrusion</td>
<td>Benefits from floodplain inundation (the more the better)</td>
<td>Spawning in the floodplain/creeks.</td>
</tr>
<tr>
<td><strong>Fish (brackish water)</strong></td>
<td>Require saltwater gradient (the longer the better as it increases the size of their habitat) The longer the saltwater conditions last, the better</td>
<td>Duration of flooding up to 3 months (the longer the better)</td>
<td>There is no significant economic difference between fish catch of floodplain spawning fish and brackish/marine fish.</td>
</tr>
<tr>
<td><strong>Clams</strong></td>
<td>Require brackish water</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aquatic weeds</strong></td>
<td>All aquatic weeds are freshwater plants and they do not withstand salt water. Increasing saltwater intrusion length is beneficial for the control of aquatic weeds</td>
<td>Weeds are washed into the sea with peak flows</td>
<td>Four types of weeds are found in the Lower Volta: floating weeds, rooted weeds, submerged weeds and weeds growing on the banks. Weeds were washed away but within 1 year they were back in same quantities</td>
</tr>
<tr>
<td><strong>Flood recession agriculture</strong></td>
<td>The Akosombo dam is capturing the fertile soils; expectations are that the flood recession agriculture will not be as productive as it was before.</td>
<td>Flood recession agriculture requires seasonally inundated floodplain (the more the better)</td>
<td>Ghana has introduced a policy on riparian zone vegetation whereby a buffer of 50 m from the river is reserved for natural vegetation to reduce bank erosion and improve the environmental health of the river.</td>
</tr>
<tr>
<td>Key issues</td>
<td>Dry season flow</td>
<td>Wet season flow</td>
<td>Remarks</td>
</tr>
<tr>
<td>------------</td>
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<td>----------------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Sediments</strong></td>
<td>To be more effective some dredging may be required, especially during the first years</td>
<td>Peak flows are required to seasonally flush out the sediments at the mouth of the estuary</td>
<td>Increased flow velocity will create sandier river bottoms which are beneficial for clams and oysters.</td>
</tr>
<tr>
<td><strong>Health</strong></td>
<td>Larger saltwater intrusion length will reduce the prevalence of the snails transmitting schistosomiasis</td>
<td>High flow velocities will wash away the snails</td>
<td>Vegetation is providing a habitat for the snails (especially aquatic weeds) Shallow water depth &lt;1.5 m is conducive for the snails</td>
</tr>
<tr>
<td><strong>Aquaculture</strong></td>
<td>Requires minimum level of salt water intrusion</td>
<td></td>
<td>Requires steady flow regime and minimal water level fluctuations, and low flow velocity Some cages were washed away during 2010 floods</td>
</tr>
<tr>
<td><strong>Irrigation</strong></td>
<td>Intakes for irrigation should not fall dry (for example intakes from Kpong headpond)</td>
<td>Releasing of floods to the Lower Volta impacts irrigation schemes depending on the level of floods released.</td>
<td>Irrigation development is mainly profiting commercial farmers, although GIDA develops areas for smallholder irrigation within their irrigation schemes</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td></td>
<td></td>
<td>Flooding affects infrastructure located within the floodplain</td>
</tr>
</tbody>
</table>

**Fisheries**

The fisheries sector in the Lower Volta has shown a general declining trend in fish catch since the construction of the Akosombo dam (Tsikata, 2006). There is also a shift in species composition, from a good mix of freshwater, marine and saltwater fish towards predominantly freshwater fish species over the same period. Key fresh water fish nowadays are Tilapia and Cat fish. The West African Manatee
(Trichechus senegalensis), listed as vulnerable, is present at Adidome, albeit in very low numbers (IUCN, 2016). The reproductive cycle of the fish is dependent on the flood regimes. Adults and juveniles take advantage of the refuge and abundance of food in the floodplains. Flooding patterns should be aligned with the pre-dam flood pattern to optimize fishery production.

The production of West African clam, Galatea paradoxas, is very important for livelihoods of downstream communities. Prior to the construction of the Akosombo dam, they were found up to 95 km from the estuary, but currently they are restricted to 15 km from the estuary. Landings of clams have been reported to have dwindled from 8,000 tons/yr before the dam construction to 1,700 tons/yr around 2000 (Adjei-Boateng et al., 2012). Due to fishermen now using ‘primitive’ diving equipment, there has been a recovery, with landings now standing at 7,000 tons/yr (Adjei-Boateng et al., 2012). Lower low flows will enable the saltwater intrusion to advance further inland and seasonal flooding will support sandy river beds that will benefit clam production.

Aquatic weeds

There are different types of aquatic weeds found in the Lower Volta River: floating, bank and submerged weeds. The presence of these aquatic weeds has a number of negative consequences. Floating weeds harbor bilharzia snails and impede the movement of fishing boats, and therefore reduce fish catch. Fish hide in the submerged weeds and fishing nets get entangled in the weeds, resulting in low fish catch. Weeds at the river bank affect access to the water by fishermen. The weeds thrive in areas of low flow velocity, freshwater and increased nutrient levels (WRI, 2013; Cilliers et al., 2003). About 15% of the Lower Volta River and 30% of the Kpong headpond are infested with aquatic weeds, in particular water hyacinth (Akpabey et al., 2017). High flow velocities in rivers (floods) and greater influence of saltwater intrusion (low flows such as in the pre-dam period) reduce the prevalence of aquatic weeds.
Flood recession agriculture

Flood recession agriculture was a productive livelihood before the dam construction with floods depositing fertile soils in the floodplains, supporting the agricultural production. An estimated 51,800 ha was used for flood recession agriculture during the pre-dam conditions (Barry et al., 2005). Seasonal flooding of the floodplain may support flood recession agricultural practices.

Groundwater

Groundwater in the Lower Volta is experiencing two issues with the water quality: iron and manganese due to the geological formation in the upper parts and salinity in the lower parts (Agyekum et al., 2017). A recent study conducted in the Lower Volta indicated that transmissivity values of the underlying aquifer varied widely from 0.116 - 264 m²/d. However, a mean of 12 m²/d in the southern section of sandy formation implied high hydraulic conductivity and porosity. The study observed that since these characteristics allowed for high rainfall recharge of aquifers it could have also contributed to the significant levels of sodium, chloride and TDS in groundwater in the Lower Volta (WRI, 2013).

Though literature on the sources of groundwater recharge regimes in the lower Volta area is scanty, recharge of shallow aquifers in floodplains could be enhanced since the aquifers are of high porosity and hydraulic conductivity.

Sediments

One key issue in the Lower Volta River is the formation of the sandbar at the estuary of the river. Without the seasonal flooding from the river, sediments build up at the mouth of the estuary, preventing saltwater intrusion which is necessary for the control of aquatic weeds, fishery and clam production, as stated above. In addition, fewer sediments are washed into the sea, causing aggravated coastal erosion to the eastern section of the shoreline which extends into the coastlines of Togo and Benin. High seasonal peak flows are required to push sediments into the sea and allow for increased saltwater intrusion into the estuary.
Health

The communities in the Lower Volta River are exposed to a variety of health hazards that are related to the flow regime, such as malaria, schistosomiasis and river blindness. After the construction of the Kpong dam, the rapids at Senchi were flooded and thereby eradicated river blindness. Schistosomiasis thrives in shallow fresh water with water depth < 1.5 m and flow velocity of < 0.4 m/s. In addition, aquatic weeds such as water hyacinth create a supporting habitat for snails (Akpabey et al., 2017). Increasing flow velocities dislodges the snails, and increasing distances of saltwater intrusion inland reduces freshwater habitat for the snails (WHO, 1997). Anopheles mosquitoes, which can transmit malaria, thrive in small shallow water bodies, such as small ponds in the floodplain. Flooding of these areas therefore increases malaria incidences.

Infrastructure

Since the construction of the dams, development in the Lower Volta has continued and is taking advantage of the steady flow regime. Several of these developments are at risk when re-operation of the two dams is considered. They include cage fishing, irrigation and commercial developments. Infrastructure investments into these activities may be at risk, as described below.

Aquaculture

In recent decades, cage fishing has become an important economic activity in the Lower Volta, where more than 1,800 fish cages are now farming Tilapia (IWMI, 2016). With a large investment cost but also potentially high returns, this has become an activity for investors. However, cage fishing has some potential risks associated with the flow regime. Rapid water level fluctuations, high flow velocity and saltwater intrusion can affect the fish population and the cages themselves.
Irrigation

Currently, both small and large scale irrigation are taking place in the Lower Volta basin, but the total area is still less than the pre-dam flood recession area. Future developments however, are on the drawing board, with an estimated 150,000 ha planned for the Accra Plains Irrigation Project (GIDA, 2009). Current water requirements for irrigation in the Lower Volta basin (mainly from the Kpong dam) are about 10 m$^3$/s, and for the near future situation (2020), 38 m$^3$/s (IWMI, 2014). Irrigated areas are currently not located in the former floodplain areas; however, future developments are planned in the floodplain.

Commercial investments in the floodplain

Several hotels are located close to the river banks, as they offer different water-based tourism activities such as boat trips and jet skiing. Houses and other structures are also constructed in the floodplain which used to be inundated during the pre-dam period. These developments are at risk of flood damage if the re-optimisation and re-operation study of the Akosombo and Kpong dams are implemented, as higher floods will be experienced.

Community consultation

The community consultations provided insights into what the communities value and the concerns they may have with regard to re-operating the dams. The majority of the population in the communities are into fishing and agriculture, while trading and mat weaving are considered as minor occupations (Baah-Boateng et al., 2017). Communities in general have access to main facilities such as electricity, pipe borne water, schools and telecommunication. Over 90% of the village elders (>50 years old) interviewed perceive the pre-dam situation to be more favourable than the current situation (Nukpezaah et al., 2017). Aquatic weeds are a major concern. Main concerns of the communities with regard to releasing peak flows ranged from damage to homes and farms, adverse effects on commercial properties and erosion of shorelines.
Restoration hydrographs

The different components have flow requirements that have sometimes complementing and sometimes conflicting objectives. Table 9.3 shows a simplified overview of the flow requirements for different components for the two seasons. This shows that irrigation and aquaculture (Tilapia) have conflicting objectives compared to weed control and other fish types.

Table 9.3: Flow requirements for the sub-sectors

<table>
<thead>
<tr>
<th></th>
<th>Dry season flow</th>
<th>Wet season flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
<td>Fish - Tilapia and catfish, aquaculture; agriculture: large and small scale irrigation</td>
<td>Weeds, Fish: all except aquaculture; groundwater: recharge; salinity: health: schistosomiasis</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>Weeds, fish - floodplain spawning fish, clams and oysters, brackish and marine fish; agriculture: flood recession farming; health: schistosomiasis</td>
<td>Fish - Aquaculture; agriculture: large and small scale irrigation; Health: malaria</td>
</tr>
</tbody>
</table>

Based on the seasonal water requirements, a first scenario takes the current flow regimes as the starting point, conducive for aquaculture, hydropower and irrigation. On the other side we introduced a scenario mimicking the natural flow regime, ideal for fisheries, clams, flood recession farming and the removal of aquatic weeds. Two additional scenarios were developed. They are between the natural and current flow regime, which are depicted in Fig. 9.4 and described below. The scenarios at this stage are theoretical and reflect the combined flow requirements of the components. Annor et al. (2017) and Balana et al. (2017) further investigate the impact of these restoration hydrographs on hydropower production and other economic returns.
Scenario 1 Hydropower optimisation

Scenario 2 2010 spillway level

Scenario 3 Maintaining sufficient water for dry season irrigation

Scenario 4 Maximizing ecosystem services
Figure 4 Reoperation scenarios for Akosombo and Kpong dams

Scenario 3 Maintaining sufficient water for dry season irrigation

Scenario 4 Maximizing ecosystem services

Fig. 9.4: Re-operation scenarios for Akosombo and Kpong dams
Scenario 1: Current flow regime (S1)

This scenario is based on the current flow regime, where flows are based on the hydropower requirement from the Akosombo dam. A steady flow regime with an approximate flow of 1,000 m$^3$/s is proposed. The proposal of 1000 m$^3$/s is based on the analysis of post dam flows as presented in Fig. 9.1a.

Scenario 2: 2010 spillway level (S2)

The second scenario is based on observed discharges for the year 2010. For the wet (flood) season, it is assumed the 2010 spill level of 2,300 m$^3$/s (of which 900 m$^3$/s was discharged through the spill way and 1,400 m$^3$/s through the turbines VRA, 2015 pers. comm.). According to VRA this amounts to the full bank capacity and therefore limited areas will be flooded. For the dry season flow the level is 700 m$^3$/s, which is roughly the same as the flows of August 2015, passing through the Lower Volta, due to severe water shortages. This scenario was included as it provides additional information on the actual impact of the flows (both high and low flows), for the cost-benefit analyses.

Scenario 3: Maintaining sufficient water for dry season irrigation (S3)

The third scenario focussed on providing sufficient water during the dry season for irrigation (both existing and planned irrigation), while restoring the dynamic flow regime. Maintaining sufficient water for irrigation is not only a function of the water requirement, but it is also dependent on access to water. For example, intakes of the gravity systems are at fixed levels and to be able to take in water, water levels need to be sufficiently high. Small scale irrigation downstream of the Kpong dam uses flexible intakes, but is often constrained by the distance it can cover. We assume that a flow of 500 m$^3$/s during the dry season flow will not affect the irrigation intakes and will provide sufficient flow to reduce the saltwater intrusion to an acceptable distance. Instead of storing all the wet season flow to provide 1,000 m$^3$/s all year round, we release some of it during the wet season to maintain a dynamic flow regime that supports downstream ecosystems. The resultant peak flow of 3,000 m$^3$/s floods an area of 24 km$^2$ (based on
inundation maps developed for the emergency preparedness plan (VRA, 2011)), including connecting some of the creeks with the main river. The expected result in terms of ecosystem services benefits was assumed to be proportional to the next scenario.

**Scenario 4: Natural flow regime (S4)**

The fourth scenario focussed on providing a flow regime that is conducive for weed control and fisheries (clam production). High flows inundate creeks and floodplains that are used by fish to spawn. Following the natural cycle of the fish, this is most effective during the months of September and October. High flows and associated high flow velocities remove weeds, floating and submerged, from their locations and direct them further downstream and eventually into the sea. High flow velocities also wash away the sediments from the river beds, providing good sandy soils for clams to attach themselves to. The peak flow was set at 5,000 m$^3$/s for the months of September and October, which is the flow that can cause a significant area to be flooded (32 km$^2$), similar to the average historical peak flows. Low flows during the dry season are beneficial for (women) entrepreneurs to harvest clams. Increased saltwater intrusion provides more suitable areas for clam production and fewer areas where weeds will grow. Not only is saltwater intrusion length affected by the flow regime, but also the sand bar at the mouth of the estuary blocks saltwater intrusion. If optimal saltwater intrusion is needed, there is the need to mechanically break the sandbar, and peak flows are required regularly to maintain the connection to the sea.

**Discussion**

The four scenarios were scored for their relative contribution to supporting the relevant identified ecosystem and ecosystem services. It is evident that decisions made on which flow regime to release from the dam will have an impact in one way or another. Scenario 1 will affect fisheries, proliferate aquatic weeds and support the formation of the sand bar. On the other hand, prioritizing ecosystem services will affect economic activities such as aquaculture, irrigation and hydropower.
Decisions will have to be made at a high level about which objective will be considered priority over other(s). Table 9.4 shows the impacts for each of these scenarios for the different sub-sectors identified. The modelling work and economic feasibility provides additional detail about the actual trade-offs to be considered (Annor et al., 2017; Balana et al., 2017).

From Table 9.4 it can be seen that there is a trade-off between flow regimes and their impact on different sectors. Scenario 1 is conducive for irrigated agriculture, hydropower generation and aquaculture. However, this has had an impact on the natural ecosystem and its services, such as fisheries, managing aquatic weeds and health. On the other hand, reinstating a natural flow regime (Scenario 4) will bring back some of the natural ecosystem services. However, this will be at the expense of irrigation, hydropower production and developed infrastructure in the floodplains (including some hotels).

Table 9.4: Expert opinion expected impact of selected restoration hydrographs

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Health</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfed Irrigation</td>
<td>Flood recession</td>
<td>River blindness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bilharzia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Malaria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aquaculture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shellfish</td>
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<tr>
<td></td>
<td></td>
<td>Finfish (fresh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Finfish (salt/brackish)</td>
</tr>
<tr>
<td></td>
<td>Weeds</td>
<td>Sediments</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Hydropower</td>
</tr>
<tr>
<td></td>
<td>Infrastructure in floodplain</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Agriculture</th>
<th>Health</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>N ++</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>S2</td>
<td>N +</td>
<td>N ++</td>
<td>N --</td>
</tr>
<tr>
<td>S3</td>
<td>N +</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>S4</td>
<td>N --</td>
<td>++</td>
<td>+</td>
</tr>
</tbody>
</table>

++ very good; + good; N neutral; - bad; -- very bad

The feasibility of releasing the above described restoration hydrographs is dependent on the minimum and maximum capacity of the releases from the Akosombo and Kpong dams. For modelling purposes, the above flow releases were proposed, but they will need to be verified against the constraints from the dams, such as spillway capacity.
and maximum flows through the turbines (Mul et al., 2017). For the economic valuation, the historical benefits attained will serve as a basis for estimating the benefits associated with this scenario. However, the proposed scenarios will be constrained in terms of reaching the actual pre-dam low flows and pre-dam peak flows (Mul et al., 2017).

**Conclusion**

To restore the typical ecosystems and their services in the Lower Volta basin, from divers fishery and clam production to flood recession agricultural practices, attempts should be made to get as close as possible to the natural flow dynamics of seasonal flooding and seasonal low flows on the lower Volta River. This requires flows high enough to flood large areas, and in particular connecting the river to the creeks in the flood plains, which various types of fish use for spawning. In addition, during the dry season, low flows in the river will allow saltwater to intrude into the estuary, improving the environment for clams and reducing the infestation of aquatic weeds and bilharzia. However, reintroducing natural flow dynamics will have a negative impact on other downstream elements. Structures located within the floodplain may be affected by the re-introduced old flow regime. In addition, hydropower production, one of the main economic drivers in the area, will be affected by changing the flow regime. A full scale trade-off analysis between the different restoration flow scenarios is needed for decision makers to make informed decisions on the selection of a re-operation scenario.

**References**


bitstream/handle/1957/35031/The%20Current%20State%20of%20the%20Volta%20Clam%2c%20Galatea%20paradoxa%20fish-ery%20in%20the%20Lower%20Volta%20River%2c%20Ghana.pdf?sequence=3 [Accessed on 02/06/2016]


TRADE-OFFS BETWEEN HYDROPOWER PRODUCTION AND DOWNSTREAM FLOW REQUIREMENTS

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Abstract

Re-operating Akosombo and Kpong dams is intended to restore downstream ecosystems and livelihoods. The Water Evaluation and Planning (WEAP) tool was used to assess four re-operation scenarios on future hydropower production and irrigation expansion in the Lower Volta basin. The scenarios are; (i) S1: Maintaining current flow regime based on hydropower requirement from Akosombo dam; (ii) S2: Reinstating natural flow dynamics (up to 2010 spillway levels); (iii) S3: Maintaining sufficient water for irrigation while reintroducing natural flow regime; and (iv) S4: Reintroducing pre-dam flows that provide the conditions conducive for aquatic weed control and clam production. Throughout the simulation period (2016-2050), the potential average hydropower generated in the reference scenario is 5,256 GWh/yr. However, S1 increased generation by 0.2% whereas S2, S3, and S4...
reduced power generation by 45%, 58% and 74%, relative to the reference scenario. Climate change projections will affect potential hydropower production, ranging from -8% for CC scenarios with decreasing water availability to +8% for CC scenarios with increasing water availability. Only Scenario 1 (optimization of hydropower production) satisfies the hydropower criteria of at least 6 GWh/day, whereas the other scenarios fail in this respect. In addition, S1 is the only scenario that manages to supply the FIRM hydropower requirement of 4,415 GWh/yr. Adding new turbines to the Akosombo dam during the wet season to make use of the extra water stored generated a 9% increase in hydropower production per turbine (S3 scenario) during the wet season, increasing annual hydropower production by 1-2% only. This by no means offsets the reduction in hydropower and requires a strategic approach to augment hydropower production with other sources of energy. For irrigation water demand, the present abstraction rate (10m$^3$/s) will not be affected during re-operation. Increasing the abstraction rate to 38m$^3$/s to account for the anticipated irrigation expansion, with effect from the year 2020, would mean that the water demand for some few dry years will not be fully met (about 0.1% shortage).

**Keywords:** Water allocation, WEAP, Dam operations, Scenarios, Environmental flows

**Introduction**

Every river basin has a unique population living in it. As a result, aquatic systems and their floodplains constitute important ecosystems that bring several socio-economic opportunities to riverine communities. One key benefit of the Volta river system is the Akosombo and Kpong hydropower dams which hitherto have supplied about 95% of Ghana’s energy demand. As a necessary ‘evil’, the creation of the hydropower dams has altered the natural flow of the Volta River thereby impacting adversely on livelihoods of downstream communities. Therefore, this study aims to investigate the technical and economic feasibility of a technique for re-operating and re-optimising the operations of the Akosombo and Kpong hydropower dams to reintroduce (or improve) downstream livelihoods and ecosystems, while maintaining, and indeed enhancing, power generation and reliability.
The concept of re-operation and re-optimisation of dams examines changing the flow regime to restore important ecosystem services that were offered by dammed rivers prior to the construction of the dam(s). Under the pre-dam conditions, there were seasonal variations in flows (very low flows in the dry season and very high flows in the wet season). The low and high seasonal flows favoured the development of some ecosystem services on which the downstream communities depended at various times of the year. These included clam harvesting during the low flows, and flood recession agriculture after the high flows. Notwithstanding these benefits during this pre-dam period, there were water-borne diseases such as river blindness (*onchocerciasis*), bilharzia and malaria. Post-dam conditions brought about a near steady water level irrespective of the season. This in a way reduced the incidence of diseases such as onchocerciasis due to the fast flowing water all year round. However, due to the steady water level (as shown in Figures 10.1 and 10.2), downstream communities lost some of their livelihoods such as clam harvesting that depended so much on the seasonal variations. Also, sandbars have built up at the estuary and weeds infested the water due to low flows (reduced peaks). The sandbar builds up at the estuary due to the low flows, thereby limiting the extent of sea water intrusion which controls aquatic weeds growth. Re-operation and re-optimisation therefore seek to operate the dams in such a way that low and high flows are released downstream in a way that is consistent with pre-dam conditions. The aim is to restore downstream ecosystem services while ensuring that power generation is increased.

Fig. 10.1: Dam operated for hydropower
The re-optimisation and re-operation study of the Akosombo and Kpong dams assessed the feasibility of re-operating the two dams to restore the past favourable flow conditions in the Lower Volta, in order to combat some of the challenges described above. Re-operating dams is an innovative way of addressing these challenges, but it can potentially increase or reduce the total annual hydropower production. The conventional way of operating a hydropower dam is depicted in Fig. 10.1. Dynamic flows fills the dam and a steady flow regime is released. Due to the difference in inflow and outflow during the season the water level in the reservoir fluctuates as well. During the dry season the water level reduces as less water flows in than flows out. The hydropower production throughout the year is relatively steady as a function of the water level and the outflow.

The re-operated dam on the other hand (Fig. 10.2) releases flows that mimic the natural flow regime. In this scenario, as inflow and outflow are almost equal, the water level in the dam is steady. Hydropower production is therefore more efficient (more MWh per m³). However, the hydropower production fluctuates throughout the year, and during the peak flow period additional investments are required to harness the hydropower. Reduction in hydropower production during the dry season needs to be compensated for by increasing electricity generation capacity in the network.
The concept of dam re-operation has existed for some years (Richter and Thomas, 2007), and more recent studies assess how it could work to maintain ecological health under climate change (Watts et al., 2011). However, there are few examples of the concept being put into practice and of actual benefits of re-operation identified. This study of the Akosombo and Kpong dam re-operation and re-optimisation was therefore carried out to determine the viability of this concept in a river system that is said to belong to an Environmental Class B (slightly modified system - Smakhtin and Eriyagama (2008)) focussing on hydropower production under different scenarios for downstream flow requirements and climate change scenarios, which are described in the next sections.

**Methodology**

The study employed desk study and discussions with downstream communities and dam operators. First a study was used to define the restoration hydrographs needed for the downstream (Mul et al., 2017). Second, a hydrological model (SWAT) was set up by WRI (2016b) to define the changes in flow due to competing water uses upstream and climate change. A water resources planning model was then set up using the Water Evaluation and Planning Tool (WEAP) to develop trade-offs between the competing uses so as to optimize hydropower production while meeting downstream flow requirements.

**Restoration hydrographs for scenario building**

Four (4) scenarios were defined for consideration in the water allocation model (Mul et al., 2017) (Fig. 10.3). Recognising that the dams are permanent structures, the flows through the turbines were presented in four scenarios towards mimicking the pre-dam conditions to guarantee the maximum benefits accrued to the communities (Mul et al., 2017). The scenarios are; (i) S1: Maintaining current flow regime where streamflow is based on hydropower requirement from the Akosombo dam; (ii) S2: Reinstating natural flow dynamics (up to 2010 spillway levels); (iii) S3: Maintaining sufficient water for irrigation while reintroducing natural flow regime; and (iv) S4: Reintroducing
the pre-dam flow that provides the conditions conducive for weed control and clam production.

For each of the scenarios, hydropower production is calculated. With the current number of turbines, the total hydropower production would automatically be reduced. Therefore, for S3, alternatives were developed by introducing additional turbines which harvest hydropower during the peak flows, thereby reducing the non-productive flows. The alternatives are composed of 1, 2, 3, 4 and 5 additional turbines.

*Fig. 10.3: Hydrographs for scenarios of re-operation and re-optimisation of Akosombo and Kpong dams*

**Climate projections for the project area**

Climate change projections used in the WEAP modelling are based on the research carried out by the Water Research Institute (2016) and are described below. To this end, climate simulations from two emission scenarios out of the six from the Intergovernmental Panel on Climate Change (IPCC, 2007) were selected and downscaled for the
Volta Basin. These are the A1B and A2 scenarios. The A1B scenario represents ‘business as usual’ and lies between the extremes produced by other scenarios (IPCC, 2007). The A2 scenario represents a more differentiated world with local traditions being held onto, which leads to a slow uptake of new technologies and over-reliance on fossil fuel, which in turn lead to high emissions (IPCC, 2007). In general, temperatures are expected to increase for both scenarios. Rainfall for each scenario is also expected to increase (WRI, 2016).

Streamflows

The changes in streamflows were assessed by running the climate change scenarios through the Volta SWAT hydrological model. The SWAT model output (WRI, 2016b) under the two climate change projections gave about a 17% increase in streamflow by 2025 (17.1% and 16.2% under the A1B and A2 scenarios respectively) basin-wide. Considering all upstream consumptive demands, inflows into Akosombo were projected to decrease up to 17% (WRI, 2016). In the WEAP model both extremes (± 17% change in stream flow) are simulated up to 2050.

Hydropower capacity and demand

According to MATREX/IESS (2016), Ghana’s power system has a total installed capacity of about 2,900 MW. The hydropower generation is distributed among the three hydro plants as follows: Akosombo (1020 MW), Kpong (148 MW) and Bui (400 MW), constituting about 54%, whereas thermal and solar power generation makes up the remaining 46%. The thermal generation is obtained from Aboadze (T3, TICO and TAPCo) and Tema (TT1PP, CENIT, MRP, Sunon Asogli and Siemens) (MATREX limited and IESS, 2016).

The peak demand for Ghana for the year 2016 is estimated to be 2,477 MW while available supply is 2,698 MW, giving a surplus of 221 MW. However, currently the contribution from hydropower seems to be on the downward trend, which calls for more thermal complements with an overall increase in energy production. This is due to a change in the distribution of annual flows as well as an overproduction of hydropower during periods with low supply from alternative sources, causing a lowering of the water levels in the dam and an overall reduction in hydropower production per unit of water.
The information obtained above from the previous studies (Obuobie et al., 2017; Mul et al., 2017) were used to set up the WEAP model described below.

**Fig. 10.4:** Schematic view of the Lower Volta WEAP model for the Akosombo and Kpong Re-operation and Re-optimisation project

**WEAP model setup**

The Water Evaluation and Planning (WEAP) system was selected for modelling the re-optimisation and re-operation of the Akosombo and Kpong dams. This was due to the fact that it is an open source software for developing countries and local capacity exists to support the beneficiary to apply it. The WEAP is an Integrated Water Resources Planning tool developed by the Stockholm Environmental Institute (SEI) in 1988 (SEI, 2012). WEAP is used for simulating water storage (surface and groundwater), water demand, water supply, streamflow (runoff), evaporation/evapotranspiration and other local water ‘losses’ (e.g. infiltration), crop water requirements, environmental flow.
requirements/ecosystem services, reservoir operations, pollution/instream water quality, hydropower generation under scenarios of varying policy, hydrology, climate, land use, technology and socio-economic factors. It integrates stakeholder processes, water balance assessment, and scenario (policy) development, and could also be linked with several models and utilities such as QUAL2K, MODFLOW, MODPATH, PEST, Excel and GAMS (weap21.org).

WEAP was first used in the Volta Basin in 2003 by Andah et al., with several follow-up models developed by the International Union for the Conservation of Nature West and Central Africa Office (IUCN-PACO) in 2008 and together with the Volta Basin Authority (VBA) in 2012, as well as McCartney et al. (2012). These models were used as tools to support Volta Basin Water Resources Planning and decision making (policies on water allocation).

Model inputs

The current model is an update of the first daily operational model developed using WEAP to simulate the re-operation and re-optimisation of the Akosombo and Kpong dams using historic data from 1981 to 2013 and projected to 2050 (Mul et al., 2015). Data used consisted of water levels, storage-elevation curves, reservoir upstream and downstream elevations, releases from the dams and hydropower generated.

Net inflow = Final storage - initial storage + release.................. 10.1

Net inflows are computed using the mass balance approach for each day of operation for the Akosombo dam and the Kpong run-of-the river hydropower dam using equation 10.1 (Mul et al., 2015).

Parameterization of WEAP

The model is set up to run on a daily time step for the Lower Volta sub-basin where the Akosombo and Kpong Dams are located as well as irrigated farms, and provisioning services for the populations. This
was developed to capture the ‘real’ operations of the Akosombo and Kpong dams by the Volta River Authority (VRA).

**Schematisation**

The model focuses on releasing water to meet the four re-operation scenarios downstream of the Akosombo and Kpong hydropower dams in order to assess the various trade-offs between the different users (hydropower, environment and irrigation). Fig. 10.4 above presents the schematic view for the model.

**Input data**

**Water demands**

For the Lower Volta, only Hydropower, Agriculture (Irrigation) and the Environmental Flow Requirements (restoration scenarios by Mul et al., 2017) are used. The current irrigation water requirement is 10m$^3$/s, which looks quite insignificant compared to the reservoir releases from Akosombo and the inflows to the Kpong Dam (approximately 1,000m$^3$/s) (IWMI, 2014). However, intakes are sensitive to water level fluctuations.

**Hydropower projections**

Fig. 10.5 shows the hydropower generation, energy consumption and projections for Ghana. The country relied solely on the Akosombo and Kpong dams for her energy needs for nearly 3 decades after construction. Taking into account the growing economy and urbanization, thermal sources were introduced in the early 1990s. The need to increase the thermal component was heightened following the energy crisis in the country in 1997, arising from the low water levels in the Akosombo dam. Recognising the insecurity related to the reliance on the weather and by extension, the climate in hydropower generation, it was necessary to safeguard and maintain the power generated to sustain economic growth of the country. In the early years of the generation mix, production (supply) exceeded demand (consumption) and hence
Ghana could export energy to other West African States. However, recent low water levels in the Akosombo dam as well as the increasing demand for energy due to population and economic growth have had a lot of negative implications for the energy sector, demanding a shift from relying heavily on hydropower to diversified energy sources (especially thermal Energy) which are normally associated with a higher cost of production per KWh relative to the former. The projections for Akosombo after 2016 were prepared with the VRA expert on the assumption that the hydropower plant would not generate more than the ‘FIRM’ (4,415 GWh) per year as shown in Fig. 10.5.

![Fig. 10.5: Ghana’s Energy demand/consumption and forecasts](image)

**Physical constraints of the Akosombo and Kpong dams**

The maximum hydraulic outflow (flows through the spillway + Turbines) is 22,297 m$^3$/s. The maximum turbine flow for Akosombo is 1,600 m$^3$/s. There was an increase in the generation efficiency from 90% to 93% after the retrofits in 2006. The Top of inactive storage for the Akosombo dam is 74,000 Million m$^3$ (equivalent of a water level of 73 m) out of the total storage of 148,000 Million m$^3$ (84 m water level).
CHAPTER 10

Model Calibration and Verification

The WEAP model is calibrated with historic inflows and power production and verified with the VRA team. The calibration uses the observed volume of the reservoir and the hydropower generated. It must be noted that one of the most sensitive parameters in WEAP is the energy demand used for the calibration. In reality, the operation of the dams is more dependent on the capacity to generate than on the demand to be met. After calibration (1981-2000), the modelled and observed Volume at Akosombo gave a regression correlation coefficient of 0.987 with a Nash–Sutcliffe model efficiency coefficient of 0.984, while the annual hydropower production (1984-2000) gave a regression correlation coefficient of 0.737 with a Nash–Sutcliffe model efficiency coefficient of 0.664 (See Fig. 10.6; Annor et al., 2016).

![Simulated and observed Water Storage Volume at Akosombo (1981 – 2013)](image)

Criteria for evaluation of Scenarios

In assessing the feasibility of the scenarios, three (3) main criteria were used. (i) Annual Hydropower power production has to be close to the current generation or at least match the FIRM (4,415 GWh) at Akosombo; (ii) The minimum daily electric output needed at Akosombo for system stability is 6 GWh, hence the percentage of time that this demand is not met is considered; and (iii) the flow scenarios should meet downstream flow requirements and irrigation demand.
Results and Discussions

Fig. 10.7 shows the daily average hydropower production at Akosombo over the simulation period (2016-2050) which depicts that only S1 meets the minimum hydropower criteria at all times.

![Graph showing daily average hydropower generation at Akosombo](image)

Table 10.1 shows that, on average, S1 generates energy comparable to the current scenario or above the 4,415 GWh ‘FIRM’ at Akosombo. Each of the restoration scenarios (without additional investments) fails to reach the FIRM hydropower production during the dry season. The hydropower production decreases from 45%, 58% and 74% for S2, S3 and S4, respectively. For the daily FIRM power generation of 6 GWh, Table 10.2 shows that only the reference and S1 are able to maintain the minimum power generation. The other scenarios fail 7, 8 and 10 months per year for S2, S3 and S4 respectively. For S4 this basically means that except for the two flood peak months (September and October) the minimum power generation is not reached.
Table 10.1: Hydropower Production at Akosombo

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GWh</td>
<td>% w.r.t Ref. GWh</td>
<td>% w.r.t Ref. GWh</td>
<td>% w.r.t Ref. GWh</td>
</tr>
<tr>
<td>Reference</td>
<td>183,970</td>
<td>100.0%</td>
<td>6,241</td>
<td>100.0%</td>
</tr>
<tr>
<td>S1 - Hydropower Optimisation</td>
<td>184,341</td>
<td>100.2%</td>
<td>6,241</td>
<td>100.0%</td>
</tr>
<tr>
<td>S2 - Flow up to 2010 Spills</td>
<td>100,618</td>
<td>54.7%</td>
<td>3,603</td>
<td>57.7%</td>
</tr>
<tr>
<td>S3 - Maintaining sufficient water for irrigation</td>
<td>76,463</td>
<td>41.6%</td>
<td>2,684</td>
<td>43.0%</td>
</tr>
<tr>
<td>S4 - Natural flow - Maximizing ecosystem Services</td>
<td>48,624</td>
<td>26.4%</td>
<td>1,581</td>
<td>25.3%</td>
</tr>
</tbody>
</table>

Table 10.2: Percentage of time minimum hydropower production is met for the various scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>% time in a year &gt;= 6 GWh</th>
<th>No. of months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>100%</td>
<td>12</td>
</tr>
<tr>
<td>S1 - Hydropower Optimisation</td>
<td>100%</td>
<td>12</td>
</tr>
<tr>
<td>S2 - Flow up to 2010 Spills</td>
<td>39%</td>
<td>5</td>
</tr>
<tr>
<td>S3 - Maintaining sufficient water for irrigation</td>
<td>33%</td>
<td>4</td>
</tr>
<tr>
<td>S4 - Natural flow - Maximizing ecosystem Services</td>
<td>17%</td>
<td>2</td>
</tr>
</tbody>
</table>

The alternatives which involve adding additional turbines do not change the minimum power generation, as the turbines will be operated only during high flows. The additional turbines are able to generate additional hydropower during the wet season, increasing the power generation by about 9% per additional turbine (Fig. 10.8). However, for the total hydropower production in a year, the added benefit in terms of hydropower generation is less than 1% per additional turbine, as they are only operational during 2 months in the year.

The impact of the climate projections from WRI (2016) leading to a +/-17% increase in streamflow resulted in either a reduction or increase in hydropower production by 8% (see Fig. 10.9). For the climate projection with increasing streamflow, the targets for FIRM and minimum hydropower production are more easily met. However, for the climate projection with a reduction in streamflow, more failures of meeting the hydropower production requirements are expected.
Fig. 10.8: Hydropower production (Daily Average from 2016-2050 at Akosombo) for S3 with 1 – 5 additional turbines

Fig. 10.9: Daily Average Hydropower Generation at Akosombo with Climate Change Considerations
Climate change (See Fig. 10.10) will cause an increase or reduction in hydropower production by 8% on average per annum.

On an annual basis, Table 10.2 shows that irrigation water shortages are negligible (less than 0.1% of the total demand) on average (2016-2050) for all scenarios. The current irrigation demand is 10 m$^3$/s, which will increase to 38 m$^3$/s by 2020 (IWMI, 2016a). Regardless of the increase, it is not expected that the shortages for irrigation in S1, S2 or S3 will become significant. However, for S4 future irrigation requirements will be affected. The downstream flow regime for S1, S2 and S3 (Fig. 10.10) follow the proposed hydrographs during the peak flows. However, during the low flows, the discharge is slightly lower than the proposed hydrographs. For S4, the peak flows do not manage to reach the target of 5,000 m$^3$/s for the months of September and October.

Table 10.3: Unmet Annual Irrigation Water Demand in the Lower Volta basin from 2016-2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Maximum Unmet Demand (m$^3$)</th>
<th>% of Demand</th>
<th>Average Unmet Demand (m$^3$)</th>
<th>% of Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>668,872</td>
<td>0.06%</td>
<td>80,696</td>
<td>0.01%</td>
</tr>
<tr>
<td>S1 - Hydropower Optimisation</td>
<td>668,872</td>
<td>0.06%</td>
<td>79,863</td>
<td>0.01%</td>
</tr>
<tr>
<td>S2 - Flow up to 2010 Spills</td>
<td>1,408,417</td>
<td>0.12%</td>
<td>385,584</td>
<td>0.03%</td>
</tr>
<tr>
<td>S3 - Maintaining sufficient water for irrigation</td>
<td>1,429,337</td>
<td>0.12%</td>
<td>560,111</td>
<td>0.05%</td>
</tr>
<tr>
<td>S4 - Natural flow - Maximizing ecosystem Services</td>
<td>1,960,448</td>
<td>0.16%</td>
<td>906,886</td>
<td>0.08%</td>
</tr>
</tbody>
</table>
Conclusions

Providing restoration flows to the downstream communities of the Akosombo and Kpong dams adversely affects hydropower production. Throughout the simulation period (2016-2050), potential average hydropower generated in the reference scenario was 5,256 GWh/yr. Hydropower optimisation (S1) was 5,267 GWh/yr; S2 generated 2,875 GWh/yr, S3 2,185 GWh/yr on average, and S4 1,389 GWh/yr, representing a reduction of 45%, 58% and 74% for S2, S3 and S4 respectively. Uncertainty in climate change projections affects potential hydropower production, ranging from -8% for CC scenarios with decreasing water availability to +8% for the CC scenario with increasing water availability. Only Scenario 1 (optimization of hydropower production) satisfies the minimum hydropower criterion of 6 GWh per day, whereas the other scenarios fail in this respect. In addition, S1 is the only scenario that manages to supply the FIRM hydropower requirement of 4,415 GWh/yr.

It is clear that re-operating the dams has major negative implications for hydropower production. Additional turbines (up to 5 additional turbines) generated a 9% increase per additional turbine in hydropower production (S3 – CC increase) during the wet season. This by no
means off-sets the reduction in hydropower due to re-operation, and it requires a strategic approach to augment hydropower production with other sources of energy.

For irrigation water demand, the present abstraction rate (10 m³/s) is relatively low and will not be affected during re-operation. Increasing the abstraction rate to 38 m³/s to account for the anticipated irrigation expansion with effect from the year 2020 would mean that the demand for a few years (possible dry years – 2018, 2023, 2029, 2038, 2042 and 2049) will not be fully met (about 0.1% shortage), especially when the outflow from Akosombo is very low with 2 turbines operated. The shortage of irrigation water demand, however, could be said to be negligible for all the plausible re-operation scenarios (S1, S2 and S3 with additional turbines).

References


IWMI (2016a). Re-optimisation and re-operation study of Akosombo and Kpong dams: Contributions to project component, Activity 1: Defining restoration flow targets to restore ecological functions and livelihoods.
IWMI (2016b). Re-optimisation and re-operation study of Akosombo and Kpong dams, Contributions to project component: Activity 4: Economic feasibility of re-operation scenarios.


PART THREE

TECHNICAL AND SOCIO-ECONOMIC FEASIBILITY OF RE-OPERATION SCENARIOS
CHAPTER ELEVEN

PERCEPTIONS OF THE EFFECTS OF RE-OPERATION OF THE AKOSOMBO AND KPONG DAMS ON THE LIVELIHOODS OF DOWNSTREAM COMMUNITIES

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Abstract

This paper assesses the extent of the perceived effects of the re-operation of the Akosombo and Kpong dams on the livelihoods of downstream communities. A total of 15 downstream communities across three regions, Volta, Greater Accra and Eastern were covered in the study. The qualitative analysis was based on data and information obtained from Focus Group Discussions (FGD) and Key Informant Interviews while the quantitative analysis used primary data collected through the administration of structured questionnaire in a field survey. The main sources of livelihood of the community are farming and fishing, with about two-thirds of the people claiming to be poorer now than before the construction of the dams. The negative socioeconomic effect of the operation of the dams is largely related to the economic activity engaged in by residents. The greatest adverse consequence of the dams’ operation reported was its effect on fish catch, followed by loss
of land, drop in farm yield and periodic flooding. The rating of the net effect varied across jobs, with the least recognition of net positive effect acknowledged by farmers. The highest recognition of the positive net effect of the dams’ operation came from those in other types of economic activities such as driving, tailoring, and carpentry.

**Keywords:** Re-operation, Dams, Perceptions, Effects, Livelihoods

**Introduction**

In 1965, the construction of the Akosombo dam, which created the largest man-made storage reservoir in Africa, the Volta Lake, was completed. While the primary purpose of the dam was for power generation, the dam provides some degree of flood protection due to its very large storage capacity relative to inflow (Richter and Thomas, 2007). In the case of the Kpong dam, also known as the Akuse dam, which began operation in 1982, it offers opportunities for some irrigation for rice cultivation in addition to the power generation.

Essentially, damming of rivers for hydropower often comes at a high cost to communities living in and around the catchment of the dammed river, and impacts considerably on the structure and functioning of the riverine ecosystems (McCartney et al., 2000). Dams alter the natural river flows by storing and releasing water according to the patterns of electricity demand, rather than follow the natural patterns of rainfall and runoff in the catchment area. The result is a reduction in the peak flows and an increase in the base flows, which affects the wetland habitats associated with the river. This in turn, impacts on wetland biodiversity and livelihoods of downstream communities.

The downside of the construction and operation of the two dams for the benefit of the entire nation is that it comes at a cost to the communities living in and around the catchment of the dammed river, with implications for the structure and functioning of the riverine ecosystems. Field consultation with downstream communities by the Centre for African Wetlands revealed that the construction of the Volta Dam had impacted negatively on their livelihoods, health and environment, resulting in increased poverty (Twum-Barimah et al.,
2013). Some of the negative socio-economic and ecological effects of the construction and operation of the two dams outlined by Twum-Barimah et al. (2013) include:

- a reduction in floodplain agriculture;
- an explosion in the growth of exotic weeds;
- an increase in the snail vectors of bilharziasis;
- the formation of a permanent sandbar at the estuary;
- a reduction in the fishery industry, particularly clam fishery.

In a consultation with 426 downstream communities across eight districts of the two dams, as part of the Water Resources Project on the Re-optimization and Re-operation of the Akosombo and Kpong Dam study undertaken by the Centre for African Wetlands, residents perceived that the damming of the Volta River had impacted negatively on their livelihoods, health and environment, resulting in increase in poverty. Some of the key negative issues and concerns raised by the communities are unpredictable flooding, loss of natural floodplains, reduced farm yield and fish catch, and increased incidence of bilharzia.

This Chapter, which is an extract from the report of a study of the socioeconomic impact of re-operation of the two dams on the livelihoods of downstream communities, assesses the extent of the perceived impact of the operation of the dam on the livelihood of the downstream communities to inform further interventions to improve community livelihoods.

Study area

The study focussed on 15 selected downstream communities across three regions of the country – the Eastern, Greater Accra and Volta regions. These communities were selected from those that were involved in the community consultation exercise undertaken under the re-optimisation and re-operation study that involved 87 communities out of 437 towns and villages within eight districts downstream of the two dams (Lower Volta).
Two communities were randomly selected from each of seven districts which had between 7 and 16 communities covered in each district in the re-optimisation and re-operation study. One of the three communities covered in the earlier study was randomly selected for this study from Lower Manya district. The distribution of the selected communities is provided in Table 11.1.

Table 11.1: Communities where Qualitative survey was carried out

<table>
<thead>
<tr>
<th>Communities</th>
<th>District</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natriku</td>
<td>Shai-Osudoku</td>
<td>Greater Accra</td>
</tr>
<tr>
<td>Atrevenya</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azizanya</td>
<td>Ada East</td>
<td></td>
</tr>
<tr>
<td>Dikanya</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abume</td>
<td>Asuogyaman</td>
<td>Eastern</td>
</tr>
<tr>
<td>Mangoase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amedeka</td>
<td>Lower Manya Krobo</td>
<td></td>
</tr>
<tr>
<td>Fodzoku</td>
<td>North Tongu</td>
<td>Volta</td>
</tr>
<tr>
<td>Natriku</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Husekope</td>
<td>Central Tongu</td>
<td></td>
</tr>
<tr>
<td>Tsetsekpo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gbenuakope</td>
<td>South Tongu</td>
<td></td>
</tr>
<tr>
<td>Agordome</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agortoe</td>
<td>Keta District</td>
<td></td>
</tr>
<tr>
<td>Dzita</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Methods

A combination of two methodological approaches of data collection – qualitative and quantitative surveys, was adopted to analyse the socio-economic effect of re-operation objectives on the livelihoods of the selected communities. The qualitative analysis was based on data and information obtained through Focus Group Discussions (FGD) and Key Informant Interviews while the quantitative analysis was carried out using primary data collected through the administration of structured questionnaire in a field survey. The quantitative analysis
made use of descriptive statistics with the aid of tables and graphs to capture the socioeconomic effects on the livelihoods of downstream communities of the dams.

**Qualitative approach of data gathering**

The qualitative survey of selected downstream communities of the two dams took the form of FGD and Key Informant Interviews. Two separate FGD were held in each community, one each for men and women. Each FGD had between 6 and 15 participants with a blend of the elderly and the youth. As a way of seeking the consent of the communities, and in conformity with Ghanaian cultural norms and practices, prior information about the project was given to district assemblies and elders in the selected communities.

The list of questions for the FGD and Key Informant Interview was divided into two: general information and main questions. The general questions sought information about the availability of social and infrastructural facilities in the community, including schools, health facilities, electricity, pipe borne water and road network. Information on the size of the population and the main and other sources of livelihood was gathered. Participants in the FGD and Key Informants were also asked about the extent to which the construction of the two dams had impacted (positive/negative) on their livelihood or economic activities.

**Quantitative field survey**

The quantitative data gathering approach was used to obtain data to examine and ascertain quantifiable implications of the construction of the two dams for the livelihood condition of the downstream communities. The total population of the selected communities based on the 2010 population and housing census stood at 18,142 in 3,703 households, yielding an average household size of about 5. A sample of 340 households representing 9.2% was selected based on a proportional sampling method (Table 11.2). About 10% of households in each community were sampled, with the exception of two communities, Fodzoku and Atravenya where the sampled proportion of households was 4.1% and 7.3% respectively.
A two-stage sampling procedure was followed. The first stage involved a random sampling of enumeration areas in each community. This was followed by household listing, out of which five households in each sampled enumeration area in a community were selected, using a systematic sampling procedure and were interviewed using structured questionnaires. The questionnaires were structured into four sections.

Table 11.2: Sample of Communities covered in the Quantitative Survey

<table>
<thead>
<tr>
<th>Districts</th>
<th>Communities</th>
<th>Population Size</th>
<th>No. of Households</th>
<th>No. of Households sampled</th>
<th>% of households sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asuogyaman</td>
<td>Abume</td>
<td>270</td>
<td>49</td>
<td>5</td>
<td>10.2</td>
</tr>
<tr>
<td>Shai-Osudoku</td>
<td>Atrevenya</td>
<td>128</td>
<td>41</td>
<td>3</td>
<td>7.3</td>
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<td></td>
<td>Natriku</td>
<td>1,525</td>
<td>234</td>
<td>23</td>
<td>9.8</td>
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<td></td>
<td>Amedeka</td>
<td>780</td>
<td>129</td>
<td>13</td>
<td>10.1</td>
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<tr>
<td></td>
<td>Mangoase</td>
<td>1,530</td>
<td>412</td>
<td>41</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>North Tongu</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Azaglokope</td>
<td>148</td>
<td>27</td>
<td>3</td>
<td>11.1</td>
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<tr>
<td></td>
<td>Fodjoku</td>
<td>2,250</td>
<td>516</td>
<td>21</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>Central Tongu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hosekope</td>
<td>247</td>
<td>39</td>
<td>4</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>Tsetsekpo</td>
<td>195</td>
<td>49</td>
<td>5</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>Ada East</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Azizanya</td>
<td>2,460</td>
<td>392</td>
<td>40</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>Dikanya</td>
<td>246</td>
<td>59</td>
<td>6</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>South Tongu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agordome</td>
<td>2115</td>
<td>453</td>
<td>45</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>Gbenuakofope</td>
<td>1852</td>
<td>341</td>
<td>34</td>
<td>10.0</td>
</tr>
<tr>
<td>Keta</td>
<td>Agortoe</td>
<td>854</td>
<td>211</td>
<td>21</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Dzita</td>
<td>3542</td>
<td>751</td>
<td>75</td>
<td>10.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>18,142</td>
<td>3,703</td>
<td>340</td>
<td>9.2</td>
</tr>
</tbody>
</table>

**Source:** Ghana Statistical Service (2014a, 2014b and 2012)

The first part of the questionnaire sought relevant information about the community, including dominant economic activity of inhabitants, availability of social and infrastructural facilities such as schools, health facilities, electricity, and pipe borne water. Section two focussed on demographic questions of household members including personal characteristics, education and economic activities. Household specific questions, including the characteristics of a household’s dwelling and access to water and sanitation facilities were covered in section three.
Section four concentrated on the main issues regarding the effect of the operations of the two dams on the livelihoods of the people. The targeted respondents in this section were adults aged at least 50 years who lived in the household and who witnessed the construction of the dams themselves, or their parents did. Where there was no adult person of that calibre in the household, a nearby household was used as a replacement. This group of people are believed to have better knowledge about the livelihood conditions, particularly before the construction of the two dams.

**Overview of Downstream Communities**

The socioeconomic impact (positive or negative) of the operations of the two dams on the communities depends largely on their access to basic facilities and infrastructure, the demographic characteristics of households and more importantly, the main source of livelihood of the inhabitants in a particular community. For instance, while farmers and fishermen in the downstream communities will be worried about the effect of the operation of the dams on farm yield and fish catch respectively, seamstresses, traders, carpenters and hairdressers whose activities depend on electricity would see the impact as positive.

**Basic Features of downstream Communities**

Access to social amenities and infrastructure varied across communities. Virtually all communities covered in the study had access to electricity, with very few respondents living in areas in the community where electricity had not reached (Fig. 11.1). Similarly, access to telecommunication was very high in all the communities, with about 94% penetration, while 90% of communities had access to pipe borne water. About three-quarters of the communities had primary and/or Junior High Schools (JHS), with no community having a Senior High School (SHS).

Access to health facilities was quite limited, with less than half of the communities boasting of a health facility (mostly CHIP compounds). Only 40% of the communities had a tarred road passing through or leading to the community, while food markets were virtually nonexistent in the communities. None of the communities had a Police Station or
Police Post, and this could have implications for crime prevention and control. The sanitation situation in the communities was generally poor, with most of the communities resorting to defecation in the bush, in pit latrines and in other forms of public toilet facilities.

![Fig. 1.1: Proportions of basic and social infrastructural facilities](image)

Fig. 11.1: Proportions of basic and social infrastructural facilities

**Characteristics of household and their members**

The characteristics of households and their members provided an indication for assessment of the economic and social status of the community and inhabitants. Table 11.3 presents information about the characteristics of the household and shows that of 340 households, about 75% owned their dwelling while 18% used the dwelling for free and the remaining 6% paid rent for occupying the dwelling. The dwellings of more than 67% of households in communities were relatively decent, with cement/sandcrete walls, while about 21.5% had dwellings with mud/mud bricks, of which 6.5% had burnt brick-walls. About 83% of households lived in cemented-floor dwellings and about 15% had a mud/earth-floor dwelling. While 56% of dwellings were roofed with metal sheet, 23% and 20% were roofed with asbestos and thatch respectively.
Most households had access to electricity and pipe borne water, but access to improved sanitation remains an issue. As shown in Table 3, about 77% of the 340 households had access to electricity in their homes; the remaining 23% resorted to other means such as kerosene, battery and others to provide light for their homes. Similarly, most of the households, specifically 68%, had outdoor pipe borne water as the main source of drinking water, while 15% had pipes in their homes and 17% relied on rivers/ponds/lakes and other means as sources of drinking water. Sanitation was quite poor on account of unorthodox means of disposal of solid and liquid waste.

Table 11.3: Basic Characteristics of Households

<table>
<thead>
<tr>
<th>Ownership of home</th>
<th>%</th>
<th>Floor material</th>
<th>%</th>
<th>Source of drinking water</th>
<th>%</th>
<th>Source of energy/light</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own</td>
<td>75.6</td>
<td>Cement</td>
<td>82.6</td>
<td>Outdoor pipe</td>
<td>67.6</td>
<td>Electricity</td>
<td>77.4</td>
</tr>
<tr>
<td>Rent</td>
<td>6.2</td>
<td>Mud/earth</td>
<td>15.3</td>
<td>Inside pipe</td>
<td>15.3</td>
<td>Kerosene</td>
<td>6.5</td>
</tr>
<tr>
<td>Use for free</td>
<td>18.2</td>
<td>Other</td>
<td>2.1</td>
<td>River/pond/lake</td>
<td>12.7</td>
<td>Battery/other</td>
<td>16.1</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>Total</td>
<td>100</td>
<td>Other</td>
<td>4.4</td>
<td>Total</td>
<td>100</td>
</tr>
<tr>
<td>Sample</td>
<td>340</td>
<td>Sample</td>
<td>340</td>
<td>Sample</td>
<td>340</td>
<td>Sample</td>
<td>340</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wall material for dwelling</th>
<th>%</th>
<th>Roofing material</th>
<th>%</th>
<th>Refuse disposal method</th>
<th>%</th>
<th>Toilet facility used</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement/sandcrete</td>
<td>68.7</td>
<td>Metal sheet</td>
<td>56.2</td>
<td>Public dump</td>
<td>57.5</td>
<td>VIP/KVIP</td>
<td>44.8</td>
</tr>
<tr>
<td>Mud/mud bricks</td>
<td>21.5</td>
<td>Asbestos</td>
<td>23.1</td>
<td>Burned by HH</td>
<td>28.3</td>
<td>None/bush</td>
<td>24.5</td>
</tr>
<tr>
<td>Burnt bricks</td>
<td>6.5</td>
<td>Thatch</td>
<td>19.8</td>
<td>Other</td>
<td>14.2</td>
<td>Pit latrine</td>
<td>17.7</td>
</tr>
<tr>
<td>Other</td>
<td>3.3</td>
<td>Other</td>
<td>0.9</td>
<td>Sample</td>
<td>340</td>
<td>Flush toilet</td>
<td>7.1</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>Total</td>
<td>100</td>
<td>Total</td>
<td>100</td>
<td>Total</td>
<td>100</td>
</tr>
<tr>
<td>Sample</td>
<td>340</td>
<td>Sample</td>
<td>338</td>
<td>Sample</td>
<td>340</td>
<td>Sample</td>
<td>340</td>
</tr>
</tbody>
</table>

Indeed, sanitation was not much different from the situation at the national level, which is far from the MDG target (NDPC, 2010). The major mode of solid waste disposal in the communities was public dumps, with 57.5% of households adopting this means of solid waste disposal. About 28.3% burned their refuse, while 14.2% resorted to other means to dispose of their refuse, such as throwing it into the bush. Faecal waste management by households in the communities was no better, as only 7.1% had flush toilets in their homes. About 25%
of households covered in the survey defecated in the bush and 17.7% used pit latrines.

A total of 1,586 members in 340 households were covered in the survey in the 15 communities, yielding a household size of about 4.7, which was not different from the 4.9 recorded for the population of the communities. Table 11.4 presents key indicators of the characteristics of household members. Females constituted the majority (55.9%) of the total sample, with males accounting for the remaining 44.1%. Children below 15 years accounted for about one-fifth (20.8%) of total household members; young people aged 15-24 years constituted the same proportion. Young adults constituted 14.7% of the total sample compared with 22.7% being adults aged 36-59 years. The old, aged 60 years and above, made up 21% of household members.

Table 11.4: Age Distribution and unemployment and literacy rate of Household members

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Age Distribution</th>
<th>Literacy</th>
<th>Level of education</th>
<th>Male</th>
<th>Female</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>All</td>
<td>All</td>
<td>No education</td>
<td></td>
</tr>
<tr>
<td>0 – 14</td>
<td>23.9</td>
<td>18.4</td>
<td>20.8</td>
<td>n.a.</td>
<td>17.3</td>
<td>39.1</td>
</tr>
<tr>
<td>15 – 24</td>
<td>23.1</td>
<td>19.0</td>
<td>20.8</td>
<td>86.6</td>
<td>17.3</td>
<td>39.1</td>
</tr>
<tr>
<td>25 – 35</td>
<td>14.4</td>
<td>14.9</td>
<td>14.7</td>
<td>71.7</td>
<td>12.1</td>
<td>7.4</td>
</tr>
<tr>
<td>36 – 59</td>
<td>18.3</td>
<td>26.2</td>
<td>22.7</td>
<td>53.9</td>
<td>3.8</td>
<td>2.3</td>
</tr>
<tr>
<td>60+</td>
<td>20.3</td>
<td>21.6</td>
<td>21.0</td>
<td>46.3</td>
<td>0.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Literacy rate in the household was relatively high, especially among young people, and this declined with age. About 87% of young people compared with 72% of young adults and 54% of adults were found to be literate (Table 11.4). Literacy rate was lowest among the old people at 46.3%. Indeed, almost every 2 of 3 individuals aged 15+ could read or write. The survey also revealed that every 3 out of 10 people older than 14 years had never had formal education; 1 out of 2 individuals in this age category had formal education up to the primary or middle/JHS (Table 11.4). About 1 out of 10 had up to secondary education
while those with vocational/technical education accounted for about 3%. Those with Teacher/Nursing training constituted only 0.9% of the working age population; the same proportion had tertiary education.

**Economic Activities of Communities and Households**

Farming is generally the main source of livelihood in the communities followed by fishing and trading, but the pattern varies across districts. As shown in Fig. 11.2, farming is the key source of livelihood of inhabitants in Lower Manya Krobo and North, Central and South Tongu districts, while people in Keta and Ada East districts earned their livelihood mainly from fishing. These two major activities have strong links with the activities of the dam and thus any adverse impact on these economic activities has implications for the incomes and livelihoods of the people.

![Fig. 11.2: Major economic activity by district (%)](image)

Overall, trading was rated the third key important source of livelihood and the main economic activity in Asuogyaman, followed by farming and fishing. During the FGD, some of the communities claimed that trading activities emerged as an alternative to the shrinking fishing and farming activities as a result of the construction of the dams. Mat weaving competed equally with trading as the second dominant economic activity in Ada District after fishing.
The main economic activities engaged in by the workforce of the households sampled were trading, fishing, fish mongering and farming. While fishing and farming were found to be the main economic activity for about 36% and 29% of the male workforce respectively, almost half (i.e. 46.3%) of the female workforce were engaged in trading and one-fifth (i.e. 20.3%) in fish mongering (see Table 11.5). About 14% of the female workforce earned their living from farming, compared with about 29% of the male workforce in the same economic venture. A higher proportion (3.3%) of males than females (1.6%) worked in the public sector while about 16% of the male workforce earned their livelihood as masons, carpenters and drivers, with virtually no females engaged in these types of jobs.

Table 11.5: Main Job of Household members aged 15+ and unemployment rates by age (%)

<table>
<thead>
<tr>
<th>Main Job</th>
<th>Male</th>
<th>Female</th>
<th>All</th>
<th>Age Group</th>
<th>Unemployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farming</td>
<td>28.9</td>
<td>13.9</td>
<td>19.8</td>
<td>Youth (15-24)</td>
<td>21.3</td>
</tr>
<tr>
<td>Fishing and related</td>
<td>35.8</td>
<td>20.3</td>
<td>26.4</td>
<td>Young adults (25-35)</td>
<td>2.6</td>
</tr>
<tr>
<td>Trading</td>
<td>4.5</td>
<td>46.3</td>
<td>29.7</td>
<td>Adults (36-59)</td>
<td>4.1</td>
</tr>
<tr>
<td>Gov’t work</td>
<td>3.3</td>
<td>1.6</td>
<td>2.3</td>
<td>Old 60+</td>
<td>4.4</td>
</tr>
<tr>
<td>Mason</td>
<td>6.1</td>
<td>0</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpentry</td>
<td>5.3</td>
<td>0</td>
<td>2.1</td>
<td>All (15+)</td>
<td>5.4</td>
</tr>
<tr>
<td>Driving</td>
<td>4.5</td>
<td>0.3</td>
<td>1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>11.8</td>
<td>17.7</td>
<td>15.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The problem of unemployment was also quite pervasive in the communities, particularly among the youth. About 21% of the youth (15-24) were found to be unemployed compared with 2.6% of young adults (25-35) and 4.1% of adults (Table 11.5). About 4.4% of the old people above 60 years were also jobless and seeking work. Overall unemployment rate among the working age population (i.e. 15+ years) was estimated at 5.4% compared to the 2013 national unemployment rate of 5.2%.
Socioeconomic implications for construction and operation of the dams

Information about the impact of the construction and operation of the Akosombo and Kpong dams was sought from 426 adults aged above 50 years. About 91% of them were born before the construction of the dam. Most of them claimed to be living witnesses of the communities prior to the construction of the dams, while about a third claimed to have been told by the elderly. Most of the respondents perceived themselves and their livelihood as poor, and this varied across the individual’s economic status. About 69% of the respondents saw themselves and their livelihood as poor, with 24% seeing themselves as being neither poor nor non-poor and only 7% seeing themselves as non-poor (Fig. 11.3). Across economic status, 69% of those engaged in farming as against 59% of fisher-folks and 70% of fishmongers perceived themselves as poor. Surprisingly, 73% of traders considered themselves to be poor compared to 69% of those in other jobs, making trading the job with the highest incidence of perceived poverty. Not surprisingly, the highest incidence of perceived poverty (76%) was reported among the jobless.

**Fig. 11.3: Current livelihood status of residents by economic status (%)**
The general perception about the living condition of downstream communities of the dams points to a poorer livelihood condition now than before the construction of the dams. The effect of the operation of the Akosombo and Kpong dams, as gathered from the interactions at the FGD and Key Informant Interviews, varied across communities and depended on the key economic activities of the community. Some of the communities were relocated to the current location and claimed to have lived better lives relative to what they were experiencing currently. Some of the communities acknowledged the benefit of the operation of the dams in terms of provision of electricity and employment opportunities. One of the communities outlined the benefits from the operation of the two dams to include electricity (which is nationwide), a clinic established by the Volta River Authority (VRA), a tarred road and Akosombo Textile Limited (ATL) that provided employment opportunities for many people in the community. Employment opportunities for electricians were also mentioned during the interaction.

In contrast, participants at the FGD largely perceived the impact of the operation of the dams as negative, mainly in relation to their fishing and farming activities. The concerns raised by the communities varied depending on their proximity to the dam, but generally, most of the concerns were the same for all the communities. Some of the general concerns raised were low fish catches, poor crop yield resulting from low soil fertility and prolific growth of aquatic weeds. The adverse effects outlined by the participants are summarized as follows:

- reduced/low fishing activities and fish catch
- disappearance of special fish species such as tilapia, tiger fish, and oysters
- poor or reduced farming activities and farm yield
- flooding as a result of occasional spillage of the dams
- reduced/vanished oyster picking activity
- water related diseases like bilharzia

In the quantitative survey, of the 426 adults who were asked to rate the socioeconomic conditions now relative to the period before the establishment of the dams, 92% perceived livelihoods to be better before than now as against only 3% who thought the reverse was the case (Fig. 11.4). Only 2% perceived no difference in their personal
livelihood condition and that of their households between now and before, and 3% were unable to draw any comparison.

None of the respondents engaged in farming and fish mongering found current livelihood conditions to be better than before the construction of the dams. Indeed, 99% of farmers and 97% of fishmongers considered current livelihood conditions to be worse than they were prior to the construction of the dams. The remaining 1% of farmers and 3% of fishmongers observed no difference in their current socioeconomic life compared to the period prior to the construction of the dams. In contrast, some respondents in fishing (2.6%), trading (1.5%) and other jobs (5.3%) rated socioeconomic conditions prior to the construction of the dams to be better than current conditions. Nonetheless, about 97% of respondents in trading, 90% in fishing and 88% in other types of jobs considered socioeconomic conditions to have worsened due mainly to the establishment of the two dams. About 5% of respondents in fishing and 3% in other jobs perceived no change in their livelihood.

![Figure 4: Relative livelihood condition before and after construction of the dams (%)](source:Computed from Quantitative Survey dataset)

Surprisingly, a considerable proportion (4.1%) of the jobless perceived livelihood conditions now to be better than before, with 87.6% (lower than those in farming fishing, fish mongering and trading) rating livelihood conditions before the establishment of the dams as better than in 2014 while 2.8% perceived no change in socioeconomic

![Fig. 11.4: Relative livelihood conditions before and after construction of the dams (%)](source:Computed from Quantitative Survey dataset)

247
conditions between now and before. Perhaps the jobless respondents who perceived life as better than before may be relying on other sources of livelihood like remittances or other positive benefits such as electricity, schools and hospitals associated with the construction and operation of the dams.

**Positive Effects of Operation of the Dams**

Clearly, the benefit of the operation of the two dams goes beyond their impact on the inhabitants living in the communities close to the dams. Generation of electricity for the benefit of the entire nation and provision of schools and health facilities that accompany the operation of the dams are benefits that readily come to mind. A question about the benefits of the dams to the individual respondents, their livelihood and the community they live in was posed and 78.3% of respondents identified electricity generation as the key benefit derived from the operation of the dams (Fig. 11.5). Most of the people who did not mention electricity generation as a major positive effect of the operation of the dams on their lives did not have access to electricity.

![Distribution of Benefits](image)

*Fig. 11.5: Benefits associated with the construction and operation of the dams*

Other benefits in the form of irrigation facility, provision of pipe borne water, schools and health facilities, as well as access roads were minimally reported. About 3% identified provision of pipe borne water
while 2% mentioned provision of a health facility associated with the operation of the dams as positive outcomes. About 1% acknowledged an irrigation facility while less than 1% identified provision of schools and access roads. Indeed, as part of the operation of the dams to generate electricity, VRA has established schools and hospitals and provided pipe borne water and access roads for the benefit of its workers and by extension, for surrounding communities.

**Adverse Effects of Operation of the Dams**

The negative effects of the operation of the dams on the socioeconomic condition of individual respondents and their households are largely related to the economic activity they were formerly engaged in. During the qualitative survey, respondents were asked to list the specific adverse consequences the construction and the operation of the dams had created in their socioeconomic lives. The dominant negative effects of the dams’ operation were related to their farming and fishing activities. The greatest adverse consequence of the dams’ operation reported was its effect on fish catch; 38% of respondents stated a drop in fish catch as a major problem the construction and operation of the dams had created (Fig. 11.6).

**Fig. 11.6: Adverse effects of the construction and operation of the dams (%)**

- Drop in fish catch: 37.8%
- Taken away land: 28.6%
- Drop in farm yield: 17.7%
- Periodic flooding: 8.9%
- Threat of ejection: 1.2%
- Other: 5.8%

About 29% of respondents attributed the loss of their land to the construction of the dams, as their creation took away the land they were farming on and thus took away their source of livelihood. A drop in farm yield was mentioned by 18% of respondents as a key negative effect of the operation of the dams on their livelihood while a major worry to about 9% of the respondents was periodic flooding that tended to destroy their farms and domestic property when the dams were opened to spill excess water. The threat of ejection of the community from their present location by operators of the dams was also raised as another major nightmare.
About 29% of respondents attributed the loss of their land to the construction of the dams, as their creation took away the land they were farming on and thus took away their source of livelihood. A drop in farm yield was mentioned by 18% of respondents as a key negative effect of the operation of the dams on their livelihood while a major worry to about 9% of the respondents was periodic flooding that tended to destroy their farms and domestic property when the dams were opened to spill excess water. The threat of ejection of the community from their present location by operators of the dams was also raised as another major nightmare.

Net Socioeconomic effect of Dams’ Construction and Operation

When the negative consequences are weighed against the benefits of the construction and operation of the Akosombo and Kpong dams to downstream communities, the result points to the negative. Overall, about 91.9% of respondents rated the net socioeconomic effect of the construction and operations of the two dams on themselves and the communities as bad or worse; only 3.3% indicated the net effect to be good, while 4.8% found the benefits to have neutralized the adverse consequences (Fig. 11.7). The rating of the net effect varied across jobs, with the least recognition of net positive effect (1.3%) of the construction and operation of the dams having been acknowledged by farmers. The highest recognition of the positive net effect of the dams’ operation was recognized by those in other types of economic activities such as driving, tailoring, carpentry etc. It is expected that carpenters and tailors who rely on electricity for their work would at least recognize the benefits of electricity generation, while farmers and fishermen who may use electricity mostly for domestic activities would rather rate the dams’ operation based on the negative effects on their economic activities.

Indeed, over 90% of farmers, traders and the jobless rated the effect of the construction and operation of the two dams to be bad or worse, with the highest proportion, 99%, having been reported by farmers (Fig. 11.7). Surprisingly, the lowest percentage of the bad or worse effect (79%) of the dams’ operation was reported by fishermen whose activities are directly affected through declining fish catch. The next
group of people with a lower percentage (85%) of bad/worse net effect rating of the operation of the dams was fishmongers. The benefits of the dam ranging from electricity generation to provision of schools, health facilities and access roads were rated higher by fishermen than the other workforce, thus significantly minimizing the negative effects. The highest percentage of the workforce that saw no net effect of the dams’ operation was recorded by fishermen with 18.4%, followed by fishmongers (11.8%). About 6% of respondents engaged in other ventures and 4% of the jobless saw no net effect of the operation of the two dams on their socioeconomic conditions.

![Fig. 11.7: Net effects of the construction and operation of the dams (%)](image)

**Measures to reverse the effects**

Restoring livelihoods of the communities could take many forms. Indeed, some of the fishermen and fishmongers as well as farmers who could not cope with the adverse effects of the operation of the dam had shifted to other activities such as trading and weaving. Others, however, remained in their farming and fishing activities. Some of the communities were relocated as a result of the construction of the dams and it might not be prudent to resettle them in their previous locations.

In the qualitative survey through FGD and Key Informant Interviews, participants made a number of suggestions to improve their worsened livelihood as a result of the establishments of the dams. These include:
• provision of better, appropriate regulation and measuring the spillage of the dams to avoid flooding of their homes and farms;
• removal of weeds grown on the river/lake as these cause low fish catch;
• establishment of irrigation schemes to support farming activities in the communities;
• provision of agricultural extension services for farmers;
• provision of schools and a scholarship scheme to support the education of children;
• vocational and technical training to make the youth employable outside the traditional farming and fishing;
• establishment of clinics to address the health needs of the communities;
• credit support for traders to expand their businesses;
• provision of cold store facilities to preserve bumper harvests of small fish that has replaced the earlier type of catch;
• fish cages for tilapia rearing.

In the quantitative survey, most of the respondents suggested financial support for their economic ventures, as also captured in the qualitative survey. Thus 47% saw financial support as a major boost to their businesses to reverse the worsened effect of the operation of the dams (Figure 8). Those who suggested support for children’s education constituted 19% while 22% had no idea. Only 12% made suggestions about the need to adjust the flow of the dams. Acknowledging the effect of the flow of water on fishing activities, a considerable proportion (19%) of fishermen suggested an adjustment of the flow of water. A quarter of respondents engaged in other jobs recommended adjusting the flow of water to restore livelihoods of the people. Based on this and the fact that about

<table>
<thead>
<tr>
<th>Economic Activity</th>
<th>Farming</th>
<th>Fishing</th>
<th>Fishmongering</th>
<th>Trading</th>
<th>Other</th>
<th>Jobless</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>22.4</td>
<td>13.5</td>
<td>20.6</td>
<td>23.5</td>
<td>13.9</td>
<td>15.8</td>
<td>18.5</td>
</tr>
<tr>
<td>Finance</td>
<td>53.9</td>
<td>48.7</td>
<td>47.1</td>
<td>55.9</td>
<td>38.9</td>
<td>38.6</td>
<td>46.6</td>
</tr>
<tr>
<td>Adjust water flow</td>
<td>5.3</td>
<td>18.9</td>
<td>5.9</td>
<td>4.4</td>
<td>25.0</td>
<td>16.5</td>
<td>12.2</td>
</tr>
<tr>
<td>No idea</td>
<td>18.4</td>
<td>18.9</td>
<td>26.5</td>
<td>16.2</td>
<td>22.2</td>
<td>29.1</td>
<td>22.7</td>
</tr>
</tbody>
</table>

Fig. 11.8: Suggestions to restore livelihood by type of economic activity (%)
survey. Thus 47% saw financial support as a major boost to their businesses to reverse the worsened effect of the operation of the dams (Fig. 11.8). Those who suggested support for children’s education constituted 19% while 22% had no idea. Only 12% made suggestions about the need to adjust the flow of the dams. Acknowledging the effect of the flow of water on fishing activities, a considerable proportion (19%) of fishermen suggested an adjustment of the flow of water. A quarter of respondents engaged in other jobs recommended adjusting the flow of water to restore livelihoods of the people. Based on this and the fact that about 17% of jobless (the third highest) recommended an adjustment of the flow of water, one could infer that the worsened fish catch might have caused such respondents to change jobs (for those engaged in other jobs) or rendered them jobless. In all, financial support as a measure to restore lost livelihoods attracted the highest percentage (49%) regardless of the type of economic activity engaged in by respondents. Support for children’s education was strongly recommended by farmers, traders and fishmongers after financial support as a key livelihood restoration measure.

**Conclusion and Policy recommendations**

Generally, the benefits of the construction and operation of the Akosombo and Kpong dams at the community and national levels are not in doubt. The direct benefits, which include power generation and irrigation facility and the indirect benefits in terms of employment generation, provision of schools, hospitals and access roads as well as economic growth are clearly documented. However, the general impression from the downstream communities’ points to the negative. The positive effects associated with the construction and operation of the two dams at the community and national levels seem to have been overshadowed by the adverse consequence of the dams’ operation on the farming and fishing activities of the community. Most inhabitants in the downstream communities of the dams rated the net effect of the operation of the two dams to be negative, pointing to reduced fish catch and farm yield and occasional flooding, among others. In the view of the communities, restoring their livelihood would require financial support for their farming, fishing and trading activities, scholarships to support their children’s education and a readjustment of the flow of
water to reverse the reduced fish catch believed to be a consequence of the operation of the dams.

The full benefit of the operation of the two dams at the community and national level could be optimised through interventions that do not only address the negative impact of the dams in relation to the farming and fishing activities of the communities, but also to create alternative employment opportunities that could reduce the high dependence of the community on the dams for their livelihood. Roads leading to or passing through most downstream communities are not tarred and in most cases not in good shape; thus the provision of good quality roads would open up the communities and help create non-agricultural jobs that are not directly linked to the flow of the dams. More basic schools with adequate numbers of teachers and senior high schools and vocational training institutions would put the youth in a better position to access non-agricultural employment to minimise the dependency of the community on the dam as the only source of livelihood. To address the problem of flooding and to ensure better and efficient flow of water from the dams for use by downstream communities requires deliberate intervention by the government.

References


CHAPTER TWELVE

RE-OPERATION AND RE-OPTIMISATION OF AKOSOMBO AND KPONG DAMS - ENGAGING DOWNSTREAM COMMUNITIES IN RE-OPERATION SCENARIO OPTIONS

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Abstract

The Akosombo and the Kpong Hydroelectric Dams were built in the 1960s and the 1980s respectively. The purpose of the dams was to accelerate the development of Ghana. However, the building of the dams affected the socio-economic lives, as well as the ecology of the riparian communities. Thus, efforts have been made over the years to improve the livelihoods of the communities downstream. However, it is important that the communities are part of the planning of any interventions. This paper seeks to examine the preferences of downstream communities regarding dam re-optimisation scenarios. A total of 283 participants from 99 communities in eight districts took part in the study. Three scenarios were presented to the communities and they were asked to indicate their preference and the reasons for their choice. The findings indicate that the most pressing challenge of the communities is the prolific growth of aquatic weeds on the river which demands urgent attention. Taking into consideration the fact that the
communities consist of different interest groups, an intervention must attempt to address the various needs of the different stakeholders.

**Keywords:** Dams, Downstream communities, Re-optimisation, Scenarios, Volta River

**Introduction**

According to the World Commission on Dams, over 45,000 large dams have been built in 160 countries, about two thirds of them in developing countries (WCD, 2000). These dams were designed to bring economic and social development to the populations. One of the major uses of the dams is hydroelectric power (HEP). Over fifty percent of all dams built in Africa are meant for hydroelectric production (Skinner *et al.*, 2009). In many countries, especially in Central America and Sub-Saharan Africa, over half of all electricity generated comes from HEP (Anderson *et al.*, 2006; Gyau-Boakye, 2001). Hydroelectric power (HEP) is an important source of energy, especially in the tropics, since it has facilitated the development of many towns and villages. In spite of the importance of dams, they have endangered the livelihoods of communities that depend on the rivers and floodplains for their nutrition and livelihoods (Bazin *et al.*, 2011; Gwazani *et al.*, 2012; Obour *et al.*, 2016). Furthermore, they have caused damage to ecosystems such as damaging freshwater systems and estuarine ecosystems that support human production systems (Thomas, 2005).

The Akosombo and Kpong Hydroelectric Dams were built in the 1960s and 1980s respectively to provide power that will serve Ghana’s domestic and industrial needs. The reservoir that was created by the Akosombo Dam was touted as the largest man-made lake in the world. While the establishment of the two dams has increased water transportation, tourism and fishing, among others, it came at a high cost to communities along the Volta River, both upstream and downstream. The impoundment of the dams has resulted in significant modification in the existing ecological and biophysical processes (Fobil and Attuquayefio, 2003). Some communities lost their ancestral lands and had to be resettled in other communities. Furthermore, the social and economic lives of the people were affected. This has led to poverty,
inequality, diseases and ecosystems destabilization (Gyau-Boakye, 2001; Miescher, 2012; Tsikata, 2006).

Scientists believe that the damage caused by the establishment of the dams is unnecessary and can be reversed by modifying the operations of the dams in a way that would not significantly reduce—it may even enhance—their power generation, irrigation and flood control benefits (Thomas, 2005). Re-optimisation and re-operation are concepts that seek to implement a flow pattern that more closely mimics the natural variability in flows, re-create artificial flood, recharge the aquifer and convert dams to ‘run-of-the-river’ operations (Thomas, 2005). Richter and Thomas (2007) are also of the view that re-operation of the dams can bring potential benefits including reactivation of floodplain forests and a balance of river erosion and sedimentation which shape the physical habitat complex. Thus, the Akosombo Re-optimisation and Re-operation Project seeks to manipulate the operation of the dams to achieve greater efficiency and help transform the lives of people who live downstream. This will further stimulate economic growth and reduce poverty through restoration of food systems and ecosystems.

Development experts have long suggested that development decisions should be a bottom-up approach and not a top-down one. This is a departure from the 1960s where development was elitist. Development was planned by the elites in the cities and introduced into the communities. This approach to development was not effective. There were instances where people did not utilise the development projects introduced into their communities. In order to make development more meaningful to people for whom it is intended, there is the need to include them in the planning, implementation and management of the process. When communities are involved in the development process, they will own the project and even manage it. It is in view of this that some development agents such as the World Bank and African Development Bank (ADB) set up guidelines for their development partners. Among these are the involvement of communities in their own development projects. In line with the above, consultations were held with the downstream communities to create awareness and seek their input concerning the re-operation and re-optimisation of the Akosombo and Kpong dams. The purpose of this paper is to describe the preferences of the downstream communities and explain the reasons for their preference.
Methods of Data Collection

In line with the idea of involving communities in the planning and execution of development projects, there was the need to adopt a methodology that will include the affected communities. Thus, the transformative scenario planning method was adopted. The transformative scenario planning allows people who want a change to transform their situation through constructing scenarios of possible futures for a situation (Kahane, 2012). The approach involves identifying the problems and then developing scenarios for the communities to make informed choices. In the approach, all actors involved in the situation (the beneficiary or affected communities and development partners) are included in the planning and execution of the project. Invariably, the approach involves holding consultations with communities, drawing future scenarios with them and looking at which one best suits their situation. In this study, three scenarios had been developed already (Mul et al., 2017); the participants discussed the advantages and disadvantages of each scenario and their preferred choice.

The Sample

According to the Volta River Authority’s Emergency Preparedness Plan Report of 2010 (VRA, 2010), there were at the time 437 communities downstream of the Akosombo dam. These communities are situated within the Eastern, Greater Accra and the Volta Regions of Ghana. Communities were selected based on their location along the Volta River—right from the dam at Akosombo to the estuary at Ada. Thus, while some of the communities such as Keta were a little farther away from the dam, others were very close to it. This was to allow for different geographic areas, occupations and experiences in the sample.

A reconnaissance visit was made to the districts that were earmarked for the study. The team met with chiefs, opinion leaders or assemblymen/women and the project was introduced to them. They were asked to nominate three people who would represent the community at the district level. The criteria were that each participant must be above 18 and willing to take part in the meetings. In each district, the representatives from the communities met at one place—in most cases
in the district capital. The team provided the communities with the date, time and venue for the meetings. The community consultations took place between January 26 and February 5, 2016. A total of one hundred communities from eight districts were selected for the study. Of these, ninety-nine communities participated in the study. In all, 283 individuals participated in the study.

**The Procedure for the consultative meetings**

The instrument used for data collection was a semi-structured interview guide. The team introduced and explained the scenarios to the participants. The participants were then invited to comment on each scenario by indicating the impact of each for various activities such as farming, fishing, diseases, tourism, irrigation, aquatic weeds and trading. They were then asked to indicate their preferred choice and the reasons for the choice. In some instances, the participants were unanimous in their preferred choice, and where there was no consensus, a vote was taken. The preferred choice was then declared based on a simple majority.

**The Scenarios**

As explained above, the goal of the re-operation and re-optimisation of the Akosombo and Kpong dams is to modify the flow of the dam to mimic the original flow of the river. In view of this, various scenarios consisting of different flow regimes had been developed by the International Water Management Institute (IWMI). The four scenarios developed by IWMI (Mul et al., 2017) are:

- Scenario 1 (S1): Maximizing hydropower generation by maintaining the current flow
- Scenario 2 (S2): Reinstating the current flow dynamics up to the 2010 spillway levels
- Scenario 3 (S3): Maintaining sufficient water for irrigation while introducing natural flow
- Scenario 4 (S4): Maximizing ecosystem services by introducing natural flow
Three scenarios were used for the study, scenarios 1, 2 and 4. Scenario 3, which is maintaining sufficient water for dry season irrigation while reintroducing the natural flow regime, was not included in the scenario options used for the consultations. The challenge was that participants found it difficult to appreciate and understand scenario 3 as it was similar to scenario 4. This scenario would be easier to explain quantitatively (that is, with the use of graphs) but not qualitatively. Taking into consideration the fact that the majority of the participants could not read graphs, the team made up for the shortfall by including questions on irrigation in the discussions. In scenario 1 which is maintaining the current flow levels, the participants were asked to indicate the impact of the current levels of the river on their socio-economic activities. Scenario 2 is reinstating the natural flow dynamics up to the 2010 spillway levels. In 2010, heavy rainfall forced VRA to open the spillways of the dam. This caused massive flooding of communities downstream. The participants were asked to indicate the impact on their livelihoods if the dam were modified up to the 2010 spillway levels. The last scenario used is the introduction of the natural flow regime. Again, participants were asked to indicate the impact on their livelihoods if the natural flow of the river were introduced.

Limitations

The discussions were conducted in the local languages—Ewe, Adangme and Twi. The team was fortunate to have one of its members being fluent in all the local languages used. The challenge, however, was how to translate some of the words in the discussion guide into the local languages. For instance, the team found it difficult to translate words such as ‘re-optimisation’, ‘re-operation’ and ‘scenarios’ into the local languages. Instead, the team went round this by explaining what the purpose of the project is. Again, explaining scenario 4, which is maximising the ecosystem services by introducing the natural flow regime, was a major problem. We explained this by comparing the natural flow regime with the pre-dam flows. Interestingly, some of the participants were young or even not born before the dam was impounded and therefore did not witness the pre-dam flows. What they knew was what the older generation had told them. This may have affected the responses for scenario 4. That is not to say that oral history
is not credible. Nevertheless, we did realise that with scenario 4, they reminisced on the past and envisaged that the effect on their socio-economic activities would be generally positive. This notwithstanding, the team made the effort to let the participants understand the scenarios.

Findings and Discussion

Below, we present the findings of the study. We start by discussing the implications of each scenario on their activities and end with the preferred scenario.

Scenario One (S1): Current Flow Regime

At the time of the data collection, the water level in the dam was low. This was due to low levels of rainfall experienced across the country in recent years. This impacted negatively on power generation and only two turbines were working. The country went through a massive power crisis. Generally, most of the responses to this scenario were negative and far outweighed the positive responses. In fact, all the challenges experienced in the communities were blamed on the current flow of the river.

Crop farming

The participants indicated that the current flow regime is not beneficial to crop farming. They were of the view that crop farming has collapsed due to inadequate rainfall and soil salinity. For instance, participants from Keta claimed that shallots, sugar cane, pepper, okro and cassava used to fare well in the pre-dam period. However, there was high soil salinity, which had reduced crop yields. Participants from Kpordzi in the Keta district also complained that the straw used for weaving mats did not thrive well in their community any longer. They mentioned that the women had to travel about five miles before they could get some of the straw to harvest. This, they claimed, had affected the mat weaving industry, which was very lucrative for the women. This is what a participant from Keta said:
Now there is no freshwater. When we dig a well to pump water to water our plants, the plants die because the water is salty. Tomatoes, pepper, shallot, sugarcane and maize used to do very well in this town. But now nothing grows here.

However, participants from communities where irrigation facilities were available, such as the Shai Osudoku and Central Tongu districts, viewed the current flow regime positively. They observed that the irrigation project enabled them to engage in all year farming and that they were able to plant rice and vegetables, which was not possible under the pre-dam flows. The irrigation project, they believe, has provided employment for the people and therefore the current flow regime should be maintained.

**Fishing**

The general concern shared by almost all the participants is the collapse of the fishing industry under the current flow regime. Participants from Keta to Ada at the estuary all complained about the collapse of the fishing industry. They explained that some fish species as well as oysters and clams were no longer available. This was how a participant from Bakpa put it:

*Due to the fact that the current flow of the river is low, the clams have moved to Ada. Previously we sold the clams and the shells as well. But currently, we don’t catch anything here.*

Apart from the slow flow of the river, participants also blamed the low fish yield on the growth of aquatic weeds. They argued that their fishing nets get entangled among the weeds and are destroyed. They also claimed that a lot of the fish are stuck upstream because of the creation of the dam. The implication is that some fish species which used to be available were no longer obtainable.

**Cage farming**

The participants were of the view that fish farming is of recent origin. They admitted that the current flow had encouraged fish farming which was more organised now than it was previously. This has been a source
of employment for the youth. Some communities were however of the view that it is the wealthy people in the communities who benefit from fish farming because they had the resources to invest in such a venture.

**Weeds**

The presence of aquatic weeds on the river seems to be the biggest challenge facing the riverine communities since almost all the participants complained about it. Some participants called it the ‘devil’s weeds’, while others said the weeds were poisonous. At the meeting with communities in the Asuogyaman district, a participant, who said he was a fisherman, brought some of the weeds to the meeting. He claimed that the particular weed he brought was a submerged plant which could not easily be detected. According to them, the aquatic weeds have made fishing difficult, because their nets are almost always getting entangled in the weeds, which causes them to tear. Apart from that, the fish hide in the weeds, leading to low catch. The aquatic weeds also serve as breeding grounds for snakes, especially in the Central Tongu district where participants complained about the invasion of pythons and other snake species in their communities. They alleged that the snakes hide beneath the weeds and bite people when they swim in the river. Some of these snakes even find their way into their dwellings. Another challenge the participants identified was their inability to retrieve dead bodies from the river. According to them, previously, bodies were washed ashore after some rituals were performed. However, the weeds have made it impossible for bodies to be washed ashore even after the performance of the rituals.

**Health**

Water borne diseases were a major concern of the participants. The major water borne diseases mentioned by participants included schistosomiasis and skin diseases, especially itching. According to them these water borne diseases are a result of the invasion of aquatic weeds on the river. They claimed the vectors for the transmission of these diseases hide in the weeds. People then get infected when they swim in the river. This observation of the communities has been documented by other studies, which indicates the dramatic increase in schistosomiasis and malaria (Yirenya-Tawiah et al., 2017).
CHAPTER 12

Employment opportunities

The participants envisaged that employment opportunities would continue to reduce if the current flow persists. The decline in employment opportunities was linked to low crop yields and the decline of clams and oysters in some communities. For instance, participants from the Keta and Sogakope districts revealed that there used to be a vibrant clam industry in their communities but that this had declined, resulting in loss of employment for people who pick the clams. This had further affected trading activities in the communities. Only a few communities reported that the current flow level had provided them with employment opportunities. For instance, some of the participants from the Manya Krobo district reported that alternative livelihood sources had been introduced with the establishment of irrigation. Irrigation had made all year farming possible. Typical examples were the rice farms at Asutuare and its environs. Furthermore, the emergence of cage fishing had also provided some of the people with employment. Other effects of the current flow regime include the establishment of tourism facilities such as hotels which provide employment opportunities for the youth.

Others

Some communities also reported that their creeks, ponds and streams had dried up, as there was not enough flooding to fill up the creeks. Furthermore, some of the participants complained about the high rate of teenage pregnancy in their communities. For instance, some participants from the Dangme East, Central Tongu and North Tongu complained that teenage pregnancy was high because of the unavailability of employment opportunities for the youth. There were also complaints about migration of people to other parts of the country. Some participants from Central Tongu and North Tongu reported that many people had migrated to Yeji and Daboya to work there and this had resulted in broken homes and poverty, as some people had left their families, especially children, to fend for themselves.
Scenario Two (S2): Maintaining Flow up to the 2010 Spill Levels

As explained elsewhere, in 2010 there was a spillage by the VRA. There was increased rainfall that year which necessitated that action. Participants were asked to indicate how a flow like the 2010 levels would impact their lives. The responses were generally positive. Below are details of the responses from participants.

Crop farming

Some communities downstream reported that their farms were flooded during the 2010 spillage and so they anticipated that the same thing would happen if the water levels went up to the 2010 spill levels. In spite of the flooding of their farms, they expect their crop yields to improve, as the receding floods would leave alluvial deposits on the lands. Communities from the Keta district reported that they were not directly affected by the 2010 spillage. However, the creeks, ponds and streams would be filled up, which would improve fishing. Further, the filled-up streams and creeks would provide them with fresh water for drinking.

Fishing

Participants reported that there was a bumper harvest during the 2010 spillage, so they expect fishing to improve. They expect the speed of the river to increase, which would in turn enable the oysters, clams, crabs and newer fish species to travel up-stream. They believed that the creeks, streams and ponds would be filled with water and support fishes.

Cage Fishing

The participants reported that some cages were washed away during the 2010 spillage. In view of this, they envisaged that cage fishing would reduce. In spite of this, they contended that fish farmers would benefit, in that the fish become active when the speed of the river is swift. The participants asked that adequate warnings be given to fish farmers before a spillage so they can reinforce their cages.
Aquatic weeds

They predicted that the growth of aquatic weeds would reduce, in the sense that the weeds would be washed away with the swift current, as was the case during the 2010 spillage. Furthermore, there would be an influx of seawater that would destroy the weeds.

Health

Participants were of the view that water borne diseases would reduce greatly. This will come about when the aquatic weeds are carried away by the swift currents.

Irrigation

The need for irrigation, they reasoned, would reduce. Farmlands would be flooded with the spillage so there would be no need for irrigation. For instance, participants from the Lower Manya Krobo district reported that their farmlands and houses, which were closer to the river banks, were flooded during the 2010 spillage and said they believed the same could happen if the water level went up. Participants from the Keta district indicated that though they would not be directly affected by water levels up to the 2010 spillage, their creeks, streams and ponds would be full, which would in turn cause the high salinity of the soil to reduce. A reduction in the salinity of the soil would mean that they would get fresh water from hand-dug wells to water their farms.

Others

Other effects they foresaw were that their boats and canoes would be carried away while boat accidents would be common. The participants reported that the 2010 spillage was the first time they witnessed flooding and as a result many of them did not know how to navigate the river. This resulted in boat accidents and boats being carried away by the floods. They therefore perceived that water levels up to the 2010 spillage might cause some accidents. Moreover, they admitted that their houses would be destroyed as some people had built close to the river and in the valley, which made them susceptible to floods. In
addition, they perceived soil erosion would occur and lives might be lost due to flooding.

**Scenario Four (S4): Introducing the Natural Flow Regime**

Participants were asked to indicate how introducing the natural flow of the river would affect their socio-economic activities and the ecosystem. Generally, participants thought that if the natural flow regime was introduced, it would affect their lives positively.

**Crop farming**

The participants were of the view that restoring the flow of the river to its natural state would improve food farming in general. They also mentioned that there would be flooding during the raining season and this would make their flood plains fertile, thereby improving crop yields. This is supported by Ayivor and Kufogbe (2001) who note that the seasonal floods of the Volta River that supported flood-recession agriculture were lost after the damming of the river. This has adversely affected the traditional system of farming that was practised by downstream farmers. Furthermore, they also anticipated that the size of the lake would reduce if the natural flow regime was introduced, which would free up some of the lands that are covered by the water for farming. Participants from the Asuogyaman and Lower Manya districts claimed that currently big rocks were buried in the riverbed. They argued that if the speed of the river increased and the river shrank, people could walk on these stones to cross over to their farms. Currently, they have to wait for the fishermen to return from fishing trips before they can use their boats to visit their farms. If the stones were visible, they would be able to go to their farms whenever they wanted, without having to wait for the fisher folks to return from fishing.

**Fishing**

It was evident from the discussions that fishing was one of the main economic activities of the downstream communities. The majority of the participants envisaged that fishing would greatly improve if the
natural flow regime was introduced. The participants suggested that the speed of the flow of the river would increase if the natural flow was introduced. They thus drew a relationship between the flow of the river and fish stock, arguing that when the flow is swift, the fish are able to move upstream. Furthermore, they believed that the streams, creeks and tributaries would all be filled with water, which would definitely increase the fish stock. Some participants, such as those from Keta, Central Tongu, North Tongu and South Tongu districts, were of the view that the fishing industry which had collapsed would be revived. They claimed that clams, shrimps and oysters used to be abundant and were their main source of livelihoods before the river was impounded. Ofori et al. (2013) attribute the decline in volume and size of the catch to modifications of the habitats through land clearing for farming, mangrove harvesting and estate development as well as over-exploitation within the lower Volta Delta.

**Cage Fishing**

The participants admitted that there was no cage fishing in the pre-dam era. However, they believed that cage fishing would be greatly enhanced if the natural flow was introduced. Currently, aquatic weeds have covered a greater part of the river’s surface. They claimed that the weeds had invaded some of the fish cages and believed that the weeds would be washed away if the speed of the river was increased. Moreover, the fish would be able to swim better if the current was swift. They also held the view that the dried up creeks and streams would be filled with water, which would enable them to trap more fish, thereby encouraging traditional cage farming.

**Aquatic Weeds**

The invasion of aquatic weeds on the river was of serious concern to the participants. The participants were strongly of the view that the aquatic weeds would be washed away if the speed of the river was increased.
Tourism

Some of the participants expressed the view that tourism would improve because some of the tourist facilities had speedboats and that patrons would better enjoy their rides if the speed of the river was swift. This would increase tourist inflows to their communities. Some of them however indicated that their communities do not directly benefit from tourism, and that it is the owners and operators of the hotels who would benefit from improved tourism. Others, on the other hand, thought that their communities would appear on the tourist map of Ghana.

Health

The participants believed that the health of the inhabitants of the area would improve. At the time of the study, they suffered from water borne diseases such as schistosomiasis and skin diseases, especially itching. These, they believed, would greatly reduce if the natural flow of the river was introduced.

Employment Opportunities

The participants envisioned that employment opportunities for communities along the lake would improve greatly if the natural flow was introduced. This, they believed, would come about if fishing, which was the main source of livelihood, was improved. For instance, participants indicated that Akuse, which used to be a landing port, would be restored, which would in turn improve trading activities among communities. Similarly, the big marketing centres such as Sogakope and Keta would bounce back. Improved trading, they claimed, would provide employment for the women who were engaged mostly in trading. When fishing is lucrative it will attract the youth into fishing.

Others

Some participants anticipated that access to fresh water would improve, which would in turn lead to an improvement in drinking water. One negative impact of the natural flow identified by the participants was
soil erosion on their farms and dwelling places. Also, participants from Dangme East envisaged that soil sediments would be washed away, and this would enable seawater to intrude into the river, which would in turn kill some aquatic weeds and snail vectors that introduce water borne diseases, while introducing new fish species into the river.

Preferred Scenario

The discussions above focussed on how the different scenarios would impact on the socio-economic activities of the people. In some instances, the preferred scenario was arrived at by consensus. In others, it was arrived at after a vote by the show of hands. At the end of the discussions, scenario two was the most preferred option of the participants. Of the eight participating districts, five preferred Scenario 2 (S2), which is the 2010 spill levels; two preferred Scenario 4 (S4), which is introducing the natural flow levels; and one community preferred Scenario 1 (S1), which is the current flow level. The districts that preferred Scenario 2 were Keta, North Tongu, South Tongu, Shai Osudoku and Dangme East, while Central Tongu and Asuogyaman preferred Scenario 4. The Lower Manya Krobo district preferred Scenario 1.

The basis of the preference for Scenario 2 was that this scenario can be modified to suit the needs of the community better than the other scenarios. While some advocated for a biannual spillage, others were in favour of an annual one. Further, some advocated that the spillage should last for a week or two. Nevertheless, the participants requested that they should be informed ahead of time, possibly three months before spilling. In addition, participants requested that the river-bed should be dredged before spillage. According to them, the dredging would increase the river depth to allow more water to fill the river so as to reduce flooding. On the other hand, those who preferred Scenario 4 based their preference on the view that the natural flow would allow them more lands for farming and also reduce water borne diseases while increasing their fish stock. The only district that preferred Scenario 1 was the Lower Manya Krobo district. This was in spite of the negative attitudes they had towards this scenario. However, they believed that Scenario 1 offered them more opportunities for cage fishing than Scenarios 2 and 4.
The data suggest that participants prefer the scenario that will flush out the aquatic weeds, reduce schitosomiasis and salinity, and allow sea water to intrude into the river system. Having said that, the question is whether the preferred scenario is feasible. The preferred scenario is practicable only to the extent that there is enough rainfall to allow VRA to spill, as is the case in Burkina Faso. Over the past five years, the Bagre dam, which is part of the Volta Basin, has been opened, causing floods in Ghana. The spill was necessitated because there was too much water in the catchment area of the dam. Thus, for VRA to spill, there should also be abundant water in the catchment area. In recent years, the rainfall pattern in Ghana has been quite low, and this has been blamed on the adverse effects of climate change. Hans and Karsten (2005) postulate that the ecological effects associated with the damming of the river have contributed to low rainfall in the catchment area. They note that if the current climatic conditions improve, rainfall will increase and allow for an improved flow regime. Others have also blamed the current flow of the river on the degradation of the environment. Indeed, some participants blamed the current flow regime on indiscriminate felling of trees and the throwing of rubbish into the river.

**Conclusions**

The study indicates that the lives of the downstream communities as well as the ecosystem have been altered by the creation of the dams. It is not only the socio-economic livelihoods of the people which have been adversely affected, but the whole ecology of the area. The natural floods that occurred before the dam was impounded allowed for recessional farming and the catching of fish as well as clams and shrimps. Similar occurrences have been reported in other countries with big dams (Bazin et al., 2011; Gwazani et al., 2012). The findings of the study indicate that implementing the preferred scenario of the communities would be challenging, as there were competing interests among the communities. While some communities preferred the 2010 spillage, others preferred the natural flow. Only a few preferred the current regime. Furthermore, there were competing interests even within the same community. For example, there were different views expressed between small-holder farmers and commercial farmers, between irrigation farmers and those in rain-fed agriculture, and between participants in traditional
fishing and those in cage fishing. Satisfying all stakeholders would be a great challenge. Whatever option that is decided on must be through consensus, so that none of the stakeholders feel that a particular option has been imposed on them.

References


CHAPTER THIRTEEN

THE ECONOMICS OF RE-OPERATING THE AKOSOMBO AND KPONG HYDROPOWER DAMS

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Abstract

This chapter presents a cost-benefit analysis of four alternative re-operation scenarios for the Akosombo and Kpong dams in Ghana to evaluate the economics of dam re-operation. The construction of the Akosombo and Kpong Dams for hydropower production has contributed significantly to the economic development of Ghana and other riparian countries. The dams provide more than 70% of the national demand of electricity in Ghana. The dams also generate additional local benefits such as lake transportation, increased fishing, new farming activities along the shoreline, and tourism. However, the construction and operation of the dams have changed the downstream flow regime from a highly dynamic one towards a steady flow regime to optimize the production of hydropower and irrigation potential, affecting the downstream ecosystems and ecosystem services that are dependent on the dynamic flow regime. The focus on hydropower generation has come at a cost for local communities and their livelihoods. In recent times, re-operating dams has gained interest for restoring downstream ecosystems and improving the livelihoods of riparian communities. The study evaluated the economic costs and benefits of 12 ecosystem component in re-operating the Akosombo and Kpong dams according to four flow scenarios. Results show that the current flow regime is
very beneficial for hydropower, aquaculture and large scale irrigation and also has the highest net present value (NPV). Though restoring natural flow conditions will contribute more towards improving rural livelihoods such as fisheries and flood recession farming, it has the lowest NPV and hence is economically inefficient. The potential of the current regime should be geared towards improving large scale irrigation and aquaculture to benefit local communities. Again, efforts should be made to address the issues of aquatic weeds and water borne diseases such as bilharzia.

**Keywords:** Dam re-operation, Ecosystem services, Cost-benefit analysis, Akosombo, Ghana

**Introduction**

The construction of the Akosombo and Kpong dams for hydropower production in Ghana has contributed significantly towards economic development in Ghana as well as in the neighboring countries in West Africa. More than five decades after its construction, the Akosombo dam, together with the Kpong dam, still constitutes the major source of electric energy in Ghana. The construction and operation of the dams has changed the downstream flow regime from a highly dynamic one towards a steady flow regime to optimize the production of hydropower. This has affected the downstream ecosystems and the flow of multiple ecosystem services that are dependent on this dynamic flow regime. The focus on hydropower generation which is of significant national interest has come at a cost to the local communities and their livelihoods.

Recently, re-operating dams, changing the operation of dams to support the restoration of downstream ecosystems and improving the livelihoods of riparian communities has gained interest (Richter and Thomas, 2007). However, most studies remain conceptual and only a few studies have incorporated the potential for improving downstream ecosystems as well as augmenting hydropower production through an increase in the efficiency of hydropower generation, which can be achieved by maintaining high water levels throughout the year. More importantly, there is a lack of evidence on the actual cost and benefits
for informed decisions on whether or not to engage in re-operating large scale hydropower dams.

This chapter looks at the economics of re-operating dams to complement the social and environmental aspects of re-operation considered in other chapters (Mul et al., 2017; Baah-Boateng et al., 2017; Ohemeng et al., 2017). It however targets the economics of environmental flow effects on ecosystem services and other components in its methodology. Specifically, it adopts the output of the positive and negative effects of the proposed dam re-operation scenarios on identified ecosystem services from Mul et al. (2016), uses both market and non-market valuation approaches to estimate the costs and the benefits and then performs a cost-benefit analysis on the different flow scenarios.

**Dam re-operation scenarios**

Four dam re-operation scenarios or flow regimes were developed for hydrological modelling and economic analysis. The scenarios present different flow distributions over the year to support different economic and livelihood activities. The brief descriptions of the four scenarios are given below. For the detailed descriptions of the four scenarios and the corresponding hydrographs (Mul et al., 2017).

- **Scenario 1: Current flow regime**
  This scenario is based on the current flow regime where flows are based on the hydropower requirement from the Akosombo dam. This constitutes a steady flow regime with approximate flow of 1,000 m$^3$/s.

- **Scenario 2: 2010 spillway levels**
  This scenario is based on the flow levels of the 2010 flood season where 2,300 m$^3$/s was recorded in the wet season, whereas river flows for the dry season reduced to 700 m$^3$/s.

- **Scenario 3: Maintaining sufficient water for dry season irrigation**
  This scenario assumes a flow of 500 m$^3$/s during the dry season and a peak flow of 3,000 m$^3$/s in the wet season. Wet season flows are geared towards minimizing the effect of the changed flow regime on irrigation, by limiting saltwater intrusion to acceptable distance and avoiding flooding of irrigated areas. This
scenario allows for limited flooding of adjoining lands, including connecting some of the creeks with the main river.

- **Scenario 4: Natural flow regime**
  This scenario assumes flow similar to pre-dam conditions i.e., an average peak flow of 5,000 m$^3$/s and a dry season flow of 50 m$^3$/s. This scenario provides conducive environments for controlling the invasive aquatic weeds and fisheries (incl. clam production). It entails high wet season flow that inundates creeks and floodplains, helping fishes to spawn. On the other hand, low flow during the dry season will increase saltwater intrusion, supporting clam production in more areas and reducing the area of weed cover.

## Methodology

### Cost-benefit analysis

Cost-benefit analysis (CBA) is an applied economic tool often used to guide resource allocations, investments or policy decisions. It is a technique that is used to estimate and sum up the present values of future flows of benefits and costs associated with resource allocation decisions or policy alternatives. CBA is intended to establish the worthiness of undertaking the stipulated alternative and to inform the decision maker about the economic efficiency of the stipulated option. In situations where benefits and costs of an action spread over time, decisions are based on comparing the present values of benefit and cost flows. With regard to decisions related to natural resources management choices, the role of CBA is to measure the benefits and costs of the different options and consequently to enable the comparison of the system with the proposed change, on the one hand, and without the change, on the other (Clark, 1996; Pearce *et al.*, 2006).

However, applying CBA in environmental decisions involves various challenges (Pearce *et al.*, 2006; Bateman *et al.*, 2011). One major challenge arises from the fact that many environmental goods and services are *not traded* directly in market transactions. Hence, attaching monetary values to them becomes difficult (Gittinger, 1982;
Bateman et al., 2011). Another major controversy is the choice of the discount rate for converting future benefits and costs into present values (called ‘discounting’). As ecosystem functions are complex and some environmental changes are irreversible, the choice of the discount rate is not as simple as in private business investment decisions. From an economic point of view, the discount rate should reflect the decision maker’s time preference. Choosing a relevant time horizon from the perspective of various stakeholders is another important consideration.

Various decision criteria can be used in CBA. However, the net present value (NPV) and internal rate of return (IRR) are the most common ones. NPV is defined as the difference between the sum total of the present value of benefit streams and that of cost streams over the life of the project. Equation 13.1 presents the mathematical expression of the NPV computation. Projects with positive NPV are accepted while projects with negative NPV are rejected.

\[
NPV = \frac{\sum_{t=0}^{T} B_t}{(1+d)^t} - \frac{\sum_{t=0}^{T} C_t}{(1+d)^t} = \sum_{t=0}^{T} \left[ (B_t - C_t)(1+d)^{-t} \right]
\]  

\(B_t\) = value of benefit streams in period ‘t’ (i.e., cash flow benefits at each period)

\(C_t\) = value of cost streams in period ‘t’ (i.e., cash flow of costs at each period)

d = discount rate

t = time periods (usually in years) \((t = 1, 2, \ldots T)\) where ‘T’ is the life span of the project.

The IRR is defined as the discount rate that needs to be applied to generate an NPV value of zero. In a business world, IRR computes the break-even rate of return showing the discount rate, below which an investment results in a positive NPV. Using the IRR criterion, accept a project if its IRR exceeds the cost of capital (i.e., the return from the capital if invested elsewhere) and reject it if the IRR is less than the cost of capital. However, IRR is not commonly used in environmental decisions (Juhász, 2011).
Fig. 13.1 indicates the schematic framework of a decision process in which two alternative course of actions are compared and how CBA can help the decision-maker determine whether or not to undertake the re-optimisation decision.

**Fig. 13.1: The ‘with and without’ approach to CBA of dam re-optimisation**
Annual cash flows for the period (2015-2050) were derived from the base year value estimates using a series of Consumer Price Index (CPI) over a period of 35 years. This time horizon was chosen to align with the hydrological modelling projection timeline (Annor et al., 2016). The CPI series used for generating future flow of value estimates was based on the average long term CPI data from the Ghana Statistical Authority, which shows that on average CPI doubles every ten years (GSS, 2015). The cost-benefit analysis focusses on the economic, ecosystem and human health impacts of the various dam re-operation scenarios. For this analysis we did not include initial investment costs, maintenance and operational costs to implement the various scenarios.

The discount rates used were based on the rates the Government of Ghana (GoG) was willing to pay on international markets to raise foreign resources (i.e., the USD). The rates the GoG pays on Eurobond in the international market vary from time to time; for instance, between 2009 to 2014, the average rate on Eurobond was 7.5 to 8%. In 2015, the Eurobond rate the GoG agreed to pay was 10.75% - this rate is the highest GoG has ever agreed to pay for a Eurobond issue since it started visiting the European bond market in 2007. Based on these rates, we used four various discount rates in the cost benefit analysis – ranging between 2.5 and 5% around the Eurobond rates, i.e., discount rates of 5%, 7.5%, 10%, and 15%.

Identification and Valuation

A total of 12 major benefit and cost components influenced by the four scenarios were identified for economic analysis (Table 13.1). Various valuation approaches were used to assign monetary values to these cost and benefit components. Secondary data sources such as the information obtained from the Environmental Management Plan (EMP) and Emergency Preparedness Plan (EPP) developed for VRA were also used (VRA, 2010; 2011). Table 13.1 gives information on the detailed methodology and data requirements and the list of cost and benefit items considered in the CBA.
### Table 13.1: Methodological approach for estimating cost and benefit for each component

<table>
<thead>
<tr>
<th>Component</th>
<th>Consideration</th>
<th>Description</th>
<th>Data requirements</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agriculture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Irrigation | Benefit | Total revenue generated from irrigation activities. | - crop types  
- irrigated areas  
- potential yield/ market price for crops  
- Influenced by the intake of saltwater | Field work/ IWMI, 2014  
Field work/ IWMI, 2014  
GIDA, 2010 (vegetables); field survey (rice and bananas) |  
Field work/ IWMI, 2014 |
|  | Cost | Irrigated areas flooded | - irrigated area within flood extent  
- cost of repairing irrigated areas | Digitized flood extent (VRA, 2011)  
GIDA, 2010 |  |
| Flood Recession Agriculture (FRA) | Benefit | Total revenue generated from FRA activities. | - flood extent  
- crop types  
- potential crop yields/ market price for crops | Digitized flood extent (VRA, 2011); location of irrigation (GIDA, 2010)  
Tsikata, 2006  
GIDA, 2010 |  |
| **Health** |  |  |  |  |
| Bilharzia | Cost | Loss of income to affected communities | - Prevalence rate  
- number of working days affected  
- main occupation of rural communities  
- lost income per working day  
- cost of medical treatment | VRA, 2010  
Fieldwork  
Fieldwork |  
Fieldwork  
NHIS, 2016 |
<p>| Malaria |  | Cost of medical treatment | | |</p>
<table>
<thead>
<tr>
<th>Component</th>
<th>Consideration</th>
<th>Description</th>
<th>Data requirements</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisheries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquaculture</td>
<td>Benefit</td>
<td>Total revenue generated from aquaculture.</td>
<td>- number of cages</td>
<td>Google Earth, 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- total production of tilapia in cages</td>
<td>Fieldwork</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- market prices of tilapia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost</td>
<td>Cost of damages to the cages due to floods</td>
<td>- number of cages affected</td>
<td>Fieldwork estimates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- cost of cages</td>
<td></td>
</tr>
<tr>
<td>Shell fish</td>
<td>Benefit</td>
<td>Total revenue for clam catch</td>
<td>- pre-dam catch data</td>
<td>Adjei-Boateng &lt;i&gt;et al.&lt;/i&gt;, 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- current catch data</td>
<td>Fieldwork</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- market price</td>
<td></td>
</tr>
<tr>
<td>Finfish</td>
<td>Benefit</td>
<td>Total revenue for fish catch</td>
<td>- pre-dam fish catch data</td>
<td>Tsikata, 2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- estimates for fish catch per scenario</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- market price</td>
<td></td>
</tr>
<tr>
<td>Weeds</td>
<td>Cost</td>
<td>Expenditure for weed removal or control</td>
<td>- cost of mechanical removal of weeds</td>
<td>VRA, 2010</td>
</tr>
<tr>
<td>Sediments</td>
<td>Cost</td>
<td>Expenditure for removal or dredging</td>
<td>- cost of dredging sandbar and canals</td>
<td>VRA, 2010</td>
</tr>
<tr>
<td>Hydro-power</td>
<td>Benefit</td>
<td>Revenue generated from hydro-power</td>
<td>- hydropower production</td>
<td>Estimates based on flow regime</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- hydropower revenue (price per kWh)</td>
<td>VRA, 2016</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Cost</td>
<td>Cost of infrastructure affected by floods</td>
<td>- number and type of infrastructure within flood extent</td>
<td>Google Earth, 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- cost of infrastructure per type</td>
<td>Acquah, 2005</td>
</tr>
<tr>
<td>Domestic intakes</td>
<td>Cost</td>
<td>Cost of improving treatment to be able to clean salty water (desalination)</td>
<td>- location of intakes</td>
<td>IWMI, 2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- production capacity</td>
<td>WRC, 2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- cost of desalinization</td>
<td>Gleick, 2008</td>
</tr>
</tbody>
</table>
For each of the four scenarios we made assumptions towards physical impacts that affect the valuation of the selected (ecosystem) services. The main physical impacts considered are the saltwater intrusion length during the dry season and the flood extent during the wet season. The assumptions are summarized in Table 13.2, with the locations and sites indicated in Fig. 13.2.

![Figure 13.2: Map of Lower Volta with key sites indicated](image)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Salinity</th>
<th>Flooding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Salinity levels are no problem in the Lower Volta.</td>
<td>No flooding taking place</td>
</tr>
<tr>
<td>2.</td>
<td>High salinity levels observed downstream of Sogakope. Moderate salinity levels between Sogakope and Aveyime.</td>
<td>Peak flows within bank full capacity, no flooding taking place</td>
</tr>
<tr>
<td>3.</td>
<td>High salinity levels observed downstream of Sogakope. Moderate salinity levels between Sogakope and Aveyime.</td>
<td>Flooded area is 24 km²</td>
</tr>
<tr>
<td>4.</td>
<td>High salinity levels downstream of Kpong dam.</td>
<td>Flooded area is 32 km²</td>
</tr>
</tbody>
</table>
All values estimates were expressed in USD using the prevalent exchange rate of the year the estimation was done. The year 2015 was chosen as a base year; hence value estimates for all benefit and cost items were adjusted to the chosen base year using the actual consumer price index (CPI) data (GSS, 2015).

**Results**

**Valuation of benefit and cost components**

This section describes how each of the 12 benefit and cost components were valued in monetary units, using the methodological approach as presented in Table 13.1 and the assumptions stated in Table 13.2.

**Agriculture**

Irrigated and flood recession agricultural production systems are the two types of agricultural practices affected by the dam re-operation scenarios.

**Irrigated agriculture:** There are 13 large commercial and public irrigation schemes in the Lower Volta. The valuation of this component is based on the total productivity of each of these irrigation schemes. Productivity is affected when insufficient water or water of low quality reaches the crop. Although total annual flows in the river are sufficient to supply the irrigation water demand (just a fraction of the total flow), for Scenario 4, water supply in the dry season is insufficient. For Scenarios 2 and 3, there may be sufficient water for irrigation, but the physical infrastructure may not be able to take in water due to low water level in the river or dam. Furthermore, extremely low flows leading to salinity intrusion affects the quality of crops produced (where salinity is moderate) or result in no cropping in the dry season (where salinity is very high) (Table 13.2). Four irrigation schemes are located downstream of the Kpong dam and are therefore at risk of taking in saline water.
High flows affect the agricultural production through the damaging of the intakes and flooding of irrigated areas. The feasibility study of Accra Plains Irrigation Project (APIP) showed investment cost ranging between USD13,096\(^1\) and USD19,828 per hectare (GIDA, 2010). For the current irrigation development, no areas are flooded for any of the scenarios. Some areas of the future development of the APIP are located within the floodplain, and could be potentially affected by the re-operation scenarios.

**Flood recession agriculture (FRA)** – The total productivity of FRA depends on the area potentially flooded under each scenario (Table 3.2). FRA can support one season crop (Leafy vegetables, water melon, okra, chillies) with a potential income of 4,885 USD/ha/yr (GIDA, 2010). We estimate that the potential area for FRA is equal to the flooded area.

**Health**

Malaria and bilharzia are the two key health related factors included in the economic analysis. The costs of the prevalence of malaria and bilharzia were determined using two indicators – cost of health care and loss of income. The cost of health care was assessed using an estimated prevalence rate of the disease for each of the scenarios for an estimated population of 80,000. Of these, 45% were fishing and 75% were farming (IWMI, 2015). According to a survey done in the area, daily income from fishermen in three districts in the Lower Volta was estimated as 16.7 USD/day (Heinze, 2015).

**Malaria** - Malaria is the number one cause of out-patient department (OPD) attendance in all the districts. Malaria cases recorded at VRA’s health facilities rose from 10,803 in 2009 to 16,241 in 2011, indicating a prevalence rate of between 13 and 20%. Regarding the prevalence rate, we took into consideration the current prevalence rate of 15 % and the historical rate of 33 % as reported by Lawson (1963) and cited in Tsikata (2006).

\(^1\) All cost estimates in USD as stated are base year (2015) estimates based on the prevalent exchange rate at the time of reporting and CPI
Reports show that malaria treatment cost in the affected areas was about USD 52,000 in 2011 (VRA News, 2012). This implies that it cost VRA about 1.31 USD to treat a malaria patient. The burden of malaria in Ghana in 2002 obtained through the cost of illness approach was estimated at 2.63 USD per capita or USD 13.51 per household (Asante and Asenso-Okyere, 2003). Currently, the cost of treating malaria using Artemether and Lumefantrine is 0.66 USD (NHIS, 2016). The low cost of treatment might be due to the introduction of the government’s subsidized National Health Insurance Scheme (NHIS). We took the value of 2.63 USD per capita (Asante and Asenso-Okyere, 2003) as it better reflects the total cost malaria treatment than the subsidized cost.

Regarding the loss of income, UNICEF (2007) estimates that on average malaria-affected families can only harvest 40% of the crops harvested by healthy families. Assuming that a typical smallholder farmer household cultivates 0.5ha of vegetables, with the total community cultivating 6,000ha (average household size of 5) with a potential income of 9,770 USD/ha/yr, the total loss in income would be a function of the prevalence rate, and hence it varies in each scenario.

**Bilharzia** - Prevalence rates of both urinary and intestinal Bilharzia rose significantly and ranged between 70% and 75% in some lakeside communities. In some cases, rates of almost 100% have been recorded among school children (VRA, 2010). An assessment of the status of both urinary and intestinal Bilharzia by VRA in five districts between 1997 and 2006 showed that prevalence ranges between 8.4% and 94.4% for the urinary form and 33.7% on average for the intestinal form.

For the cost of healthcare, we took the average prevalence rate of 33% for Scenario 1. VRA (2010) estimated that this rate can be reduced to 5% through their bilharzia prevention programme. The treatment and control of bilharzia included the use of Metrifonate and Praziquantel for mass treatment in heavily infected communities. Vector control was done by mechanical removal of weeds known to harbour host snails. The current NHIS cost of treating bilharzia is 0.63 USD per case (NHIS, 2016).

A survey conducted by VRA observed that since bilharzia does not directly affect the functioning of the patient, out-patient department cases recorded were low. Comparable to an earlier study done in
Cameroon, this current study adopted the findings that a reduction of 10% in the infection rate of Bilharzia would result in a paddy production increase of 4.9% (Audibert, 1985). The total income loss is therefore a function of the prevalence rate, which varies across the scenario. For fishing communities, the loss of income was estimated to be a function of the daily income of fishermen and the expected number of days they are not able to go out to fish.

**Fisheries**

The Lower Volta is an area rich in fish, both in numbers and in diversity, and has been severely affected by the changing flow regime. The effect of each flow scenario on aquaculture, finfish catch, and shellfish production is considered in the economic analysis and described below.

**Aquaculture** – Cage farming of Tilapia fish has taken a leap in the last decade in the Lower Volta. The number of cages was estimated from Google Earth. The 2015 images show a high number of fish cages in the Lower Volta, adding up to 1,836 cages in total. Although it is expected that aquaculture will expand in the future, for the base year analysis we considered the current number of cages. Cage fishing requires steady flow regimes and cannot tolerate salinity. Flooding and high flow velocity affect cages. For Scenario 2, we estimated that 20% of the cages were affected by the floods, similar to the 2010 spilling, and for Scenario 3, 25% of the cages were expected to be affected.

The economic valuation was done by considering the total production of Tilapia fish, based on the number of fish cages that are operational, with one cage producing 15,158 USD/yr per year. In addition, costs are calculated in terms of the investment cost of affected cages at 1,053 USD per cage.

**Finfish** - The general perception among fishermen was that fish catch has declined considerably since the construction of the dams, mainly due to the absence of seasonal flooding of the flood plains and creeks supporting fish spawning (Dankwa and Gordon, 2002). The absence of creek fishing has a major impact on the total fish catch. With changing conditions, such as siltation of the creeks and infestation with aquatic weeds, we estimated that creek fishing can be restored up to 50% of
the pre-dam fish catch for Scenario 4. Creek fishing during pre-dam conditions was 12,552 ton/yr (Tsikata, 2006) and river fishing 10,000 ton/yr before Akosombo (Coppola and Agadzi, 1977). For scenarios 1 and 2 no flooding of the creeks was expected, thus only river fishing was assumed to be contributing to the total production. Prices were assumed to be similar to the current cost of Tilapia at 3.16 USD per kg.

**Shellfish (Clams)** – Clam harvesting was and is an important livelihood activity of the people in the Lower Volta. Before the construction of the dams, clam production supported the livelihood of about 2,000 people, harvesting about 8,000 ton/yr (Amador, 1997; Lawson, 1963). After the construction of the two dams, clam harvesting declined to a low of 1,700 ton/yr, resulting from a reduction in the saltwater intrusion length and high water levels (Kuma, 2000; UNEP, 2002). But the introduction of new techniques to harvest clams at depths up to 10 m has increased production to the current 7,700 ton/yr, with an estimated value of 1,126,929 USD (Adjei-Boateng *et al*., 2012). With the improved equipment, we estimate that improving the natural condition in combination with the improved equipment could double the clam harvest (Scenario 4). For Scenarios 2 and 3, we estimate an increase of 150% in clam harvest.

**Aquatic weeds**

Aquatic weeds are a menace to the communities living in the Lower Volta. They thrive on a slow flowing freshwater with high nutrient levels. Managing these weeds is a time and resource intense activity. The EMP estimates the current total cost of aquatic weed management in the head pond and the Lower Volta at 543,016 USD (VRA, 2010). Increasing salinity levels naturally kills off many aquatic weeds; peak flows also dislodge weeds and transport them into the sea. The cost of aquatic weed management therefore is lower for scenarios with more natural flow dynamics. However, we do not expect that all aquatic weeds can be managed solely by changing the flow regime. We estimate that the cost for aquatic weed management for Scenario 4 is 50% of the total current cost, and for Scenarios 2 and 3 we estimate that the cost will be reduced by 25% compared to the current cost.
CHAPTER 13

Sediments

The buildup of the sandbar at the estuary is creating an unfavourable environment, increasing flooding in the downstream end as water is held back by the sandbar. The naturally brackish environment is also turning more fresh, affecting the local ecosystem. VRA is currently engaged in dredging activities to control the sandbar. According to the EMP, the cost of dredging the sandbar is 4,234,755 USD per year (VRA, 2010). We assume that reintroducing seasonal peak flows will help erode some of the sandbar. However, we assume that this is very limited, consistent with the observations during the 2010 spill event. For Scenarios 2 and 3 we estimate that the dredging cost comes down by 10% and for Scenario 4 the cost comes down by 20%, as some of the deposited sands will be carried into the sea during the peak flow events.

Hydropower

The main purpose of the Akosombo and Kpong dams is hydropower production. Value estimates of the total power production were based on electricity tariffs (GHS per kWh). The total value of the hydropower production is based on the VRA tariffs of 0.24 GHS/kWh in October 2015, equivalent to 0.058 USD/kWh. The total hydropower production was based on the following assumptions: (a) hydropower production is a function of flow and head and efficiency of the plant; (b) there is no constraint in terms of water availability and water level, i.e., the dam level is at maximum capacity (68.88 m); (c) turbine efficiency is set at 0.7% (VRA, 2010); and (d) excess releases will not generate electricity beyond the current maximum turbine flow rate of 1,450 m$^3$/s. The highest annual hydropower production is observed for Scenario 1, with the lowest observed for Scenario 4.

Infrastructure

Infrastructure located in the floodplains is at risk through the reintroduction of floods in the proposed scenarios. Infrastructure affected includes commercial properties, such as hotels, as well as residential properties. In estimating the total cost of damage to property we considered two types of properties, commercial and residential.
Structures affected were identified by overlaying the flood maps onto Google Earth and counting the properties that fall within the flood extent. Downstream of Sogakope, more structures were considered commercial, while upstream of Sogakope, more infrastructure was found to be residential. We estimated that the commercial properties had a value of about 300% compared to residential structures. The standard cost of a residential apartment (43,000 USD) was adopted from government rates on affordable housing for a household size of 5 in a two bedroom self-contained apartment (Acquah, 2015).

**Domestic intakes**

Five domestic water intakes are at risk of taking in saltwater. Three intakes are located downstream of Sogakope (total water rights 2,979,465 m³/yr) and are affected by Scenarios 2, 3 and 4. Two intakes are located between Akuse and Sogakope (total water rights 67,452 m³/yr). To keep these facilities up and running, the treatment facilities have to be upgraded to be able to treat salt water. We estimated that once the desalination treatment plant is in place it will treat all the water supplied from this facility. The total capacity is therefore equal to the water rights (WRC, 2013). The cost of desalinating one cubic meter water is between 0.45 to 2 USD/m³ (Gleick, 2008). We therefore used an average value of 1 USD/m³ for the valuation.

**Overall valuation**

For each of the scenarios the total benefit and cost for the base year are presented in Tables 13.3 and 13.4. Scenario 1 provides the most benefit, and with each scenario approaching more natural flow conditions, total benefits are reduced. For the cost in Scenario 1, a large part of the cost is associated with the loss of income of riparian communities being affected by water borne diseases. Scenario 2 shows a decrease in total costs due to improving health aspects. However, flood damages in Scenarios 3 and 4 offset the incremental benefits of improving health and increase total costs mainly due to infrastructure damages.
### Table 13.3: Total Benefits (USD) per scenario for base year 2015

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Agriculture/irrigation</th>
<th>Agriculture/flood recession farming</th>
<th>Fish/Aquaculture</th>
<th>Fish/Clams</th>
<th>Fish/Finfish</th>
<th>Hydropower</th>
<th>Total benefit</th>
<th>Deviation from scenario 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12,542,460</td>
<td>0</td>
<td>25,793,560</td>
<td>1,126,929</td>
<td>29,268,293</td>
<td>237,029,180</td>
<td>305,760,422</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>9,450,810</td>
<td>0</td>
<td>20,634,849</td>
<td>1,690,393</td>
<td>29,268,293</td>
<td>203,450,080</td>
<td>264,494,425</td>
<td>41,265,997</td>
</tr>
<tr>
<td>3</td>
<td>9,450,810</td>
<td>11,724,000</td>
<td>19,345,170</td>
<td>1,690,393</td>
<td>38,452,683</td>
<td>175,796,840</td>
<td>256,459,896</td>
<td>49,300,526</td>
</tr>
<tr>
<td>4</td>
<td>6,840,333</td>
<td>15,632,000</td>
<td>0</td>
<td>2,253,858</td>
<td>47,637,037</td>
<td>122,465,260</td>
<td>194,828,488</td>
<td>110,931,934</td>
</tr>
</tbody>
</table>

### Table 13.4: Total Cost (USD) per scenario for base year 2015

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Bilharzia</th>
<th>Malaria</th>
<th>Fish/Aquaculture</th>
<th>Weeds</th>
<th>Sediments</th>
<th>Infrastructure in floodplain</th>
<th>Domestic water intake</th>
<th>Total cost</th>
<th>Deviation from scenario 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9,815,018</td>
<td>3,548,760</td>
<td>0</td>
<td>543,016</td>
<td>4,234,755</td>
<td>0</td>
<td>0</td>
<td>18,141,549</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2,974,248</td>
<td>4,731,680</td>
<td>358,244</td>
<td>407,262</td>
<td>3,811,280</td>
<td>0</td>
<td>0</td>
<td>2,979,465</td>
<td>15,262,179</td>
</tr>
<tr>
<td>3</td>
<td>2,974,248</td>
<td>5,914,600</td>
<td>447,804</td>
<td>407,262</td>
<td>3,811,280</td>
<td>24,284,940</td>
<td>2,979,465</td>
<td>40,819,599</td>
<td>-22,678,050</td>
</tr>
<tr>
<td>4</td>
<td>1,487,124</td>
<td>7,807,272</td>
<td>1,790,000</td>
<td>271,508</td>
<td>3,387,804</td>
<td>68,660,940</td>
<td>3,046,917</td>
<td>86,451,565</td>
<td>-68,310,016</td>
</tr>
</tbody>
</table>
Net Present Values (NPV)

Overall, all the scenarios have shown positive NPV (Table 13.5 and Fig. 13.3), which implies that from a purely economics point of view, all scenarios are economically feasible.

Table 13.5: NPV of the four flow scenarios at various discount rates (in billions of USD)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>NPV, d=5%</th>
<th>NPV, d=7.5%</th>
<th>NPV, d=10%</th>
<th>NPV, d=15%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.90</td>
<td>9.11</td>
<td>6.36</td>
<td>3.62</td>
</tr>
<tr>
<td>2</td>
<td>12.04</td>
<td>7.90</td>
<td>5.51</td>
<td>3.13</td>
</tr>
<tr>
<td>3</td>
<td>10.42</td>
<td>6.83</td>
<td>4.77</td>
<td>2.40</td>
</tr>
<tr>
<td>4</td>
<td>5.24</td>
<td>3.43</td>
<td>2.40</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Introducing the natural flows to maximizing ecosystem services (Scenario 4) is the least preferred option in terms of the overall NPV and Scenario 1 (i.e., maintain the current flow regime to maximizing hydropower) is economically the most preferred scenario. Given the crucial role that electricity plays in the economy of Ghana, particularly in a country where the lion’s share of electricity power comes from the Akosombo dam, it is not surprising to see why Scenario 1 is the most
beneficial option. Despite the growing concern and widespread rhetoric on the impacts on ecosystem health, ecosystem services and local livelihoods of major infrastructural projects (either new developments or existing infrastructure), major economic commodities or services such as electric power clearly dominate the decision-making process, as demonstrated in this study. The overall benefit (in NPV terms) of Scenario 1 is about 3 times more than that of Scenario 4. Based on the NPV, Scenarios 3 and 2 appear in the 3rd and 2nd positions respectively. So, overall, the economic results support the status quo (i.e., current dam operation) as economically the most beneficial dam utilization regime. However, given limitations in the assumptions for the data generation and others such as not including the initial investment costs required for realizing dam re-operation in the first place, the results presented in this study are indicative; they are neither conclusive nor definitive.

**Discussion**

The CBA focusses on the impacts that can easily be monetized. However, some impacts are difficult to value, such as displacement of people due to flooding, and were therefore not included in the analysis.

Another key aspect is the distributional issues, i.e., who benefits and who loses in each scenario. From the analyses it is clear that Scenario 1 is very beneficial for the main economic components, such as hydropower, aquaculture and large scale irrigation. Though these benefits are significant, they do not necessarily provide direct benefits to local communities, and therefore riparian communities prefer scenarios that would deal with issues such as the proliferation of aquatic weeds, health and lack of economic opportunities. Improvement in these elements would translate into better livelihood forms and less expenditure on their incomes. Benefits accrued in Scenario 4 mainly contribute towards improving rural livelihoods, such as fisheries and flood recession farming. On the one hand, regular flooding affects the economic activities of large scale investors and threatens the livelihood of riparian communities, destroying properties. On the other hand, low flows affect access to freshwater for domestic use and the potential for dry season smallholder agriculture.
The results presented above have a number of limitations that need to be highlighted to assist readers to clearly understand and interpret the results:

- The cash flows for the entire time horizon of 35 years were based on the estimates of the base year. We linearly extrapolated base year values using the CPI to adjust for inflationary situations. In the real world, apart from inflation, the cost and benefit items may have different values over time.
- A number of simplifying assumptions were made in generating value estimates. Relaxing some of these assumptions could have resulted in different NPVs for the various scenarios.
- Initial investment costs were not included. As described previously, the analysis focussed only on impacts of the re-operation, not on the costs involved in the re-operation.
- Some of the benefits/costs do not have market values. Most of the value estimates were based on anecdotal data which may not reflect the true values.

**Conclusions and policy implications**

This study presents the economic analysis of re-operating the Akosombo and Kpong dams in Ghana. The results show that the current flow regime provides the largest overall benefits. Major potential economic, environmental and social impacts were valued in monetary terms using a number of assumptions to derive values for various cost and benefit items. The results of the cost benefit analysis show a realistic picture of the current situation as far as the evaluated dams are concerned. The predicted decrease in hydropower production is difficult to off-set by increasing benefits in other benefit components. Keeping hydropower production at the same level for the other scenarios requires substantial investments in both installing additional hydropower capacity and improving the power distribution network in general. Based on the results, the policy recommendation is that impacts of large water infrastructure on local communities need to be mitigated by strategizing flow releases that are beneficial to these communities from the design of the project. In the case of existing
dams, one might consider devising alternative livelihood strategies that support the downstream communities and ensure that communities cope with the changes due to the changing environment, instead of re-operating the dams, which may upset the same communities for a second time.

References


Dams, development and downstream communities: Implications for re-optimising the operation of the Volta dams in Ghana (Chapter 11), Digibooks Gh. Ltd, Tema, Ghana.


Ghana Irrigation Authority (GIDA) (2010). Feasibility study of Accra plains irrigation project.


CHAPTER FOURTEEN

FRAMEWORK FOR RE-OPERATING THE LARGE HYDROPOWER DAMS TO IMPROVE LOCAL LIVELIHOODS AND POVERTY REDUCTION

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Abstract

The construction of the Akosombo and Kpong dams in the 1960s and 1980s, respectively, changed the flow regime of the Volta River significantly and affected the livelihoods of downstream communities. Therefore, re-optimisation and re-operation of the two dams were assessed to ascertain the feasibility of improving livelihoods of downstream communities. This chapter describes a framework developed to assess the feasibility of re-operating a large dam, consisting of three elements: technical, economic and social feasibility. Technical feasibility assesses water availability for the proposed re-operation scenarios, the physical constraints of water releases and structural feasibility of adding new turbines. The economics of re-
operation should increase the economic value of the system and result in a reasonable return on investments. Social feasibility is the willingness of people to adapt to the re-operated regime and institutional support network required for adaptive management. This framework, as applied to the Akosombo and Kpong dams, shows that their re-operation is technically feasible. However, system stability requirements of at least 6 GWh/day of power generation at Akosombo pose a challenge, especially in the dry season for which optimal hydropower production is not feasible. On economics, the Net Present Value of economic activities in the area reduces with increasing levels of re-operation, mainly due to reduction in hydropower production. Re-operation requires huge investments in alternative power supplies and transmission capacity, and proves untenable downstream, thereby decreasing with increasing re-operation. Socially, communities have adjusted to the post-dam regime and reported negative impacts from the 2010 spilling event. Therefore, they are reluctant to accept and adapt to the restoration flows. Moreover, the institutional landscape is weak to support communities to manage the changes. Although re-operation of the Akosombo and Kpong dams is not recommended, the framework can be applied to other dams, especially recently constructed dams with lesser contribution to the national power grid.

**Keywords:** Technical feasibility, Economic feasibility, Net Present Value, Scenarios

### Introduction

Water based ecosystems have developed as a result of the natural flow regime of the rivers they are connected to. They are therefore site specific. Changes in flow regimes, in terms of increasing flow, decreasing flow, and changes in timing of floods and droughts can negatively impact the ecosystem services they provide (Poff *et al.*, 1997). It is important to note that the natural variability in floods and droughts that seem to damage the ecosystem, actually support the ecosystems by regeneration from time to time. Dam operations change the natural flow regime depending on the type of use. Hydropower dams stabilise the flows and create a flow regime that limits the high and low flows in order to optimise hydropower generation. This means in some
times of the year the flow is reduced and in other periods the flow is increased. On the other hand, dams for irrigation typically reduce the flow throughout the year, and in particular during the dry season.

These changes in flows could have adverse impacts on downstream communities and livelihoods. Dam re-operation to restore these downstream benefits targets the release of more natural flows and supports downstream requirements (Richter and Thomas, 2007). Re-operating dams does not have only positive impacts, it also affects the sectors for which the dams were originally constructed, such as irrigation and hydropower. Therefore, assessing the trade-offs between increasing ecosystem services and hydropower or irrigation is key in assessing the feasibility of dam re-operation. However, as the decision to re-operate dams will affect downstream communities, there should be a willingness and support from these communities for the re-operation. It also requires that the communities fully comprehend the changes that will be accompanying the re-operation. Finally, managing the re-operation, the releases of the floods and responses from the downstream communities to optimize the benefits from the flow regime, requires strong institutional support. This chapter presents a framework for assessing the feasibility of re-operating dams as it applies to the Akosombo and Kpong dams in Ghana.

**Framework**

To evaluate and recommend the re-operation of a dam, it should be clear that re-operation will improve the general state of the system, not only in terms of the environmental status but also in terms of the overall benefits generated from the system, from both the natural and built infrastructure. It should be clear that the general conditions of the downstream communities have improved and they are supporting the re-operation. Finally, there is a need for an institutional network to implement and manage the re-operation. A framework was therefore developed that consists of three feasibility criteria, i.e., technical, economic and social feasibility as described in the following sections (Fig. 14.1). To evaluate and recommend re-operation a number of flow scenarios are developed and compared using the proposed framework.
Technical and structural feasibility

The technical feasibility considers the water availability for the different sectors, the stability of the power generation and its distribution network (Fig. 14.1). It therefore considers the operational capacity of the dams.

The stability of the power distribution network is dependent on the minimum power generation from the dams. During low flows this is dependent on the minimum number of turbines that can be operated. During regular flows, releases are a function of the number of turbines that are in operation and the releases are not continuous but stepwise. Structural feasibility is related to the capacity of the spillway to cope with the high releases, as well as the structural concerns related to the possibility of constructing additional turbines in the spillway. The stability of the dam structure should not be affected by adding turbines in the spillway. Increasing releases from the dam can also increase the tail water levels, reducing the effectiveness of the existing turbines.

The water availability for the different sectors is assessed using a water allocation model. Different dam operations are run through the model and assessed for total annual hydropower production, failure
to meet minimum hydropower production for the system stability, the provision of sufficient water for other users and the ability of the dams to provide the proposed downstream flows, i.e. to assess whether there is sufficient water available for each proposed scenario.

Economic feasibility

The economic feasibility examines the differences in costs and benefits generated in the system for each of the developed flow scenarios. This is based on the cost-benefit analysis (CBA) which is an economic tool applied to guide investment or natural resource management decisions. The net present value (NPV) and the internal rate of return (IRR) are two of the most commonly used decision criteria in the CBA (Fig. 14.1). The NPV compares the discounted cash flow of net benefits of different re-operation scenarios over time. The NPV provides the relative desirability of scenarios in terms of the overall economic consideration of alternative re-operation options. On the other hand, the IRR criterion establishes the break-even rate of return and guides investment decision – to invest in a project if its IRR exceeds the cost of capital and reject the investment if the IRR is less than the cost of capital. In terms of dam re-operation, the IRR looks at the return on the investment necessary to implement the re-operation against the cost of capital financing.

The economic valuation of the various benefit and cost components identified under the different flow regimes presupposes the technical feasibility of the scenarios and the realization of corresponding proposed hydrographs (Balana et al., 2017). Adjustments in the flow regimes to meet the technical and structural feasibility criterion imply possible changes in the benefit and cost components and their economic values.

In addition, the economic analysis includes investment costs, such as installation cost for additional turbines as well as the cost of improving the electricity network; this includes additional electricity capacity to compensate for the lower production levels during the dry season and the investment costs of improving the transmission network to distribute the excess power during the wet season and to distribute the power from the additional plants that are needed. The
capacity requirements can be assessed by using power generation and distribution system models and cost estimated using historical estimates. The framework presented in Fig. 14.1, therefore provides a flexible approach that enables adjustment of the economic feasibility assessment for changes in flow scenarios.

Social feasibility

The social feasibility is dependent on the willingness of the communities to accept the proposed re-operation scenarios in comparison to the base case scenario (Fig. 14.1). Regarding the willingness of the communities to accept re-operation, community engagement is essential, starting with capacity building of the affected communities to deal with the changes and assessing in participatory workshops the expected impact on their livelihoods. In the case of newer dams, the communities are often well aware of the impact of flow regimes that are similar to the historical flows, and their impact on floodplains remain clear. With older dams, historical benefits are often more anecdotal and floodplains are used for various purposes. Secondly, a strong institutional environment is needed to manage adaptation to the new flow regime (Fig. 14.1). In order to properly manage the restoration flow releases, a strong institutional framework is required to plan, predict and coordinate the releases with the communities. Institutions involved are required to have strong collaboration to ensure that benefits are optimized and the damages minimized.

Application of the Framework – the Akosombo dam case study

The framework is applied to the Akosombo and Kpong dams in the Lower Volta, southern Ghana. Recently there has been an interest to improve the livelihoods of the communities living downstream of the two dams through re-operation. These communities have been seriously impacted by the construction, operation and management of the dams (Mul et al., 2017; Tsikata, 2006). Four flow regimes, developed by Mul et al. (2017), were assessed for their relative feasibility using the framework outlined above. These scenarios are briefly described and each tested against the proposed criteria as explained below.
Scenarios

Scenario 1 - Current flow regime: This scenario is based on the current flow regime, where flows are based on the hydropower requirement from the Akosombo and Kpong dams. A steady flow regime with approximate flow of 1,000 m³/s was proposed and adopted to serve as one of the scenarios for modelling.

Scenario 2 - Reinstating the current flow dynamics up to the 2010 spillway levels: This is based on observed discharges for the flood season, the 2010 spill level of 2,300 m³/s (1,400 m³/s through the turbines and 900 m³/s through the spillway). According to VRA, this implied full bank capacity with limited areas flooded. River flow for the dry season was assumed to be 700 m³/s, the same as the average dry flow passing through the Lower Volta due to severe water shortages and low dam levels.

Scenario 3 - Maintaining sufficient water for irrigation while introducing natural flow. This scenario focussed on providing sufficient water during the dry season for irrigation (both existing and planned irrigation), while maintaining partly the dynamic flow regime. Total water requirements needed downstream considering all developments will probably not exceed 200 m³/s. However, the intakes require a sufficient water level in the river for which the minimum flow was assumed to be 500 m³/s. The water saved would be distributed during the wet season to partly restore a dynamic flow regime. The resultant peak flow of 3,000 m³/s floods an area of 24 km². Two alternative sub-scenarios were developed under Scenario 3, whereby Scenario 3a included the investment cost of a reduction in power generation during the dry season flows and Scenario 3b included the investment cost and benefits of adding 5 additional turbines.

Scenario 4 - Introducing natural flow: This scenario focussed on providing a flow regime that was conducive for aquatic weed control and fisheries/clam production. This entailed a high flow that inundated creeks and floodplains used by fish to spawn, following the natural cycle of the fish, during the months of September and October. High flows and associated high flow velocity were characterized by the removal of weeds (floating and submerged) from their locations and
their being directed further downstream into the sea. High flow velocity also washed away the clay from the river beds, providing good sandy soils for clams to attach themselves. The peak flow was set at 5,000 m$^3$/s, similar to the average historical peak flows which had significant areas being flooded (32 km$^2$). On the other hand, low flows during the dry season were beneficial for women entrepreneurs harvesting clams (lowering water levels sufficiently for manual picking of the clams). Increased saltwater intrusion provided more suitable areas for clam production and fewer areas where weeds could grow. Saltwater intrusion into the river was not only affected by the flow regime, but also by the sand bar at the mouth of the estuary. In case optimal saltwater intrusion was needed, there was the need to mechanically break the sandbar, and peak flows were required regularly to maintain the connection to the sea.

**Technical feasibility**

The Water Evaluation and Planning (WEAP) system model was used to assess the water availability and water allocation in the Lower Volta (Annor *et al*., 2017; SEI, 2012). The model was calibrated based on observed water levels and hydropower production. The results from the WEAP model provided the information on actual hydropower production and the actual releases from the dams compared to the proposed restoration scenarios (Annor *et al*., 2017). Table 14.1 provides an overview of the hydropower production for each of the four scenarios. In addition to the four scenarios, Scenario 3b considered 5 additional turbines in the spillway of Akosombo to make productive use of water during peak releases for hydropower. For all scenarios, the hydropower generation is below the reference scenario (close to Scenario 1). Additional turbines for Scenario 3 increased total hydropower production; however, it was not able to get close to the reference (Table 14.1).
Table 14.1: Hydropower production for different re-operation scenarios

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investments</td>
<td>None</td>
<td>None</td>
<td>a) None</td>
<td>b) 5 turbines</td>
</tr>
<tr>
<td>Hydropower production (GWh/a)</td>
<td>5,267</td>
<td>2,875</td>
<td>2,185</td>
<td>3,146</td>
</tr>
<tr>
<td>Difference with reference (GWh/a)</td>
<td>11</td>
<td>-2,381</td>
<td>-3,071</td>
<td>-2,110</td>
</tr>
<tr>
<td>Difference with reference (%)</td>
<td>0.2</td>
<td>-45.2</td>
<td>-58.3</td>
<td>-40.1</td>
</tr>
</tbody>
</table>

According to VRA, the minimum power generation from the Akosombo and Kpong dams to maintain the stability of the national electricity grid is 6 GWh/day, corresponding to operating about 2 turbines (Annor et al., 2017). Except from Scenario 1, all other scenarios fall below this minimum requirement at some point in time during the year.

The structural feasibility of the proposed additional turbines (Scenario 3b) was also discussed. The proposed construction requires significant alteration of the existing structure, in particular in relation to the spillway. The proposed intervention is very similar to constructing a new dam, and equal consideration should be given to ensuring structural stability and safety. The proposed intervention is structurally feasible, albeit it requires monitoring to ensure the safety of the existing dam and surrounding communities. A detailed feasibility study is required before engaging in such an endeavor.

**Economic feasibility**

The economic feasibility as presented by Balana et al. (2017) presents the NPV of the four scenarios, based on a number of economic benefits and costs. Balana et al. (2017) assumed that water was not a limiting factor in providing the restoration hydrographs, and water in the dam was assumed to be at maximum levels in the calculation of hydropower production. With the results of the WEAP modelling in hand, these values were updated (Table 14.2). To assess the total economic benefits from hydropower, the hydropower production is multiplied by the unit price of hydropower as defined in IWMI (2016). As expected, the hydropower benefits show a similar trend in hydropower production, with Scenario 1 providing the highest benefits and the remaining scenarios showing a reduction of 40% or more.
Table 14.2: Hydropower benefits based on technical and structural feasibility

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hydropower production (GWh/a)</th>
<th>Unit price ($/kWh)</th>
<th>Total economic value for hydropower (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,267</td>
<td>0.058</td>
<td>305.5</td>
</tr>
<tr>
<td>2</td>
<td>2,875</td>
<td>0.058</td>
<td>166.8</td>
</tr>
<tr>
<td>3a</td>
<td>2,185</td>
<td>0.058</td>
<td>126.7</td>
</tr>
<tr>
<td>3b</td>
<td>3,146</td>
<td>0.058</td>
<td>182.5</td>
</tr>
<tr>
<td>4</td>
<td>1,389</td>
<td>0.058</td>
<td>80.6</td>
</tr>
</tbody>
</table>

Table 14.3 shows the revised total Net Benefits for each of the five scenarios. It compiles the total benefits and cost as presented by Balana et al. (2017) complemented by the corrected hydropower benefits. Compared to Scenario 1, all other scenarios show a reduction in Net Benefits, indicating that changing from the current status towards those scenarios decreases the economic value (Table 14.3).

Table 14.3: Net Benefit ($) per scenario for the base year 2015

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Benefit</th>
<th>Total Cost</th>
<th>Net Benefit</th>
<th>Changes in Net Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>374,217,242</td>
<td>18,141,549</td>
<td>356,075,693</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>227,794,345</td>
<td>15,262,179</td>
<td>212,532,166</td>
<td>-143,543,527</td>
</tr>
<tr>
<td>3a</td>
<td>207,393,056</td>
<td>40,819,599</td>
<td>166,573,457</td>
<td>-189,502,236</td>
</tr>
<tr>
<td>3b</td>
<td>263,131,056</td>
<td>40,819,599</td>
<td>222,311,457</td>
<td>-133,764,236</td>
</tr>
<tr>
<td>4</td>
<td>152,925,228</td>
<td>86,451,565</td>
<td>66,473,663</td>
<td>-289,602,030</td>
</tr>
</tbody>
</table>

Increasing hydropower production by adding turbines in the spillway, while at the same time restoring downstream ecosystem services and livelihoods of downstream communities (Scenario 3b) is the second best scenario. However, in all scenarios the Net Benefits are lower than those of the baseline scenario (Scenario 1). Similarly, the NPV which were calculated using different discount rates for the period 2015-2050, show a decrease in NPV compared to Scenario 1 (Fig. 14.2).
The analysis of the NPV does not include the investment costs required to manage the power distribution network with increasing intra-annual fluctuations in hydropower production from the two dams. The investment costs include increasing the alternative power capacity (using thermal and other clean energy sources) and transmission lines to compensate for the reduction in power generation during the dry season. Where hydropower capacity is increased through the addition of turbines, the costs include those for installing turbines, transformers and additional transmission lines from Akosombo. The total capacity required is based on the power generation reduction expected in the dry season (Table 14.4). The total cost for expanding the electricity capacity in the network is based on average cost for thermal power plants, estimated to be about 1.5M$/MW (MATREX/ IESS, 2016).

Table 14.4: Total cost for expansion of the network capacity

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Power production during low flows (MW)</th>
<th>Potential power production (MW)</th>
<th>Additional capacity required during dry season (MW)</th>
<th>Cost of additional capacity in the network (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>473</td>
<td>473</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>331</td>
<td>473</td>
<td>142</td>
<td>213</td>
</tr>
<tr>
<td>3</td>
<td>263</td>
<td>473</td>
<td>236</td>
<td>355</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>473</td>
<td>449</td>
<td>674</td>
</tr>
</tbody>
</table>
The required improvements to the power distribution network were estimated using the West African Power Pool (WAPP) model (MATREX/IESS, 2016). They cover the three realistic scenarios, Scenario 1 and Scenarios 3a and 3b (Table 14.5; MATREX/IESS, 2016).

Table 14.5: WAPP implications of the re-operation scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of turbines at Akosombo operation</td>
<td>6</td>
<td>3/6</td>
<td>3/11</td>
</tr>
<tr>
<td>Number of turbines at Kpong operation</td>
<td>4</td>
<td>2/4</td>
<td>2/4</td>
</tr>
<tr>
<td>Total hydropower production capacity (MW)</td>
<td>1,168</td>
<td>1,168</td>
<td>1,870</td>
</tr>
<tr>
<td>Hydropower production at Akosombo and Kpong (GWh/yr)</td>
<td>5,256</td>
<td>2,684</td>
<td>3,816</td>
</tr>
<tr>
<td>Investment in electricity generation capacity (MW)</td>
<td>0</td>
<td>355</td>
<td>355</td>
</tr>
<tr>
<td>Investment in power distribution network (M$)</td>
<td>0</td>
<td>177.04</td>
<td>229.54</td>
</tr>
<tr>
<td>Investment in turbine capacity (M$)</td>
<td>0</td>
<td>0</td>
<td>1,000$^1$</td>
</tr>
</tbody>
</table>

Any investments required to operationalize any of these re-operation scenarios will result in a decrease of the NPV, and will therefore be deemed not economically viable (Table 14.6).

Table 14.6: Total investment costs, NPV (discount rate of 10%) for selected scenarios with and without investment

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Investment cost (M$)</th>
<th>NPV without investment (B$)</th>
<th>NPV with investment (B$)</th>
<th>Change in NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>7.87</td>
<td>7.86</td>
<td>0</td>
</tr>
<tr>
<td>3a</td>
<td>532.04</td>
<td>4.21</td>
<td>3.34</td>
<td>-21%</td>
</tr>
<tr>
<td>3b</td>
<td>1,584.54</td>
<td>5.44</td>
<td>3.50</td>
<td>-36%</td>
</tr>
</tbody>
</table>

$^1$ Assuming 200 M$ per turbine
Social feasibility

The main reason for re-operating the Akosombo and Kpong dams is the potential improvement of downstream ecosystems and livelihoods of downstream communities. As this is the main aim of the project, the proposed scenario should be well received by the downstream communities. Based on the work done by the Centre for African Wetlands (CAW)(2016a), the communities remain nostalgic when they remember the historical flow regime, for which they have shown their preference. However, returning to the historical flow regime as indicated above is not feasible. The proposed technically feasible scenarios restore limited natural dynamics and are not able to mitigate the key challenges the communities are faced with, such as the proliferation of aquatic weeds and the health related hazards. The socio-economic survey carried out by CAW shows that even for the 2010 spilling, predominantly negative impacts to the downstream communities were observed (Centre for African Wetlands, 2016b). Respondents indicated that they expected a higher impact if more water was released.

Re-operating the Akosombo and Kpong dams requires substantial adjustments from the downstream communities, who are still struggling to come to grips with the changed conditions after the construction of the two dams. Re-operating the dams also requires good communication between the dam operators and community members, including well planned releases and forecasts. Institutions should be strengthened and given a clear mandate to manage the effects of the re-operation (IESS, 2016b). What the 2010 spilling indicates is that the institutions are not yet ready for such hands-on adaptive management.

Conclusions

Decisions for re-operating dams need to be substantiated by factual information in order to make informed decisions. This chapter discusses three important issues that need to be taken into consideration when deciding to re-operate a dam. The first consists of technical conditions, the amount of water available and structural constraints, all of which contribute towards the technical feasibility of the re-operation project. The second is related to the economics of the re-operation project.
This requires a sound economic analysis and careful consideration of economic decision criteria such as the NPV and IRR to judge the economic viability of proposed dam re-operation. Finally, the social aspects are important, with the downstream communities’ commitment towards the re-operation project being an essential part. Engagement of these communities throughout the process is crucial for the success of the dams’ re-operation.

The results of the feasibility study of the re-operation of the Akosombo and Kpong dams indicate that the project is technically feasible, but it reduces hydropower production substantially. Due to the high reliance of Ghana and the region on hydropower from the two dams, the constraint in releasing a minimum flow through at least two out of the six turbines to maintain the stability of the power network reduces the potential for restoring downstream ecosystems. Feasible peak flow releases only flood limited areas during the wet season for restoring floodplain ecosystems and related services.

The economic feasibility shows that the NPV for Scenario 1 is the highest and it decreases for each of the re-operation scenarios. The installation of the turbines in the spillway for Scenario 3 increases the NPV substantially. Including the significant investment required for re-operation in the economic analysis resulted in a higher cost of capital against the IRR of the investment. Thus, from an economic point of view, the dam re-operation is not a viable investment option.

From the social point of view, it is not clear that the downstream communities will actually benefit from the re-operation. Negative socio-economic impacts have been observed after a relative minor peak release during the 2010 spilling event. The communities need to be highly adaptive and well-informed to be able to manage the new dynamic flow regime in an effective manner. The institutional landscape to support these communities is however very limited.

In conclusion, the study has shown that the re-operation of the Akosombo and Kpong dams is technically feasible, but not to be recommended from an economic or social point of view. More emphasis should be put on alternative livelihood strategies which have the potential to help transform the lives of downstream communities at a much lower cost and with less disruption.
Finally, the re-operation study of the Akosombo and Kpong dams has developed a framework to support decision making on re-operating large dams. This framework can be applied to other dams (especially cascading dams) facing similar situations. In particular, dams that are of less national or regional importance for power supply are more likely to be technically and economically feasible. Dams that have either been recently constructed or are on the drawing board are also more likely to be feasible from a social point of view, as communities have the capacity to deal with dynamic flow regimes and are less likely to have developed alternative livelihood strategies in the floodplain.

References


PART FOUR

MANAGING OF RE-OPERATION AND RE-OPTIMIZATION SCENARIOS
CHAPTER FIFTEEN

INSTITUTIONAL CAPACITY AND MANAGEMENT OF THE VOLTA LAKE SHORES AND THE LOWER VOLTA RIVER CHANNEL

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Abstract

The loss of ecosystem services resulting from damming has made dam development a highly contested issue in sustainable development. As a result, the idea of restoring some of the ecosystem services of dammed rivers through re-operation and re-optimisation of the dams has received attention among stakeholders in dam development. This study examined institutional response to fluctuations in the water level of the Volta Lake and the Lower Volta River Channel with a view to drawing lessons for the re-operation and re-optimisation of the Volta dams. Data for the study were derived from fieldwork involving discussions and interviews with officials of 31 institutions in 11 administrative districts and 8 traditional leaders. The study established that fishing activities are boosted during times of high water level in the lake and the river channel, which suggests that water discharges from the reservoir during re-operation and re-optimisation will help revamp the dried up creeks and will help water the floodplain areas to boost their ecological functions. However, the experiences of local institutions with respect to high water levels suggest that they are not adequately resourced to effectively manage any mishaps in the event of re-operating the dams. The paper therefore advocates greater institutional support,
both monetary and logistics, from central government. Again, the paper recommends greater inter-agency collaboration of efforts and activities, as well as proper coordination of programmes between the Volta River Authority and the local institutions in the management of the lake shore environment.

**Keywords:** Farming, Fishing, Flooding, Re-operation/re-optimisation, Volta Lake

**Introduction**

Under undisturbed conditions of a functional riverine ecosystem, there is lateral exchange between the river channel and its floodplain in terms of hydrological flows and other constituents such as nutrient load and life forms. Junk *et al.* (1989) used the river channel as a transport and migration corridor to underscore the functional relationship between the main river channel and its floodplain. According to Arthington *et al.* (2004), flow regimes of rivers are characterized by flow quantity and temporal variables, each of which has individual and interactive regulatory influence on the biophysical structure and functioning of rivers and floodplain ecosystems. These processes in turn influence the ecosystem goods and services provided by rivers for human benefit. Thus, floodplains constitute important ecosystems that bring several socio-economic opportunities such as natural irrigation, transportation, recreation, habitats for plants and animals, as well as the production of fish and other foods and marketable goods to riverine communities.

However, river damming results in ecological changes that diminish these aforementioned opportunities. According to Bunn and Arthington (2002), flow alteration can lead to disturbance of channel and floodplain habitats. Fahlund (2000) also noted that apart from the fact that dams block free-flowing river systems which hinder the flow of nutrients and sediments and impede the migration of fish and other wildlife, healthy in-stream ecosystems are also dewatered, thus impacting negatively on their functionality. The upstream areas experience inundation of large expanse of land, resulting in the loss of arable land, displacement of animal and human habitats and marked changes in the micro-climate (Moxon, 1969; Amanor, 1994). At the downstream end of the dams
the residual river flow is artificially controlled to maintain sufficient water of requisite power generation capacity in the dam. As a result, the annual flooding which most of the rivers experienced during peak rainy periods is curtailed and the ecological conditions of both the river water and the floodplain soils become altered (Petts, 1984, Ayivor and Kufogbe, 2001).

The hydrological changes resulting from damming and the accompanying loss of ecosystem services that impact negatively on the livelihoods of riparian communities have made dam development a highly contested issue in sustainable development (World Commission on Dams, 2000). The costs of the multiple benefits of damming are largely borne by displaced people upstream and downstream riparian communities (Survival International, 2010), whose livelihood strategies are the result of intimate engagement with the flood regime of rivers and resources in their natural surroundings. Globally, 7,000 large dams have affected an estimated 472 million river-dependent downstream people as a result of alterations in river flows and other ecosystem conditions (Richter et al., 2010).

The ecological changes resulting from damming and the related issues mentioned above have all informed stakeholders in dam development to ask whether existing dams cannot be re-operated to mimic pre-dam conditions. The idea of restoring some of the ecosystem services of dammed rivers while at the same time maximizing hydro-electric power (HEP) output is defined by the concepts of re-operation and re-optimisation. The whole idea is to improve on the environmental performance of hydropower dams. For example, the World Bank is re-engaging in energy and water infrastructure through re-operation of hydropower dams to improve their environmental performance in an environmentally responsible and socially acceptable manner (Thomas and DiFrancesco, 2009).

Indeed, opportunities exist through the re-operation and re-optimisation of dams, which could lead to the successful rehabilitation of river ecosystems. Dam re-operation and re-optimisation means the implementation of environmental flows designed to restore downstream ecosystem functions and services (e.g., floodplain livelihoods, food production systems) without significantly decreasing
power production. According to Richter and Thomas (2007), re-operation is a means of modifying the operations of existing dams to recover many of the environmental and social benefits of healthy ecosystems that have been compromised by present modes of dam operation. In Michigan for example, resource managers noticed a significant increase in natural fish recruitment below dams that have been altered in several rivers, from a peak flow to a more natural run of the river, which resulted in improvement in both water quality and habitat structure (Fahlund, 2000).

Against this background, this paper assesses the capacities of institutions responsible for the management of the Volta Lake/River systems and the adjacent lands. In particular, the study used the experiences of institutions and local communities during the 2009/2010 high water level of the lake and the spillage of the reservoirs that affected the downstream riverine areas. Their experiences should serve as a lesson for re-operation and re-optimisation of the Volta dams in Ghana.

The study setting and methodology

The Volta Lake Shores and Lower Volta River Channel

The study covered the Volta Lake Shores (VLS) and the Lower Volta Basin (LVB) (Fig 15.1). The major arms of the lake include the Black Volta, the White Volta and the Oti rivers, which drain the northern areas of Ghana, and the Afram which drains the central part of the country. The lake itself stretches for a distance of about 450 km from its southernmost point at Akosombo to Yapei in the North (Fig. 15.1). It covers a total area of about 8,500 km², roughly 3.5% of Ghana’s land area. Its shoreline is 4,800 km and it has a storage capacity of 152bn m³ at full supply level (Kalitsi, 1999). The Lake region provides numerous opportunities including fishing, farming, transportation, livestock watering, and irrigation (Acres, 1992), which have attracted many people from several parts of the country, particularly the LVB (Geker 1999; Tonah, 2001; Ofori, 2012a). There are over 1,500 settlements along the lake (Government of Ghana, 1995), 43 of which serve as market centres (Ofori, 2012a; Ofori and Asiedu, 2013). The major market centers
are important transshipment points, service and administrative centres and drivers of the urbanization process in the Volta Lake Region (Ofori, 2012a; Ofori and Asiedu, 2013). The land-based activities and those on the water are influenced by fluctuations in the level of the lake, and the activities also have implications for the lakeshore environment in general (Ofori, 2012b).

The Lower Volta River Channel (LVRC) lies below the dam-wall at Akosombo and extends to Ada Foah, where the river empties into the Gulf of Guinea (Fig. 15.1). Lying below the dam-wall is the Kpong Headpond, which extends to Akuse where the second dam, Kpong Dam, was constructed. Broadly, the downstream riverine area is defined by the main Volta River Channel and its subsidiary river courses including a maze of lagoons, marshlands and swamps, creeks and the Volta delta. The right bank of the main river channel is poorly drained and has only three major streams. The relatively well-drained left bank has over six streams as major outlets (Ayivor and Kufogbe 2001).

The approximately eighty kilometre (80 km) longitudinal stretch of the LVRC traverses several administrative districts. They are the Upper Manya Krobo and Asuogyaman Districts and Manya Krobo Municipal Assembly in the Eastern Region, the Ada East and Shai-Osudoku in the Greater Accra Region, and the North Tongu, Central Tongu, and South Tongu Districts in the Volta Region, including the Keta Municipal Assembly.
Fig. 15.1: Map of the study area, the Volta Lake/River system
Methodology

The study targeted institutions whose mandate, core functions and activities deal with the management and/or use of the water and resources of the Volta Lake/River system. Officials of these institutions were engaged in discussions with the guide of an interview schedule. In all, 31 institutions in 11 administrative districts, 8 in the LVB and 3 in the Volta Lake Region (VLR) were covered. For the VLR the districts were selected to ensure a fair geographical coverage of the area. Specifically, the following settlements were focused on: Akateng - Upper Manya Krobo District in the southern section and Tapa Abotoase - Biakoye District in the middle portion and Yeji - Pru District in the northern section. Discussions were also held with 8 traditional leaders (with some community members present), 5 in the Lower Volta and 3 in the Lake region.

Information gathered focussed on the capacities of local institutions to manage anticipated changes associated with the re-operation of the Volta River. Specifically, the discussions centred on the human and financial resource capacities of these institutions and sources of funding. Staff capabilities, together with working conditions and morale, were also assessed. Issues regarding governance of the Volta Lake/River were also brought to the fore and discussed with specific questions on water resources management, engagement in water extraction, and collaboration with other organizations in addressing challenges associated with the lake/river system. Questions were also asked on individuals’ understanding and perceptions of re-operation and re-optimisation of the Volta dams and whether or not capacities exist within the institutions to manage any adverse effects in the event of re-operation. The past experiences with regard to flooding in the basin, particularly the 2010 excess water spillage and its effects on the floodplain communities, were also discussed.
Findings and Discussions

Water Management Regimes

The legal regime for the management of water resources in Ghana combines both the formal and informal customary law principles (Opoku-Agyemang, 2005). Under the Act that established the Water Resources Commission (WRC), Act 522 of 1996, water resources are subject to state ownership (Republic of Ghana, 1996). Thus, the management of all water resources is vested in the WRC which is mandated to permit the diversion, damming, storage or use of water resources. However, in the acquisition of rights for the use of water resources, the Act encourages public hearing through collaboration with local government institutions, which are the Metropolitan, Municipal and District Assemblies (MMDAs), and traditional authorities. The Water Use Regulations of 2001, LI 1692 vest registrable water uses in the MMDAs who are required under law to submit to WRC all registered water uses every quarter. Customarily, surface water resources are public good or community property. They are also considered as gods in some areas and it is a taboo to desecrate them. Community leaders, represented by the chiefs and their elders, and religious leaders have the responsibility to ensure that the whole community does not abuse water bodies. Thus the inclusion of traditional authorities in administration of water resources is to ensure that customary and traditional water management concepts and practices are recognized (Opoku-Agyemang, 2005).

Apart from being in charge of power generation from the dams on the Volta River system, the VRA, under the Volta River Development Act (Act 46) of 1961, is mandated to manage the Volta Lake and adjacent lands extending 1.6 km (1 mile) off the lake shores at its maximum fill at 280 feet contour elevation.

Water Management Institutions

In addition to the VRA and WRC it is the Fisheries Commission and the Irrigation Development Authority which are directly involved in the management of water and/or its resources. All other institutions and agencies which operate under the MMDAs deal indirectly with
water resources. The Volta Lake Company (VLTC) operates vessels on the north-south route of the lake as well as cross-lake ferry services at vantage points along the lake shore, whereas the Ghana Highways Authority operates ferry services on the river channel in the lower basin. The Ghana Maritime Authority Act of 2002 (Act 630) requires this institution to manage safety on the lake under its Inland Waterways Division. This task is undertaken in collaboration with the Naval Task Force, which in addition, has been empowered by the Fisheries Commission to check illegal fishing activities such as the use of bamboos on the lake.

By the Local Government Act (Act 462) of 1993, the MMDAs are the highest political, legislating, budgeting and planning authorities at the local level. Together with their decentralized agencies and departments, they constitute the key institutions responsible for the administration and governance of resources at the local level. The decentralized agencies include the Agricultural Directorate, the Fisheries Commission, Town and Country Planning Department and National Disaster Management Organisation (NADMO). Others are Environmental Health Units of the Assemblies and the district offices of the Wildlife Division and the Ghana Highway Authority. Most of the assemblies visited were created at different times based on executive decisions and in accordance with the Local Government Act 462. For instance, the Keta District Assembly which has been in operation since the inception of the assembly concept achieved municipal status in 2007, whereas the Central Tongu District Assembly was established only in 2012.

As per the Act establishing the district assemblies, they are mandated to exercise political and administrative authority in the district, provide guidance, give direction to, and supervise the other administrative authorities in the district.

There are several sources of revenue for the district assemblies for carrying out their mandate. These include:

1. The District Assemblies Common Fund (DACF) which is a constitutionally stipulated minimum share of government revenue received from central government. It is the main source of funding for most districts in the country.
2. The District Development Fund which is also allocated to the assemblies by the central government for specific development projects in the district. A set of criteria has to be met by each district to benefit from the fund.

3. Ceded revenue which covers entertainment duty, casino revenue, betting tax, advertisement tax and others. This revenue is centrally collected by the Internal Revenue Service of the Ghana Revenue Authority and the total amount transferred to the Ministry of Local Government which shares it among the DAs using a formula approved annually by the Cabinet.

4. Internally generated revenue including locally generated income tax, license/store fees, kiosk rent, property rate, market toll, hawkers license, levies on slaughter houses, toilet fees, bar operation license, lorry park tolls, street/light/water levy, special levies, and birth and death registration.

5. Rates levied over specified areas for the purpose of specified projects approved by the District Assemblies and rates made and levied over the whole district for the purpose of developing the district.

Other external sources of revenue include support from donor agencies channeled through the Local Government Service based on performance, individual support and support from the Embassies to individual District/Municipal Assemblies. With respect to the Asougyaman District, for example, the Chief Executive intimated that the Assembly receives special dispensation of 50% of revenue collected by the VRA in the management of Akosombo Township.

In spite of the large number of revenue sources, many local authorities have concentrated on a few which are easier to access and mobilise. Many assemblies are unable to meet their internally generated revenue targets because of inefficiencies in the collection process. For instance, the Unit Committees are the smallest administrative units of the assemblies and have the responsibility of revenue collection within their respective jurisdictions, that is, the unit area. Unfortunately, as indicated by officials of the Municipal and District Assemblies during fieldwork, most of the units are ineffective and hardly meet their revenue targets.
Experiences during changes in water level

The 2009/2010 rise in the water level of the reservoirs was a major landmark event that was referred to by the institutions contacted during field work. The rise in the water level had not been experienced for over 22 years. As a result, people had taken advantage of the low water levels and constructed houses and other permanent structures in the draw-down zone of the lake shore. But the rise in the water level was significant to cause extensive damage to the communities and farmlands along the river bank.

Between July and November 2009, the lake level rose from 77.45 to 82.45 m, a rise of 5 m (16.39 ft) (www.vra.com/Publications/lakelevels/levels.php), and considering the low-lying nature of the landscape along most parts of the lake, this meant significant horizontal displacement. Farms were flooded, residents had to evacuate their homes as the water level rose, buildings collapsed and market spaces and structures were consumed by the water. At Yeji, a water processing plant that served the community was flooded, together with entertainment spots and residential structures. At Abotoase, several buildings, artisanal shops and the entire lakeshore space used for marketing activities were inundated. In Akateng, structures close to the lake including the main transport terminal were all flooded. Elsewhere, most of the low lying areas got flooded, drowning several hectares of farmlands and residential areas. However, as the flood waters receded, most of the residents took advantage of the situation and planted fast growing crops, which boosted household food production over the period and enhanced their livelihoods.

Since the mid-70s, pressure on the lake for fishery purposes has increased. The number of canoes increased from 9,113 in 1971 to 24,035 in 2000 and the average yield of fish catch decreased from 46.8 kg/ha in 1976 to 32.6 kg/ha in 1998, giving an annual decline of 0.255kg/boat/day (Braimah, 2001). However, it was revealed during discussions with the traditional authorities and interviews with officials of some of the institutions, particularly the Fisheries Commission, that the high water level was associated with increases in fish catch in the lake region and the downstream area. They explained that the high water level of the lake and increased volume of water in the lower river channel, coupled
with the flooded bushes, created new spawning sites for fish, resulting in a boom in fish landing within the period. In the Lower Volta Basin, it was revealed that the floods resulted in momentary rejuvenation of the virtually ‘dead creeks’ through fresh water intrusion. This boosted creek fishing in the area. Officials of the Fishery Commission in Ada East District, for instance, noted that fish catch during the period of the floods included species believed to have moved away from the Volta estuary, and according to them, this indicated an increase in the total fish stock.

The negative impacts of the floods on the fishery industry were described as enormous during discussions with the chiefs in the LVB. Officials of the Fisheries Commission and the traditional authorities of the South Tongu District, for example, reported that the floods destroyed aquaculture facilities, especially fish cages and fishing nets in the river channel, and stalled clam picking from the river bed because of high flow current. River transport became very risky and virtually grounded to a halt due to high flow velocity, which affected fishing activities. For example, at Dufor Adidome close to the Kpong dam in the North Tongu District, the community leaders prevented fishermen from going to the river to fish as a precautionary measure due to the high water current. This denied the people the opportunity to benefit from fishing. There was also the aquatic weeds menace which obstructed navigation and fishing activities.

According to the Artisanal Fisheries Station at Yeji, fish catch and landings are low during periods of low water level as experienced in 1984, 1994, 1998, 2003, 2006 and 2015. It was mentioned that when this happened, the fishers resorted to all kinds of illegal fishing such as the ‘atidza system’, ‘adra’, ‘nifanifa’ and ‘wangari’ as well as the use of bamboo traps. Bamboo fishing targets mostly catfish (Cristisia oretus). Unfortunately, it is mostly the gravid fish that is trapped and this constitutes a major threat to the fish species.

As the water level rose to 277.54 ft, above the VRA regulated level of 276 ft, the Authority was compelled to open the spill gates at both the Akosombo and Kpong dams to save the dams from any damage. The effect of this action was overwhelming, causing serious river bank erosion in areas close to the Kpong dam, whilst resulting in flooding in the lower reaches of the river.
Institutional capacity and responses to floods

During the 2009/2010 floods, the VRA as the manager of the Volta Lake/River and the Dams, provided adequate and timely information on the increasing water level of the lake and the subsequent opening of the spillways of the dams. People in areas that were to be affected were informed about the likely effects of the floods and they were kept on the alert to avert disasters. Generally, the VRA, in collaboration with the MMDAs and their agencies including NADMO, the Information Services Department, the Environmental Health Unit and the District Agricultural Directorate, carried out massive community outreach exercises on the impending flood and safety measures that were to be undertaken. The channels of information delivery were the local FM stations and media houses, community public announcement stations (CPAS) and village level local/traditional announcements originating from the chief’s palace.

It was noted that for all the districts in the Lower Volta Basin which were potentially prone to the flood waters of the spillways, elaborate programmes were put in place to manage the likely impact of the spillage. Information about the volume of water being released and the likely effects of the spillage were relayed from the VRA through NADMO to the MMDAs and the communities. The officials of the DAs indicated that they mobilized their decentralized agencies/units, especially the Information Services Department, in alerting the communities about the floods. The South Tongu District Assembly, for example, made available boats and other life-saving equipment to assist potential victims in anticipation of the floods. Apart from keeping community members on the alert about possible disasters, the traditional authorities also appealed to them to house those who were likely to be displaced.

In the lake region the institutional preparedness and responses to the high water level were no different from those in the Lower Volta. However, in view of the fact that the fisher folks prefer to settle very close to the water, most of these settler communities were affected. NADMO officials enumerated about 135 of such settlements in the Pru district alone, but could only provide limited assistance to them. The NADMO zonal office at Abotoase registered about 1,439 flood victims.
Unfortunately, it was only able to provide 65 students’ mattresses, 200 sleeping mats and small quantities of other relief items for the victims. The DAs also indicated that they could not do much to support the people who were affected by the floods due to lack of funds. They lamented the non-payment of their share of the DACF by the Central government which is a statutory requirement. Thus, the decentralized agencies of the MMDAs were limited in providing emergency support services and logistics to the flood affected individuals.

In all cases, the traditional leaders could not do much to assist their people because they lacked the logistics to do so. According to them, all they could do was liaise with NADMO and other agencies to advise the people to move to higher ground. They also sought the support of religious institutions for the displaced. The chiefs emphasized that they received no reward for their efforts and could not use their personal resources to support flood victims.

The chiefs in the lake region lamented the diffused nature of control over the buffer zone along the lake which has led to the construction of housing structures and other facilities including market structures along the lake shores. According to the chief of Yeji, this trend has led to increased siltation of the lake and resulted in the reduced water holding capacity of the reservoir. The chiefs attributed the massive destruction by the floods in the communities to unplanned development along the lakeshores which the local authorities responsible have failed to check. They also blamed the situation partly on politicians who intervene on behalf of culprits apprehended for engaging in unacceptable practices along the lake.

Moreover, the chiefs alluded to the poor relationship between traditional authorities and the DAs with respect to land allocation and lease of lands for development along the lake shores. On this particular subject there were counter-accusations. At Yeji the DA indicated that there were instances where local chiefs allocated plots to individuals for development in the buffer zone, below the 280 ft contour delineated by the VRA. In other instances, developers hide under the guise of traditional leaders to undertake developments on their own without authorization. According to the Paramount Chief of Tapa (at Abotoase), the traditional authority has no share in the revenue collected at the Abotoase market even though it provides support in the management
of the market and ensures good sanitary conditions at the lake shore. He indicated that in 2008/2009 the Environmental Protection Agency (EPA) notified the residents of Abotoase of serious public health risks posed by the filth at the market, the faecal matter and plastic bags in the lake and advised the residents not to draw the lake water for domestic use. However, these conditions still prevailed at the time of the survey and people were found fetching water from the lake for domestic purposes.

The traditional authorities at Tefle in the Lower Volta, as well as those of Yeji, Abotoase and Akateng in the Lake Region, indicated that they have a role to play in the management of water resources and adjacent lands. While blaming the VRA for its inability to monitor developments along the lakeshore, the chiefs emphasized that as the traditional leaders on the ground, they lacked legislative backing and support from government and the VRA to enable them play meaningful roles in the management of the lake resources and the adjoining lands. In fact, there was ample evidence that the VRA has not done much to control settlement development and other human activities along the lakeshore as required under Act 46. This situation has adverse implications for the reservoir and calls for greater alertness on the part of the VRA, DAs and disaster management institutions as well as community residents, in order to minimize losses from floods.

Like the traditional authority, the Agricultural Directorate of the districts indicated that they educate and sensitize the community residents to maintain a buffer of 100 m along the lake, but residents continue to utilize the draw-down for farming as the water level recedes. They expressed serious concern about the effects of the use of agrochemicals on aquatic life-forms, but they lack the capacity to monitor and enforce what the VRA is mandated to do.

Apart from the Fisheries Directorate, all the units under the MMDAs indicated they have adequate manpower capacity. The jurisdiction of the Fisheries Directorate at the Dangbe East District, Keta District and Asuogyaman District, all in the Lower Volta, and Yeji of the Pru District in the Lake region, go beyond the administrative districts where they are located. In other words, they are overstretched. Though some of the decentralised units indicated that they have adequate staff, they all complained of inadequate logistics and resources as well as inadequate
and irregular release of funds to enable them effectively carry out their activities.

**Views on re-operation and re-optimisation**

The concept of re-operation and re-optimisation was well articulated by the local government institutions and the traditional authorities and their community members. This was borne out of their experiences with respect to fluctuations in the water level of the lake and the river channel, particularly the boom in fishing activities associated with the high water level. The elderly in the LVB readily recounted the pre-dam flow regime of the river system. The general expression by the individuals was that the whole idea of re-operation and re-optimisation is laudable once the managers of the dams are able to determine the right water levels for power production and benefits to the local communities. They however expressed concern about how the scheme will work vis-à-vis optimal power generation from the dams against the backdrop of low inflows into the lake in recent years due to poor rainfall.

**Concluding remarks**

This study has examined the capacities of the local government and traditional institutions in the management of the Volta Lake/River system by drawing on their experiences with respect to fluctuations in water level. The experiences of the decentralized agencies of the local government administration and the traditional authorities in the VLR and the LVRC hold useful lessons for the re-operation and re-optimisation of the Volta Dams.

The study revealed that fishing activities are boosted during times of high water level in the lake and the river channel. This implies that water discharges from the reservoir during re-operation and re-optimisation will help revamp the dried up creeks of the LVB and water the floodplain areas to bring back their ecological functions. Thus, there is the potential for restoring creek fishery and drawdown farming to boost local livelihoods. These notwithstanding, the
question of whether re-operation and re-optimisation can improve the reliability of and access to water and ensure guaranteed electric power supply was a major concern noted by the institutions. Other issues of concern expressed during the study include: possible disruption of post-dam survival strategies adopted by the communities and other local initiatives; increased shoreline erosion in the upper sections of the lower Volta floodplain resulting from the high flow rate of water spilled from the reservoir; and the inability of re-operation and re-optimisation to remove aquatic weeds and curb the menace of bilharzia in the LVB.

With respect to the capacity of the local government administration (and its decentralized agencies) and the traditional authorities, the study noted that they are not adequately resourced and supported by the central government to effectively deal with the effects of high water level of the lake and river system. This is particularly so with reference to support for people affected by floods during periods of high water levels. The study also noted that there is weak inter-agency coordination and there are no clearly defined collaborative programmes between the VRA and the local authorities in the management of the lake shore environment. All these have resulted in poor monitoring of developments along the lake shores and the buffer zone, culminating in abuse of the environment.

Therefore, the key lesson from the study is that to enable the local institutions respond effectively to the anticipated implications of re-operation and re-optimisation, there will be the need for greater support from the central government and the VRA, thus both monetary and logistic assistance. Other essential requirements will be greater inter-agency collaboration of efforts and activities, proper coordination of programmes between the VRA in particular and the local institutions in the management of the lake shore environment, as well as, greater political commitment to law enforcement at all levels of governance. In all these, there will be the need for media support for sensitization, education and advocacy directed towards the local community members.
References


CHAPTER SIXTEEN

ADAPTIVE MANAGEMENT DESIGN FOR THE
AKOSOMBO AND KPONG DAMS’ RE-OPTIMISATION
AND RE-OPERATION: THE PRINCIPLES AND PRACTICE

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Abstract

When the Akosombo and Kpong Hydroelectric dams were constructed, some forms of management regime were instituted to regulate the emergent responses of the natural ecosystems as well as the socio-economic impacts in the Lower Volta basin. Over the years, negative socio-economic and environmental outcomes have revealed the ineffectiveness of adopted management interventions. The Akosombo and Kpong dams’ re-operation and re-optimisation study project was designed to assess options to optimise the socio-economic and environmental benefits of the Lower Volta basin. For the project to respond to its expected objectives, a new overarching management regime is required. This management approach must, offer a framework that is flexible, adaptable and responsive to uncertain outcomes from management actions, and improve understanding for an enhanced decision process. The Akosombo and Kpong dams’ re-operation and re-optimisation project has adopted Adaptive Management (ADM) since it offers these opportunities. This chapter documents an ADM process as a formal management strategy for the implementation of the Akosombo and Kpong dams’ re-operation and re-optimisation project. The chapter is presented in four parts – an introduction, requirements
necessary for effective adoption of adaptive management, design and development of adaptive management, and finally an ADM framework for downstream ecosystem restoration.

**Keywords:** Adaptive, Uncertainty, Natural systems, Stakeholder, Iterative

**Introduction**

The socio-economic and environmental outcomes of the construction, operation and management of the Akosombo and Kpong hydroelectric dams (Fig 16.1) for the ecosystems and communities of the Lower Volta have been generally negative. This is largely due to the complex dynamics of the processes and interactions of multiple factors: hydrological, climatic, demographic, and socio-economic, and demands on power (Barry et al., 2005; Bergkamp et al., 2000). When the Akosombo and Kpong Hydroelectric Dams were constructed, flow management regimes were instituted to regulate the emergent responses of the natural ecosystems and socio-economic impacts on the Lower Volta. Over the years, however, management outcomes have revealed the ineffectiveness of the adopted management interventions. Managing such complex integrated natural and socio-economic systems is challenging (Atindana et al., 2015; Wildi, 2010), requiring continuously improved knowledge inputs as the system becomes better understood.

**Adaptive Management**

According to Bird (2012), the failure of the traditional management regimes to deliver desired socio-economic and environmental outcomes can be attributed to limited knowledge of complex socio-economic and environmental systems being managed, and their responses to management interventions. The benefit of experience, accumulated knowledge and understanding suggests that the management of complex systems should be adaptable (Susskind et al., 2012). More importantly, management should be informed of the lessons learnt from the outcome of earlier interventions.
Adaptive management provides a structured process for making decisions over time through active learning that enables adjustments in programme implementation as new information is gleaned and becomes available. Adaptive management embraces scientific approaches that involve identifying explicit goals and objectives, developing and implementing management actions, assessing the system’s response to the action(s), and then using that knowledge to make management decisions (Susskind et al., 2012; Williams et al., 2009). ADM is designed to be iterative, allowing for the incorporation of new knowledge through every step of the process.

For adaptive management (ADM) to be effective, many scholars and regulatory authorities advocate for decision-making processes that are flexible and designed for adaptability in the face of uncertainties, as outcomes from management actions and other events become better understood (Innes and Booher, 2010; Williams et al., 2009). Adaptive management encourages an ecosystem-level, rather than a disjointed approach to natural resource management. This encourages close collaboration among scientists, managers and other stakeholders, and promotes multi-sectoral integration of key policy decisions (Jacobson, 2003; see Fig. 16.2).

**Adaptive Management of the Akosombo and Kpong Dams: The Purpose**

The Akosombo and Kpong dams’ re-operation and optimisation seek to identify a flow regime with associated requirements through systematic analyses of complex factors. This can be done using experiments, managing learning and application through iterative processes to achieve the desired environmental responses that support acceptable socio-economic benefits (Williams, 2011). This means effectively resolving conflicts and managing trade-offs between key actual and potential stakeholders’ aspirations whilst maintaining sustainable environmental conditions.

The ADM for the Akosombo and Kpong dams’ re-optimisation is a formal process of continually improving management policies and practices by learning from outcomes, and of incorporating natural variability in evaluating the results of management actions.
It is based on the appreciation of the conditions of the entire human-environmental system of the area, based on knowledge generated from feasibility studies commissioned in connection with the re-operation and the restoration projects, and from relevant previous studies. It goes beyond solely on tracking and reacting to the fast, immediate variables, which would lead to perpetual reactive or crisis management; rather, as explained by Light and Blann (2001), it is a planned approach that will reliably show why policies and management actions succeed or fail.

The context of the Lower Volta

The Lower Volta River stretches from Kpong to the estuary at Ada, though governance and policy considerations will necessitate the incorporation of the entire Volta Basin and transboundary concerns. This reach of the Volta River is of interest to the project because the Akosombo and Kpong dams, built in 1965 and 1982 respectively, have distorted the natural river flows by storing and releasing water to meet electricity demand patterns rather than in rhythm with the seasonal patterns of rainfall and runoff in the catchment area (Barry et al., 2005). The Akosombo dam created Lake Volta, the largest man-made water storage reservoir in the world at the time of construction (Gyau-Boakye, 2001). Twenty-five kilometres downstream, the Kpong dam operates as a run-of-the-river facility with minimal storage to re-turbine the Akosombo releases. The Akosombo and Kpong dams were originally designed to generate an average of 6,100 GWh/yr, which represented 95% of Ghana’s electricity consumption at that time (Barry et al., 2005). In addition to power generation, the Akosombo dam provides some degree of flood protection to areas downstream of the dam due to its very large storage capacity relative to inflow, and Kpong supplies a small amount of irrigation (only about 100 ha) for rice cultivation (Barry et al., 2005). Navigation and a robust lake fishery are important additional benefits of the reservoir (Biney, 2010).
The Akosombo and Kpong dams store water during the rainy seasons, including years of high inflow, for power generation throughout the year, including periods of lower inflow. Denholm et al., (2010) explain that an energy demand pattern normally necessitates the operation and generation at a relatively constant output of power daily and seasonally. The flow regime created by this type of power production is different from the natural river flows (Lytle and Poff, 2004). The effect on the downstream flow pattern is reduced peak flows and increased low flows which practically eliminate flooding that creates links between the river and its floodplains, wetlands, deltas, estuaries, mangroves and beach environments (Alhassan, 2009). The natural hydrological processes promote riverine and marine biodiversity and the environmental services support myriads of human livelihoods (Bergkamp et al., 2000).
Eliminating the annual floods in the Lower Volta River floodplain and estuary has led to a drastic reduction in sediment deposition of farmlands, as natural flooding no longer leaves rich alluvial deposits that improve soil fertility (Baatuuwie, 2015). According to Akrasi (2011), as sediments accumulate in the channel, they no longer replenish the beaches in Ghana, Togo and Benin, resulting in massive beach erosion, loss of mangrove habitats and reduction in the productivity of the Guinea Current and its pelagic fishery. The formation of sandbars at the estuary prevents the intrusion of seawater upstream during high tides. The alteration in the flow regime has led to physico-chemical changes in the water and consequently, a gradual shift in the habitat of clams, from the upper and mid-section of the lower Volta River, towards the estuary, with a substantial decline in abundance of the clam (Abarike et al., 2015).

The slow water movement, coupled with the increase in commercially intensive agricultural activity along the banks, has resulted in a more fertilizer run-off into the river. This, coupled with run-off from nearby cattle stocks and sewage pollution, has caused eutrophication of the river waters (Bobobee et al., 2012). The nutrient enrichment, in combination with the low water velocity, has allowed for the invasion of aquatic weeds. These weeds have become a formidable challenge to water navigation and transportation (Barry et al., 2005). Reduced salt concentrations due to periodic blockade of the Volta estuary by sandbars and the resultant increase in aquatic weed population have created conditions that encourage the emergence of Bilharzia vectors (Biney, 1990). This has raised the prevalence level of the disease to almost 100% among the communities. Currently, large amount of funds are used to physically remove these water weeds.

**Adaptive Management Design: Requirements and Process**

A number of formal definitions have been advanced for adaptive management. The National Research Council (2004) defines it as a ‘decision process with flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood’. Careful monitoring of outcomes that advance scientific understanding and help adjust policies or operations as part of an iterative learning process is stressed.
One of the most popular definitions that provide critical perspectives that guided this project comes from Jacobson (2003). He defines adaptive management as a ‘cyclic learning-oriented approach to the management of complex environmental systems that are characterized by high levels of uncertainty about system processes and the potential ecological, social and economic impacts of different management options’.

Requirements

The above generic explanations of ADM make it clear that not all situations lend themselves to successful adoption and implementation of adaptive management regimes. Hence, prior analysis of the prevailing situation in the area was conducted to examine the suitability of its application to the Lower Volta. This was addressed as part of the formulation of the re-optimisation project. The following conditions justified the adoption of an ADM regime.

- High management uncertainty is a basic requirement for the adoption of adaptive management (Doremus, 2010). Doremus et al. (2011) suggest that in the presence of risk and uncertainty, the adaptive management process provides a capacity to act in an informed, judicious manner.

- Second, there should be the need and opportunity for establishing clear and measurable objectives to guide decision-making for monitoring (Day, 2008; Nyberg, 1999).

- Third, there must be an opportunity to learn and apply learning outcomes to management to ensure improvement (Fabricius and Cundill, 2014). Learning is a key output of the adaptive management process; it is driven by treating management policies as hypotheses and the resulting knowledge is fed into subsequent actions (Tedsen et al., 2013; Stankey et al., 2005). Principally, adaptive management is seen as an evolving process involving learning (the accumulation of understanding over time) and adaptation (the adjustment of management over time) (Williams and Brown, 2014). The sequential cycle of learning and adaptation leads to two beneficial consequences: better understanding of the resource system, and better management based on that understanding (Fabricius and Cundill, 2014).
• Fourth, the project must prioritize and be committed to monitoring to reduce uncertainty (Loucks et al., 2005). Analysis and assessment of monitoring data will result in better understanding of systems processes and improve management based on improved understanding. Without periodic monitoring of the relevant resource attributes, learning and subsequent adjustment of management actions are not possible (Duncan and Wintle, 2008).

**Adaptive management process**

Adaptive management is neither a series of trial and error activities, nor a process of perpetual reaction and crisis management. It is deliberately planned and well structured. It requires explicit design with specific problem-framing, objective setting and problem solving processes, implementation, monitoring and evaluation, roles allocation, relationship management and learning processes. Conventionally, the cycle of the practice of ADM is categorized in two phases: the Set-up or deliberative and the Iterative phases, with typical elements of well-defined structure and sequence. In the development of the ADM for the Akosombo and Kpong dams re-operation and re-optimisation projects, some modifications are made to the conventional approach to suit local circumstances and resource availability.

The set-up phase is for the development and planning of the ADM framework, and takes the greatest amount of time and resources (Williams and Brown, 2014). Williams (2011) states that it takes care of a set of critical activities such as scoping of the problem, objective setting, development of management actions and monitoring and evaluation protocol development. All implementation strategies, resource planning, allocation of roles, governance and communication strategies are addressed at this stage. Main activities in the set-up phase of adaptive management of the Volta re-operation include: stakeholder identification, definition of issues/problems, conceptual framing and hypothesis formulation, objectives setting, management action adoptions, predictive model development, development of monitoring and evaluation protocols, and communicating strategy development, among others. In this framework, some of the stages in this phase are merged (Fig. 16.2).
The iterative phase will utilize the management strategies developed in the set-up phase in an iterative operational implementation, monitoring, evaluation and learning for progressively improved understanding of decision-making and management processes.

**Problem definition, Goal and Objectives setting**

Problem definition and scoping should be based on sufficient information and knowledge of all the systems to be managed. This should include information on both socio-economic and natural resources. This baseline information should reflect evidence of the socio-economic conditions and resources. A conceptual framework should be constructed to identify the linkages between all the relevant factors. Meaningful hypotheses should be formulated as basis for definition of collective acceptable problems. Relevant stakeholders
should be involved in clearly defining the problems to be corrected or managed and scope them, based on group or stakeholder collective-negotiated decisions and choices.

Successful implementation of adaptive management depends on a clear statement of project objectives (Williams and Brown, 2012). These should be derived from the formulated hypotheses. Objectives represent benchmarks against which to compare the potential effects of management actions, and serve as reference points to evaluate the effectiveness of management strategies. Clear and specific objectives should be set for desired performance of environmental conditions of the Lower Volta, energy production and Socio-economic status of the communities of the Lower Volta. The objectives must be negotiated; that is, they must be mutually acceptable to interested stakeholders.

**Options of Management Actions**

Adaptive decision making requires a portfolio of potential alternatives from which actions are selected at each decision point (Johnson et al., 2015). Some actions might have direct or indirect impacts on the systems analysed. Learning and decision making both depend on our ability to recognize differences in the consequences of different actions, which in turn offers the possibility of comparing and contrasting them in order to choose the best action (Williams, 2011; Fabricius and Cundill, 2014).

Specific sites should be identified for planned management actions based on the set of issues at play. Each site should reflect specific problems that stakeholders have mutually identified as requiring corrective actions (Rist et al., 2013; Bormann et al., 1995). This should be a group activity, and the selection should be done with mutually acceptable criteria. The boundaries of each site should be carefully delineated and mapped, and the baseline conditions clearly defined and described in terms of the issues, reasons for the existence of the issues and anticipated level of improvement required.

*Models:* Models play critical roles in adaptive management implementation, as expressions of our understanding of the resource, as engines of ecological inference, and as indicators of the benefits, costs, and consequences of alternative management strategies (Chades
et al., 2012). Models are used to characterize resource changes over time, as the resource responds to fluctuating environmental conditions and management actions (Williams and Brown, 2012). There should be frequent dialoguing with stakeholders about which variables will add the most value to the investigations and negotiations (Walkerden, 2006). If consensus is reached or there is widespread agreement, stakeholders formalize their commitments to each other in a Memorandum of Understanding (MoU), a Statement of Joint Intent, or a similar agreement.

Monitoring

Adaptive management implementation requires monitoring and evaluation to assess progress towards success of management actions performance. Monitoring and evaluation depends on a clear statement of project objectives. Objectives provide the standards for determining the level of performance of different management actions. Monitoring provides the information needed for both learning and evaluation of management effectiveness. To make monitoring useful, choices of relevant environmental/ecological, socio-economic and health indicators should be made. Also, the frequency, extent, intensity, measure etc. of monitoring should be determined. This must be linked closely to the management situation that motivates the monitoring in the first place, as well as to practical limits on staff and funding (Douvere and Ehler, 2011; Johnson, 1999). The motivations for direct usefulness of collecting and analysing information should be clear (Graham and Kruger, 2002). “Who will use the information and for what purpose”, are the most relevant questions (Johnson, 1999).

The approach to the process of the monitoring will be participatory. All key stakeholders will be involved in all stages of the monitoring process, and incorporate methods and indicators meaningful to the stakeholders concerned. Participatory monitoring is not only scientific, but also social, political, and cultural. It requires openness, a willingness to listen to different points of view, recognition of the knowledge and role of different participants. Communities and other stakeholders will be empowered and helped to participate in identifying and measuring key environmental and social indicators, to analyse data and take corrective measures (Allen et al., 2011; Fernandez-Gimenez et al., 2008).
CHAPTER 16

Evaluation, Learning and Decision

Evaluation defines the rules for periodic assessment of data gathered in the monitoring phase. The purpose of evaluation is to determine whether the plan is working as intended, what impacts it is producing and the reasons why it is producing the identified impacts. Analysis of deviations from anticipated levels of performance is determined (McFadden et al., 2011; Franklin et al., 2007). Information collected is analysed and disseminated for decisions and for recommendations for future decisions and actions. Unlike the monitoring programme that is generally continuous, evaluation needs to be either triggered or regulated to happen in certain intervals or in a combination of both (Williams and Brown, 2012). The evaluation programme must achieve a number of objectives, including: examining the adequacy of the monitoring programme; examining the adequacy, appropriateness, efficiency and effectiveness of the strategy in managing risk; addressing the issue of uncertainty by continuous evaluation of management responses and the change in environmental forces; evaluating responses to management decisions; evaluating the impact of change in environmental forces; addressing the issue of uncertainty; and prioritizing emerging uncertainties (Doremus et al., 2011; Plummer and Armitage, 2007).

Learning is a key output of the adaptive management process, and is driven by treating management policies as hypotheses and feeding the resulting knowledge into subsequent actions (Tedsen et al., 2013; Stankey et al., 2005). Principally, adaptive management is seen as an evolving process involving learning (the accumulation of understanding over time) and adaptation (the adjustment of management over time) (Williams and Brown, 2014). The sequential cycle of learning and adaptation leads to two beneficial consequences: better understanding of the resource system, and better management based on that understanding (Fabricius and Cundill, 2014).
Adaptive Management Design for Volta Dams’ Re-optimisation

Design of adaptive management

The design of the ADM (Fig. 16.3) for the Volta (Akosombo and Kpong) dams’ re-optimisation adopted the structured model, processes and principles described in the previous section. In practice, it reflected the details and complexity consistent with the knowledge and information generated from the baseline information and outcomes of previous studies. It is intended to develop an adaptable management regime of monitoring and evaluation of actionable evidenced-based informed decisions appropriate for the achievement of the goals and objectives of the re-operation and restoration of the Kpong and Akosombo dams. The plan outlines the elements of the set-up and the iterative phases. Specification of principles and conditions required for the successful implementation are highlighted.

Fig. 16.3: Adaptive management cycle of the Volta Dam Re-optimization
Stakeholder identification and Communication Strategy

The design acknowledges a diversity of interests across social, economic, administrative and political boundaries, since the project will affect a large number of different stakeholders at local, regional and national levels. These stakeholders value the anticipated outcomes of the re-optimisation implementation differently. Those who are responsible for governance, policy, and implementation decisions, or provide information for the decision-making process in the project area, are deemed parties with significant stakes. Others such as funding agencies are critical actors. Stakeholders with strong interests or considerable influence must definitely be included. These are crucial for conflict resolution, problem scoping and provision of funding. Local organizations and others engaged in advocacy, public education and awareness creation are also stakeholders.

Relevant national and local government institutions, ministries, agencies, central and local governments, policy makers, departments, traditional authorities, community representatives, resources managers, NGOs, CBOs, development partners, regional representatives, identifiable groups, the private sector and industry, etc. are potential specific stakeholders identified for the projects. Scientists from relevant disciplines and institutions are important stakeholders of the project.

To execute an adaptive management strategy for the Lower Volta Restoration, a communication strategy has to be developed. The structure must establish clear lines of communication between the re-optimisation programme management, the ADM Planning team and the various stakeholders. (See Table 16.1)
Table 16.1: Potential group and specific stakeholder groups

<table>
<thead>
<tr>
<th>Stakeholder Groups</th>
<th>Specific Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central and Local Governments</td>
<td>Ghana Government</td>
</tr>
<tr>
<td></td>
<td>Municipal and District Assemblies</td>
</tr>
<tr>
<td>Ministries</td>
<td>Energy and Power</td>
</tr>
<tr>
<td></td>
<td>Food and Agriculture</td>
</tr>
<tr>
<td></td>
<td>Environment, Science, Technology and Innovation</td>
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<tr>
<td></td>
<td>Health</td>
</tr>
<tr>
<td></td>
<td>Water Resources, Works and Housing</td>
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<tr>
<td></td>
<td>Finance Adam</td>
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<tr>
<td>State Departments</td>
<td>Water Resource Commission</td>
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<tr>
<td></td>
<td>Volta River Authority</td>
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<tr>
<td></td>
<td>Ghana Grid Company Limited</td>
</tr>
<tr>
<td></td>
<td>Electricity Company of Ghana</td>
</tr>
<tr>
<td>Communities</td>
<td>Communities where sites are selected are best candidates.</td>
</tr>
<tr>
<td>Scientists and Students</td>
<td>Universities</td>
</tr>
<tr>
<td></td>
<td>Research Institutions</td>
</tr>
<tr>
<td>Traditional Authorities</td>
<td>Communities selected for implementation most appropriate</td>
</tr>
<tr>
<td>Regional Representatives</td>
<td>Neighbouring countries: Burkina Faso, Togo, Mali, Benin, Cote d’Ivoire</td>
</tr>
<tr>
<td></td>
<td>Volta Basin Authority</td>
</tr>
<tr>
<td>Private Sector and Industry</td>
<td>Tourism, hotel, real estate</td>
</tr>
<tr>
<td>NGOs and CBOs</td>
<td>To be selected for implementation</td>
</tr>
</tbody>
</table>

Problem framing and hypotheses formulations

The ADM examined various reports compiled by the studies commissioned in connection with the re-optimisation project to identify the most critical issues in the basin. These included environmental, economic/livelihoods, social and health issues that are relevant to the stakeholders involved. These were defined in terms that were clearly understood by all stakeholders. A team of stakeholders must assist in selecting the most important issues in relation to the ecological, socio-economic and other challenges being addressed.

A critical first step in the dam re-operation and restoration project was to gain an understanding of the nature and magnitude of the emergent hydrologic changes engendered by the construction and operations of the dams. Informed by this knowledge, scientists and water managers understood and postulated the connections between hydrologic
alterations, and the consequent ecological and socio-economic issues. Studies conducted at the start of the Volta Dam re-operation project allowed insights into what may require fixing, depending upon the ecological and social goals for the project.

The framework (Fig. 16.4) focusses primarily on the downstream section of the dam. It examines the ecological and socio-economic consequences associated with the flow alterations, and the implications for the Lower Volta catchment ecosystems and community livelihoods. These linkages informed the formulation of suitable hypotheses that link hydrologic alterations to the dynamics of fauna and flora populations, and their distribution in both water and flood plains (Barry et al., 2005). The linkages were ranked and prioritized to identify flow characteristics that could have significant ecological consequences. Testable hypotheses describing the understanding of the flow-ecology relationships should be formulated. These hypotheses provide foundations for experimental testing during the implementation of the re-operation scheme.

Conditions that are directly tied to specific ecosystem services such as commercial or subsistence fish populations were prioritized. In this connection, seasonal flooding of farmlands and inundation of fish breeding grounds were priority considerations for the productivity of agriculture and fisheries. These dynamics are important for livelihood flows that are linked to socio-economic conditions such as employment, household income, poverty, job availability and family stability (Gyau-Boakye, 2001). Other issues that are directly or indirectly linked to the flow alterations, ecological impacts and socio-economic dynamics were diseases and recreational/tourism infrastructure or sites (Fig. 16.4).

It is recommended that the linkages are examined from the perspective of ecosystem services of support, provisioning, regulating and culture.
Fig. 16.4: A Conceptual Framework of the Volta Dams Operational Impacts on Downstream Ecology and Communities
The complex nature of the interactions of the system and subsystems of the entire Lower Volta ecology and communities was fully acknowledged. Predicting the outcomes of environmental-human responses to management interventions is challenging. Therefore, the effort to gain knowledge from such complex systems is based on stochastic, rather than deterministic logic. The predicted outcomes of applying re-operational interventions or management actions are chanced/probabilistic rather than deterministic and the purpose of adaptive management implementation. This is realised by minimized potential risks whilst improving the chances or likelihood of success of the intervention implementations by controlling the complexity of interactions, and manipulating factors through iterative processes of experimentation and learning (Allen et al., 2011; Blann and Light, 2000).

In the Volta Dam re-operation and restoration processes, hypotheses will guide the direction of interventions and actions of ADM. These formulated hypotheses are based on a concrete understanding of flow regimes and socio-ecological responses captured in constructed conceptual framework designed for the ADM process.

The following broad and specific problem areas were identified for problem management during the re-optimisation project. (See Table 16.2)
### Table 16.2: Issues and Specific Problem Areas

<table>
<thead>
<tr>
<th>ISSUES</th>
<th>SPECIFIC PROBLEM AREAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental/ecological</td>
<td>• Hydrological</td>
</tr>
<tr>
<td></td>
<td>• Estuary processes</td>
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<tr>
<td></td>
<td>• Salinity and salt intrusions</td>
</tr>
<tr>
<td></td>
<td>• Aquatic waterweed infestation</td>
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<tr>
<td></td>
<td>• Soil on flood plains and farmlands</td>
</tr>
<tr>
<td>Health</td>
<td>• Malaria</td>
</tr>
<tr>
<td></td>
<td>• Diarrhea</td>
</tr>
<tr>
<td></td>
<td>• Salinity related</td>
</tr>
<tr>
<td></td>
<td>• Bilharzia</td>
</tr>
<tr>
<td>Socio-economic</td>
<td>• Cropping systems</td>
</tr>
<tr>
<td></td>
<td>• Fishery</td>
</tr>
<tr>
<td></td>
<td>• Poverty levels</td>
</tr>
<tr>
<td></td>
<td>• Animal rearing</td>
</tr>
<tr>
<td></td>
<td>• Other livelihoods</td>
</tr>
<tr>
<td>Governance and institutional</td>
<td>• Governance structure and decision processes</td>
</tr>
<tr>
<td>capacity</td>
<td>• Institutional capacity</td>
</tr>
<tr>
<td>Power generation</td>
<td>• Adequacy of generation power generation</td>
</tr>
<tr>
<td></td>
<td>• Supply of water to reservoir</td>
</tr>
<tr>
<td></td>
<td>• Water supply from reservoir to downstream</td>
</tr>
<tr>
<td>Population, settlements and</td>
<td>• Population/Settlements</td>
</tr>
<tr>
<td>infrastructure</td>
<td>• Infrastructure</td>
</tr>
<tr>
<td></td>
<td>• Tourism</td>
</tr>
</tbody>
</table>

### Description of sites for ADM implementation activities

The management activities will be applied in a wider area and different localities. However, areas with pronounced expressions of specific problems, and those with baseline information will be prioritized. The selected sites must be carefully and objectively selected based on stakeholder-negotiated decision criteria for each issue. This could be done by using GIS as a decision support system since the choice process will be both spatial and integrated, and will also ensure objectivity. Areas with the highest values for the GIS analyses must be chosen as candidates are further considered in a final selection process in respect of stakeholder considerations. This final selection process should identify sites agreeable to all, which must be the locations for intervention actions, and for the implementation of monitoring and evaluation activities. The number of sites selected for each issue would depend on:
• The importance of the issue considered (e.g., seriousness of impact) (Williams and Brown, 2014).

• Pervasiveness or geographical spread.

• The variability in the issue and its effects along the stretch of the Lower Volta.

• The density and size of population impacted.

• It would be preferable to use the same sites for different issues in cases where a number of issues being addressed occur concurrently, or in localities where issues with widely known causal relationships co-exist.

### Monitoring and Evaluation Strategies

Monitoring and evaluation depends on a clear statement of project objectives. Objectives provide the standards for determining the level of performance of different management actions. The objectives were derived from the specific problems and the anticipated outcomes. Specific indicators were selected for these objectives. All key stakeholders will be involved in all stages of the monitoring process. It will be ensured that the adopted indicators are meaningful to the stakeholders concerned. The social processes of openness, willingness to listen to different points of view, and recognition of the knowledge and role of different participants are recommended.

The monitoring programme is designed to be able to evaluate the adequacy of the plan to capture changes and to make required refinements when necessary (Williams and Brown, 2014). The Volta Dam ADM will use three types of monitoring: compliance monitoring, effectiveness monitoring, and targeted studies (Williams and Brown, 2012).

• **Compliance monitoring**: will examine the level of compliance of project execution/implementation with the dictates of design of planned actions (Sreekanth and Datta, 2013; Williams and Brown, 2012) (Table 16.4).

• **Effectiveness monitoring**: this evaluates the success of the planned management actions in meeting the stated objectives (Williams and Brown, 2012) (Table 16.3).
- **Target monitoring**: this is a more detailed version of effectiveness monitoring. It provides the opportunity to experiment and pro-actively assesses the environmental, social and economic responses to management decisions. (Table 16.4)

### Table 16.3: Action impact monitoring

<table>
<thead>
<tr>
<th>Issues</th>
<th>Objectives</th>
<th>Indicators</th>
<th>Measurement</th>
</tr>
</thead>
</table>

### Table 16.4: Strategy/action effective monitoring

<table>
<thead>
<tr>
<th>Monitoring Types</th>
<th>Expected compliance</th>
<th>Real Nature of deviations</th>
<th>Frequency of deviations</th>
<th>Remarks</th>
</tr>
</thead>
</table>

**Broad Activities for developing monitoring strategy**

The following specific activities need to be carried out to develop the protocol.

- Identification of identifiable stakeholder groups and capacity-building needs
- Identifying indicators for all the factors to monitor, and agreement on operational definition for the indicators to monitor
- Design and tools for data collection and analysis

**Data collection, analysis and information dissemination**

Responsibility for monitoring activities must be allocated. Who will use the information and for what purpose are some of the most relevant questions. It is essential to identify the following stakeholders for these monitoring activities:

- Who will collect and register particular information?
- Who collates information?
- Who analyses information?
- Where data collection and analysis occur (which community or site/area)?
- Which sampling methods to use?
- When and how often do the relevant activities happen (which month/week/day)?
- Who disseminates the final findings, how it is done and with whom the findings are shared?

The evaluation strategy would follow the one adopted for the monitoring, except that the deviation between actual measured responses from management actions or interventions and expected/predicted socio-economic conditions based on management models/decisions must be compared. This should stimulate a progressive learning process that improves knowledge of the socio-economic conditions of the Lower Volta, and informs adjusted and enhanced management decisions for next actions.

**Management actions and responsible organizations**

Management action will be targeted to address specific issues in the localities identified. These actions are largely the recommendations made by studies conducted for the re-operation project. It is, however, suggested that recommendations made are subjected to further discussions by the stakeholders for acceptance. Others must be designed to complement the proposed ones. The actions should be conducted with full reference to the set objectives and formulated hypothesis.

The actions should be undertaken at particular times when the desired effect could be optimized. Target groups and implementing partners should be selected by the working groups and key stakeholders. Responsible institutions, communities, groups and individuals should be selected for these activities. For those who will be part of implementation, it will be important to build their capacities to enable them effectively apply and engage in the actions.
Iterative phase of ADM

The actual process of adaptive management entails decision-making that reflects the current levels of understanding. Decision making at each decision point considers management objectives, resource status, and knowledge about consequences of management actions. Decisions are then implemented by means of management actions.

Follow-up monitoring

Monitoring will provide information to establish the status of socio-ecological and economic conditions of the Lower Volta, directly or indirectly affected by the Volta Dam re-operations. Information generated will underpin decision making and facilitate evaluation and learning after decisions are made. It will be an ongoing activity, conducted according to the protocols developed in the set-up phase.

Assessment

Data produced by the monitoring activities, along with other information captured from other relevant sources, will be used to evaluate management effectiveness, understand resource status and reduce uncertainty about management effects. Outcomes predicted by models will be compared with data-based estimates of actual responses.

Learning and feedback

Understanding derived from the monitoring and evaluation will inform decisions on the choice of future management actions. The iterative cycle monitoring, assessment, learning and feedback must lead to improved knowledge and better understanding of the socio-ecological dynamics and enhanced methodologies (Williams and Brown, 2012). Ultimately, the improved knowledge must drive a series of adjustments in the flow regime and management strategy. Periodically, the project objectives, management alternatives, and other elements of the set-up phase need to be reconsidered for adjustment as part of the double loop process of the adaptive management process.
Conclusions, Challenges and Recommendations for Successful ADM Implementation

Usually, human-environment/natural resource systems are managed based on the assumptions that socio-economic systems and natural/environmental capital remain static in structure and process. Thus, management decisions fail to anticipate, capture and benefit from accurate knowledge that minimizes management uncertainty and improves management effectiveness. Uncertainties, which are key requirements for the applications of ADM, are also a source of challenge for its developments and implementations. It is instructive to mention these two sources of uncertainties: first, natural uncertainties inherent in complex environmental systems vary in time; and second, the failure to capture actual processes at play in the Lower Volta which were the basis for formulating the problems, the objectives and associated actions.

It is suggested that the re-optimisation implementation working group fully recognize these critical sources of uncertainties, and carefully isolate the natural environmental uncertainties from those associated with changes in the construction of the dam. Further, inherent socio-economic challenges in the communities that are independent of those occasioned by the damming must be identified and addressed. In the implementation, adequate information must be generated to progressively improve the understanding of the socio-economic and ecological issues in the Lower Volta, and how they respond to different flow regimes.

Not all stakeholders, especially, not the communities, were adequately equipped to engage in the design process of the ADM at the deliberative or set-up phase. Thus, they may have missed opportunities to adequately negotiate some of the objectives. To make the achievement of the socio-economic objectives of the re-optimisation project a reality, coordinators of the implementation at the iterative phase must train the people in these communities for an actual and meaningful re-optimisation project. It is suggested that the recommendations made for stakeholder participation are considered and adhered to.
References


Bird, E. (2012). The Socioeconomic Impact of Hydroelectric Dams on Developing Communities: A Case Study of the Chalillo Dam and the Communities of the Macal River Valley Cayo District, Belize, Central America (Doctoral dissertation, University of Vermont).


CHAPTER SEVENTEEN

PUBLIC HEALTH IMPACT OF DAM RE-OPTIMISATION AND RE-OPERATION: THE CASE OF THE LOWER VOLTA BASIN

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Abstract

The concept of dam re-operation is a strategic adaptation to restore hydrological situations to, if possible, pre-dam water flow regimes so as to reverse environmental conditions that support the proliferation of water-related disease vectors. This is expected to cause a reduction in prevalence of these diseases in downstream communities. The idea of the re-operation of the dams is premised on the notion that the spill gates of the Akosombo dam could be opened and controlled to mimic the pre-dam flow regime of the Volta. If this were done, the river would assume a close to natural state, thus mitigating most of the problems associated with sluggish flow such as the proliferation of aquatic plants which comes with several waterborne diseases. This study thus sought to specifically examine possible public health impacts in the event of the Akosombo and Kpong dams’ re-optimisation and re-operation. Both primary and secondary data were collected between April 2013 and May 2015 for the study. Key activities undertaken included exploratory visits, community fora, surveys, hospital data reviews and environmental assessment. The risk assessment covered risk of bilharzia, malaria, malnutrition, onchocerciasis and flooding,
among others. The assessment revealed that in the event of the re-operation and re-optimisation of the dams, the risk status of bilharzia and malnutrition would reduce. However, that of malaria, flooding and diarrhoeal diseases, among others, is expected to increase during periods of high water releases downstream. This chapter concludes by providing mitigatory measures for the high public health risks identified.

Keywords: Public health, Water related diseases, Aquatic vegetation, Heavy metals, Mitigation

Introduction

The development of rivers for hydropower has conventionally come at a high cost in terms of riverine livelihoods and ecosystem services (Okoye and Achakpa, 2007). This is because the construction of such hydroelectric dams has often resulted in the creation of large water bodies whose ecological dynamics with their floodplains affects the livelihoods and health of communities downstream of such dams. In Ghana, the creation of the Akosombo and Kpong dams on the River Volta are classic examples. The Akosombo dam was completed in 1965, forming Lake Volta, the largest man-made lake in Africa and the world at the time (Gyau-Boakye, 2001). Twenty-five kilometres downstream, the Kpong Dam operates as a run-of-the-river facility with minimal storage to re-turbine the Akosombo releases. The Akosombo and Kpong dams were originally designed to generate an average of 6,100 GWh/year which was 95% of Ghana’s electricity consumption (Barry et al., 2005). In addition to power generation, the Akosombo dam provides some degree of flood protection and the Kpong dam supplies a small amount of irrigation (only about 100 ha) for rice cultivation. Navigation and a robust lake fishery are important additional benefits of the reservoir (Biney, 2010).

In Ghana, the demand for electricity has increased over the years. This has resulted in the operation of the Akosombo hydropower to generate a relatively constant output of power daily and seasonally (Barry et al., 2005). The construction of the Akosombo dam has distorted the natural river flow as a result of storing and releasing water in rhythm with the
patterns of electricity demand (Lytle and Poff, 2004). The effect on the downstream flow pattern is to reduce the peak flows and increase the base flows, effectively eliminating the dynamic interactions between the river and its floodplains, wetlands, deltas, estuaries, mangrove and beach environments (Alhassan, 2009). These are the great engines of riverine and marine biodiversity and the environmental services that they provide for the myriad of human livelihoods that are dependent upon a fully-functioning river system (Bergkamp et al., 2000). These hydropower dams have also devastated the livelihoods of the downstream communities and the physical ecosystem processes on which they depend. This has resulted in a drastic reduction in floodplain agriculture as natural flooding which brought rich alluvial deposits that improved soil fertility in the overlying upland areas no longer exists; instead, there is the growth and explosion of exotic weeds that have choked off the once lucrative shell fishery (Baatuuuwie, 2015).

The creation of the dams has changed the fast flowing river system to a much slower one and this has promoted the breeding of certain vectors of diseases and the emergence of new epidemiological patterns. Further to this, conditions are also created for increased disease transmission associated with inadequate sanitary measures in the lakeside settlements (Zakhary, 1997).

In many developing countries, there are dam-related public health concerns with high rates of infection and adaptability of some of the waterborne diseases. Financial constraints and poor adherence to control measures, among others, contribute to these high rates (Molyneux, 1997). The communities living downstream of the Akosombo dam in Ghana are no exception. The Akosombo and Kpong dams’ re-optimisation and re-operation project seeks to contribute to economic growth and poverty reduction through improvement of downstream ecosystem functions and livelihood. The aim of this study was to assess the public health impacts in the event of the Akosombo and Kpong dams’ re-optimisation and re-operation.
CHAPTER 17

Methods

Study area

The study area was downstream of the Akosombo and Kpong dams to the estuary of the Volta River. The area is within the coastal savannah climatic zone in Ghana. The Lower Volta experiences two rainy seasons from March to November with peaks in May/June and October. The number of rainy days in the area ranges between 60 and 120 in a year (MWH, 1998). The mean annual rainfall in the area is about 870.4 mm/yr with mean annual temperature around 27.9°C and annual relative humidity between 74% and 94%. The main water source in the basin comes from stream flows and groundwater. The Lower Volta stream flow is derived mainly from turbined water from Akosombo and the Kpong hydropower facilities. The mean flow rate of the river per annum ranges from $35.6 \times 10^9$ m$^3$/yr to $38.2 \times 10^9$ m$^3$/yr (FAO, 1997), depending on the period covered by the data set used in the flow estimation. Due to the fact that stream flow in the Lower Volta is controlled by reservoir operations at Akosombo, the high seasonal variation in flows, as observed in most of the Volta Basin, is absent in the Lower Volta. The predominant vegetation is grassland and shrub or thicket, but strand and scrubby mangrove vegetation occur along the coastal fringe and in the Volta Delta.

Vulnerable communities identified in eight districts stretching from the Akosombo dam to 100 km downstream to Ada were studied (Fig. 17.1). The communities and districts selected were Adidome in North Tongu, Sogakope in South Tongu, Central Tongu, Big Ada and Ada Foah in Dangme East, Asutsuare in Shai-Osudoku, Lower Manya Krobo, Keta and Asuogyamang. The delineation of study area (districts) was done by reviewing Volta Basin Research Project reports, holding consultations with Volta River Authority and making a reconnaissance trip.
Fig. 17.1: Map showing sampling area for environmental assessment.
Scoping activities

Scoping activities involved exploratory visits to the study area, consultative meetings with key stakeholders, interviews and community fora to facilitate information gathering and to establish contact with key influential people whose networks helped the project team access relevant documents and information in relation to the project.

Epidemiological methods were used for conducting situational and potential risk assessment. This involved the collection of both primary and secondary data. Both primary and secondary data were collected between April 2013 and May 2015, using questionnaires that were analysed to postulate the health impacts should the dams be re-optimised. Primary data consisted of 1) questionnaire guided interviews with key stakeholders including Community leaders, Assembly men, Chiefs, Heads of households and Community members, 2) consultation with District health management groups, Disease Control officers, Local health facilities, Volta River Authority, and Public Health Management Committees, 3) hospital data, 4) direct site observations 5) environmental sampling for bilharzia vectors. Secondary data comprised district health and VRA public health reports. Information gathered targeted existing dam related health problems, potential disease risks and the bilharzia vector density situation, general expectations and views on expected effects of re-operation of the dams and mitigation measures. Assessment of stakeholders’ opinions on the project (e.g., expectations, fears and responsibilities) was done through community fora, interviews, questionnaire administration and field observations.

Environmental Assessment

The sampling area for environmental assessment is presented in Fig. 17.1. The prevailing water quality situation of the study communities was assessed by collecting water samples and analysing them for key physico-chemical parameters. Both physical and chemical parameters such as temperature, pH, salinity, total dissolved solids, dissolved oxygen, and electrical conductivity were determined using an OAKTON PCD650 Waterproof Portable Meter kit. Heavy metal concentration was analyzed using the atomic absorption spectrophotometry (AAS).
Snail density assessment was also conducted along the human water contact sites in the study area. This was done by sampling for snails within a 1 m² quadrat at 20 m intervals over a 100 m shore line distance. Snails collected were sent to the University of Ghana Ecological Laboratory for identification.

Results

Identified Public Health Risks within existing environmental conditions

The key public health issues to be impacted by re-optimisation of the dams were identified as follows 1) Vector borne diseases such as malaria and schistosomiasis (bilharziasis), dracunculiasis (Guinea worm disease) filariasis (elephantiasis) and onchocerciasis (river blindness); 2) drinking-water related diseases such as diarrhoea, cholera; 3) skin diseases; 4) malnutrition; 5)access to health-care service 6) medicine and technology; 7) flooding; and 8) drowning

Table 17.1 provides a summary of public health risks within the existing environmental condition and project impact.
<table>
<thead>
<tr>
<th>Health issues</th>
<th>Environmental situation promoting health problem</th>
<th>Community Vulnerabilities Root causes/social, economic, cultural</th>
<th>Expected Environmental change</th>
<th>Mitigative/adaptive opportunities, Risk status associated with project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilharzia</td>
<td>Slow flow rate of the riverine system, sedimentation and high nutrient load, aquatic vegetation proliferation, Water quality support vector establishment.</td>
<td>Heavy human water contact activities (children swimming, bathing, women engaged in washing, men, bathing, fishing), use of water transport, Majority of affected persons self-medicate, limited potable water and sanitation infrastructure</td>
<td>Periodic changes in river flow rates, washing downstream of aquatic vegetation and schistosomiasis vectors, disruption of disease transmission by salt intrusion - difficulty to access river water for domestic use for safety reasons during periods of increased flow releases.</td>
<td>District Assemblies must enhance their efforts at provision of water and sanitation infrastructure. (Approaches such as Community Led Total Sanitation- CLTS may be used to facilitate sanitation practices and infrastructure provision). Provide support for Zoomlion brigades (they contribute to cleaning human water contact site), Ghana Health Service must intensify mass drug administration activities in the study area.</td>
</tr>
<tr>
<td>Malaria</td>
<td>Poor environmental sanitation, discharge of grey water openly, open defaecation, inadequacy/unavailability of drainage infrastructure in rural communities. -Indiscriminate dumping of waste, -children under 5 years and pregnant women at higher risk of malaria.</td>
<td>Release of water during re-operation may cause flooding resulting in increased number of stagnant pools for breeding mosquito, increase growth of surrounding grasses close to households.</td>
<td>Promotion of the usage of insecticide treated nets by Ghana Health Service; Undertake mosquito control (spraying), environmental and health education through the use of environmental health officers, community health practitioners/ NGOs/CBOs and community advocates; promotion of registration of National Health Insurance; Community involvement in national sanitation day; improved access to health facilities (health centres, CHPS compounds).</td>
<td>Increased risk during high flows</td>
</tr>
<tr>
<td>Health issues</td>
<td>Environmental situation promoting health problem</td>
<td>Community Vulnerabilities Root causes/social, economic, cultural</td>
<td>Expected Environmental change</td>
<td>Mitigative/adaptive opportunities, Risk status associated with project</td>
</tr>
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<td>-------------------------------</td>
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<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Skin diseases</td>
<td>Frequent contact with river water.</td>
<td>Bathing, swimming and washing in river, water transport (people often have to wade in river to get into canoes)</td>
<td>Human water contact activities may reduce because of increased flow rates and associated safety issues</td>
<td>Health awareness creation by health authorities, promotion of registration on National Health Insurance Scheme, improved access to health facilities (health centers, CHPS compounds), participating in national sanitation day, promote good hygiene practices</td>
</tr>
<tr>
<td>Diarrhoal Diseases</td>
<td>Poor environmental sanitation, practice of open defecation, Intense human activities in river system, high prevalence of diarrhoeal diseases in the study area. Reported in the top 10 OPD diseases</td>
<td>Practise open defecation, inadequate toilet, poor hand washing practices and general hygiene practices, unavailability of safe potable water</td>
<td>Flooding may result in outbreak of diarrhoeal diseases including cholera</td>
<td>Provision of water and sanitation infrastructure must be expanded and hygiene education enhanced</td>
</tr>
<tr>
<td>Health issues</td>
<td>Environmental situation promoting health problem</td>
<td>Community Vulnerabilities Root causes/social, economic, cultural</td>
<td>Expected Environmental change</td>
<td>Mitigative/adaptive opportunities, Risk status associated with project</td>
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</tr>
<tr>
<td>Malnutrition</td>
<td>Loss of soil fertility, reduction in fish catch from unsustainable fishing practices, reduction in clam production because of changes in the riverine ecology.</td>
<td>Many lower Volta community members have migrated out of the area, less hands to engage in farming, farming not considered to be lucrative by younger generation-out migrate to the cities for supposed better job opportunities.</td>
<td>Downstream flooding of flood plains, restoring flood plain agriculture, increased spawning grounds for fish. Short term farming activities disrupted from flooding,</td>
<td>Interventions by Ministry of Food and Agriculture must be put in place to promote agriculture among the youth, Moderate reduction in risk</td>
</tr>
<tr>
<td>Intestinal worms</td>
<td>Endemic in the area</td>
<td>Poor hygiene practices, children at risk of infection</td>
<td>Increased flow rates of river may cause overflows into human habitations and possible flooding of sanitation facilities (pit latrines KVIPs, and in places where open defaecation is practised, expanding exposure to eggs and larvae of intestinal worms in the immediate term)</td>
<td>Need for District Assemblies to enforce sanitation regulations and enhance the workings of sanitation courts, Community health nurses, CBOs/NGOs promote good hygiene practices, parents/guardians must permit school aged children to participate in national deworming exercise, Increased risk</td>
</tr>
<tr>
<td>Health issues</td>
<td>Environmental situation promoting health problem</td>
<td>Community Vulnerabilities</td>
<td>Expected Environmental change</td>
<td>Mitigative/adaptive opportunities, Risk status associated with project</td>
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</tr>
<tr>
<td>Onchocerciasis</td>
<td>Eliminated in the area due to reduced river flow rate</td>
<td>High concentration of small settlements along the river Volta</td>
<td>Re-emergence of the disease is dependent on how water is regulated with re-operation of the dams and also restoration of high flows and suitable habitat may provide suitable environment for blackflies to deposit egg.</td>
<td>Disease surveillance unit of the Ghana Health service must expand their surveillance activities for black flies and larvae in the area, Community health nurses, environmental health officers, NGOs/CBOs engage in community education on the disease, prevention, vector features to establish early warning systems for control activities to be implemented if required.</td>
</tr>
<tr>
<td>Flooding</td>
<td>Topography is low lying.</td>
<td>Location of settlements very close to river banks</td>
<td>Possible effect on aquaculture industry - increased of infectious diseases e.g. malaria, diarrhoea, risk of infection, water-borne diseases contracted through direct contact with polluted waters, such as wound infections, dermatitis, conjunctivitis, and ear, nose and throat infections.</td>
<td>-regulate flow of water during re-operation of dam so as not to suddenly release significant amounts of water downstream, -Municipal and district assemblies and communities trained to construct dry water holding ponds adjacent to river banks and streams -NADMO establish emergency preparedness measures, including putting in place early warning systems and community notification procedures.</td>
</tr>
<tr>
<td>Health issues</td>
<td>Environmental situation promoting health problem</td>
<td>Community Vulnerabilities Root causes/social, economic, cultural</td>
<td>Expected Environmental change</td>
<td>Mitigative/adaptive opportunities, Risk status associated with project</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td>--------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Drowning</td>
<td>Vast body of the Lower Volta River</td>
<td>Usage of the river for domestic, occupational, recreation and transport purposes</td>
<td>Anticipated increased water currents from re-operation of dams</td>
<td>NADMO lead community education and awareness creation about risks of drowning, deploy life savers at human water contact sites (e.g. we observed the presence of Volta Lake transport staff (life savers) at Kpong periodically). Early warning systems must be put in place NADMO must also enhance efforts in using traditional warning systems, and community education</td>
</tr>
<tr>
<td>Health care infrastructure</td>
<td>Adequate number of health care facilities in many of the communities. Level of facility range from CHP's compound, health centres, clinics (both private and governmental), hospitals, active presence of health volunteers in some communities that support professionals.</td>
<td>Limited access to health facilities because of non-renewal of NHIS cards, challenges of drugs stocking, irregular payments to providers for submitted claims.</td>
<td>Possible resurgence and increase of prevailing diseases of public health concern e.g. onchoceriasis, malaria, diarrhoeal diseases etc.</td>
<td>The Ghana Health Service with the National Health Insurance Authority must forestall potential challenges in stocking of drugs and other health supplies, Need for health education of community members on, promotion of NHIS registration to facilitate access to health care</td>
</tr>
</tbody>
</table>
Schistosomiasis

The slow rate of flow of the Volta River downstream with coastal sandbar formation, high nutrient load, and the proliferation of aquatic vegetation have created favorable conditions for *Schistosoma* vectors. However, sampling along human water contact sites revealed low occurrence of vector snails in many of the sampled sites in 2014 (Fig. 17.2). Urinary schistostomiasis prevalence in the Lower Volta area, below the Akosombo dam, ranged between 38.8-96.2% in school-aged children after the dams’ creation (Wen and Chu, 1984). Recent studies have however shown downward trends in schistosomiasis prevalence rates in the area. Nkegbe (2010) reported urinary schistosomiasis prevalence rates ranging between 2 and 21% in five Lower Volta Communities. Similar observations have also been made by the VRA public health team (VRA, 2012). In 2012, urinary schistosomiasis prevalence was 24.5%, 13.6% and 6.2% at Asuogyaman, North Tongu and South Tongu districts respectively.

Heavy human water contact activities (children swimming, bathing, women engaged in washing, men engaged in fishing), were the main cause of their vulnerability. Limited potable water and sanitation infrastructure were indicated by the communities to be the root causes of the high prevalence of the disease, especially among school aged children.

Environmental assessment also reveals varied levels of aquatic weed proliferation as shown in Table 17.2. Aquatic vegetation proliferation also varied at various human water contact sites surveyed (Table 17.2). The Kpong head pond was the most infested with vegetation. Although manual and mechanical clearing of aquatic weeds is being undertaken in the Kpong head pond, it was not seen to be impacting positively on vegetation cover at the human water contact site here. Also, intense human activity was observed at the Kpong head pond when the team visited. Although generally low vector densities were observed in many of the human water contact sites except for the Kpong head pond which was heavily infested, the prevailing conditions observed continue to be conducive for vector life.
**Table 17.2: Aquatic vegetation situation in selected human contact sites**

<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinates</th>
<th>Elevation (m) above sea level</th>
<th>Aquatic vegetation situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Atimpoku</td>
<td>N 06° 13.957' E 000° 05.603'</td>
<td>26</td>
<td>There was evidence of removal of aquatic vegetation at this site – thus no significant aquatic plant presence. However, patches of the following plants were observed: <em>Ceratophyllum sp.</em>, <em>Vallisneria</em>, <em>Ludwigia sp.</em>, <em>Ipomea</em>, <em>Polygonon</em>, <em>Cyperus sp.</em>, <em>Echinochloa sp.</em>, <em>Vossia</em>, <em>Cupsidata</em> (grasses).</td>
</tr>
<tr>
<td>2 Kpong Head Pond</td>
<td>N 06° 09.520' E 000° 03.879'</td>
<td>25</td>
<td>There was heavy proliferation of aquatic vegetation. The ‘normal’ members of the aquatic vegetation of all life forms was observed in significant quantities especially <em>Azolla</em> and <em>Lemna</em> spp., despite the presence of harvesters. Emergents: Grasses – <em>Vossia</em>, <em>Echinochloa sp.</em>, <em>Nymphaea sp.</em> <em>Ludwiga</em>, <em>Polygonum</em>, <em>Ipomea</em>, <em>Typha</em>, <em>Cyperus sp.</em>, Sedges. Submerged: <em>Ceratophyllum</em>, <em>Vallisnena</em> Floating: <em>Pistia</em>, <em>Nymphaea</em>, <em>Neptunia</em>, <em>Azolla</em> <em>Lemna</em>, <em>Salvinia</em>.</td>
</tr>
<tr>
<td>3 Asutsuare</td>
<td>N 06° 05.754' E 000° 11.966'</td>
<td>15</td>
<td>No significant aquatics found at the sampling/water collection site. Yet “sudds” dominated by <em>Vossia</em> and <em>Echinola</em> species found in the vicinity.</td>
</tr>
<tr>
<td>4 Asutsuare Rice Farm</td>
<td>N 06° 04.615' E 000° 12.988'</td>
<td>16</td>
<td>There was evidence of removal of aquatic vegetation to enhance water flow in canals; Vegetation mainly composed of <em>Ceratophyllum</em>, <em>damasum</em>, <em>Typha</em>, <em>Vallisneria</em>, <em>Potamogeton</em>.</td>
</tr>
<tr>
<td>5 Volivo</td>
<td>N 06° 06.049' E 000° 15.013'</td>
<td>11</td>
<td>No significant vegetation presence was observed at the collection site except the grass-dominated vegetation in the environs and main channel. Water collection site has bamboo well extending into the river. <em>Water hyacinth</em> (<em>Eichhornia crassipes</em>) sighted at time of survey. These obnoxious aquatics which have recently invaded the Lower Volta Basin poses danger to aquatic life in the area and are likely to spread.</td>
</tr>
<tr>
<td>6 Battor</td>
<td>N 06° 04.359' E 000° 24.168'</td>
<td>1</td>
<td>Aquatic vegetation was present at the sampling site in marginal quantities probably due to massive sand mining activities. The following macrophytes were observed at this site: <em>Cyperus</em>, <em>Vossia</em>, <em>Echinochloa sp.</em>, <em>Loudetia</em>, <em>Phragmites karka</em>, <em>Entamopogrhoana</em>, <em>Oryza longistaminata</em>, etc.</td>
</tr>
<tr>
<td>7 Mepe</td>
<td>N 06° 04.839' E 000° 26.143'</td>
<td>7</td>
<td>Water collection site is (virtually) free from any significant macrophyte presence. However, the following - <em>Nymphaea</em>, <em>Ceratophyllum</em>, Grasses (<em>Vossiacupidata</em>, <em>Echinochloasp.</em>), <em>Phragmiteskarka</em>, <em>Oryzalongistaminata</em>, <em>Lemna</em> were found. Grasses dominate vegetation at this site.</td>
</tr>
<tr>
<td>Location</td>
<td>Coordinates</td>
<td>Elevation (m) above sea level</td>
<td>Aquatic vegetation situation</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
<td>-------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>8 Sogakope</td>
<td>N 05° 59.741' E 000° 35.269'</td>
<td>3</td>
<td>Grasses such as <em>Vossiacupidata, Echinochloa sp., Leersia sp., Leptochloa</em>, were in appreciable quantities with water hyacinth. <em>Commelina</em> (a semi-aquatic), <em>Polygonum, Ipomoea, Ludwigia, Lemna, Azolla, Ludwigiastrontera, Ludwigialeptocarpa, L. hyssopifolia, L. eracta, Nephthia, Mimosiapigra, Alternantherassesslis</em></td>
</tr>
<tr>
<td>9 Sogakope</td>
<td>N 05° 59.741' E 000° 35.269'</td>
<td>3</td>
<td>Similar situation as Sogakope 1: <em>Commelina</em>, water hyacinth. Water collection site untidy due to presence of remnants of dredged aquatics, some in decomposing state. Plants found were similar to those found at Sogakope 1 in addition to <em>Andropogon</em> on the shore.</td>
</tr>
<tr>
<td>10 Anyanui</td>
<td>N 05° 47.073' E 000° 43.312'</td>
<td>4</td>
<td>Very fine loose sand substratum. Widespread vegetation dominated by mangroves, grasses and <em>Ceratophyllum</em>. Shells of snails are abundant here. The water lies just behind a market. Human activities were enormous.</td>
</tr>
<tr>
<td>11 Ada (Azizanya)</td>
<td>N 05° 46.516' E 000° 39.127'</td>
<td>8</td>
<td>Very clean sampling site and completely devoid of any aquatic vegetation.</td>
</tr>
<tr>
<td>12 Dzetokoe</td>
<td>N 05° 53.889' E 000° 36.561'</td>
<td>5</td>
<td>Massive water hyacinth (<em>Eichhornia crassipes</em>) vegetation opposite the sampling site seemed to be in transition/moving. This island of vegetation were aided by wind action as it was moving against water flow impeding the movement of a passenger boat, which could not land. Plants encountered here included <em>Pycreus, Cyperus, Commelina, Bracharia, Water hyacinth (Eichhornia crassipes), Typha, Nymphaea, Grasses (Vossia, Echinochloa sp.)</em></td>
</tr>
<tr>
<td>13 Agorta</td>
<td>N 05° 51.481' E 000° 38.974'</td>
<td>12</td>
<td>Massive weed presence dominated by Water hyacinth (<em>Eichhornia crassipes</em>), <em>Bracharia, Ceratophyllum, Pycreus, Vossia, Echinochloa sp.</em>, <em>Leersia sp.</em> and <em>Paspalum orbiculae</em>.</td>
</tr>
<tr>
<td>14 Togorme</td>
<td>N 06° 06.927' E 000° 08.132'</td>
<td>9</td>
<td>Aquatic plants and patches in marginal quantities, especially grasses (<em>Bracharia, Ceratophyllum, Pycreus, Vossia, Echinochloa sp.</em>, <em>Leersia sp.</em> and <em>Paspalum orbiculae</em>). Potamogeton observed for first time in survey. Others include <em>Vallisneria, Ceratophyllum, Aponogoton, Cyperus, Ludwigia Polygonum</em>.</td>
</tr>
<tr>
<td>15 Fodzoku</td>
<td>N 06° 09.155' E 000° 06.978'</td>
<td>26</td>
<td>Similar situation to that of Torgome but additionally had <em>Typha, Cyperus, Luffa, Ipomoea, Azolla, Ceratophyllum, Acrostichum, Salvinia, Ludwigia, Polygonon, the Grasses (Bracharia, Ceratophyllum, Pycreus, Vossia,Echinochloa sp.,Leersia sp. and Paspalum orbiculae)</em></td>
</tr>
<tr>
<td>16 Volo</td>
<td>N 06° 03.720' E 000° 18.051'</td>
<td>7</td>
<td>Aquatic plants and patches in marginal quantities, especially grasses (<em>Bracharia, Ceratophyllum, Pycreus, Vossia, Echinochloa sp.</em>, <em>Leersia sp.</em> and <em>Paspalum orbiculae</em>). Potamogeton observed for first time in survey. Others include <em>Vallisneria, Ceratophyllum, Aponogoton, Cyperus, Ludwigia Polygonum</em>.</td>
</tr>
</tbody>
</table>
Malaria

Malaria is endemic in Ghana. All health facility reports reviewed in the study area placed malaria on top of the ten diseases most frequently reported to the outpatient departments (OPD). Malaria cases often peak during the major rainy season between May and August and the minor rainy season in September/October.

The vast riverine system, coupled with the proliferation of aquatic weeds and poor environmental sanitation practices, all tend to promote mosquito breeding. The time within the year when the spill gates would be opened may also impact on malaria transmission patterns. Inhabitants of settlements close to the river banks are likely to have increased exposure to mosquito bites. It is anticipated that under dam re-operation scenarios, more mosquito breeding sites in the form of small pools of water may be created from flooding during periods of high flows. Study communities attributed the environmental cause of malaria to poor environmental sanitation, the open discharge of grey water, defaecation in the open, inadequacy/unavailability of drainage infrastructure and indiscriminate dumping of waste in rural communities. Children under 5 years and pregnant women were noted to be at a higher risk of malaria.

Onchocerciasis, Dracunculiasis and Filariasis

Onchocerciasis has not been of significant public health importance in the post dam era in the Volta River basin. No report of the disease was observed from health facility data and community survey. Earlier studies have shown that the larvae of the black fly (*Simulium sp.*) thrive in waters with velocity preferences of 0.5 to 2.5 m/s (Phillipson, 1957).

Although dracunculiasis and filariasis were never mentioned during stakeholder assessment, the literature indicates that these diseases were found at some time in the Lower Volta Basin (Bene and Russel, 2007). Dracunculiasis (Guinea worm disease) has been eliminated countrywide but filariasis is still endemic in some areas in Ghana. Mosquito species belonging to the *Anopheles, Culex and Aedes* genera are carriers of the filarial parasite (De Souza *et al.*, 2012). Thus the possibility of filariasis occurring in the area cannot be ruled out. It is anticipated that disease surveillance will be enhanced to prevent the upsurge of the disease.
Skin disease

Skin disease is frequently reported as one of the water associated diseases in riverine communities studied and, from district health reports analysed, it is also among the top 10 outpatient diseases. Riverine communities associate skin diseases with frequent contact with river. Water is a known carrier of many bacteria and parasites that can penetrate the skin and create skin inflammations, e.g., cercarial dermatitis.

Diarrhoeal and intestinal worm diseases

Diarrhoea is endemic in the study area and reported as one of the major health problems by riparian communities. Poor environmental sanitation, limited toilet facilities, poor hygiene practices and the siting of toilets close to river banks are among other factors that account for the prevalence of this disease. It is expected that during high flows associated with dam re-operation, the situation could be aggravated as flood waters overflow onto the river banks and nearby communities, thereby flooding toilet systems and spreading diarrhoea disease-causing agents and intestinal worm infestation.

Malnutrition

Although malnutrition was mentioned by some health care workers in study communities, particularly in the Adidome and Sogakofe areas, it did not feature prominently among the ten top Out-Patients-Department morbidities in the health facility reports. Nevertheless, evidence of loss of soil fertility and dwindling agriculture, clam picking, and fishing activities in the lower Volta River basin is well documented and may be associated with malnutrition reported in some of these riverine communities.

Flooding and drowning

The study revealed that many inhabitants have moved to settle close to the river banks since the reduction of the flow rate in the riverine system. The Volta Basin Research Project’s environmental impact study of the dams found that there were over 130,000 inhabitants in more
than 400 small rural settlements along the Volta River downstream to the estuary (VBRP Report 1996). With human settlements in close proximity to the river system, intense human activity is observed to be ongoing along river banks. The Lower Volta River system also serves as a means for domestic water supply, bathing and swimming; it is used for transport and for many other economic ventures such as aquaculture, clam picking and sand winning, among others. During re-operation of the dam, it is anticipated that released water will cause high water currents, thus posing a risk to users of the river. There is the need to educate lake shore community members on anticipated changes in the riverine system as well as develop and establish early warning systems to reduce possible drowning cases.

Health care infrastructure

Health care infrastructure in the Lower Volta Basin can be said to be adequate. Many of the rural communities have either a Community Health Planning Systems (CHPS) compound or a health centre. Urban areas are also well endowed with health facilities ranging from clinics to community hospitals and district hospitals. Generally, access to health facilities in urban areas can be said to be adequate, and many of the road networks to these hospitals are tarred. On the other hand, road networks to rural communities are mostly untarred and can be rendered unmotorable, especially with increased water releases during re-operation of dams. Almost all CHPS compounds and health centers have motorbikes to facilitate transportation of health workers. The presence of health volunteers in many of the rural communities also helps to enhance health service delivery. Fortunately, all governmental health institutions are service providers under the National Health Insurance Scheme. Nevertheless, the management challenges faced by the scheme are a major potential threat to public health. Irregular payment of claims impacts negatively on the ability of the institution to stock drugs and medical supplies. In spite of such challenges, promotion of registration onto the insurance scheme is important to facilitate access to health care.
Snail density and physico chemical parameters

Low vector densities were observed in many of the human water contact sites except for the Kpong head pond which was heavily infested (counted the highest number of snails (62) per 1 m² quadrat, made up of one *Biomphalaria sp.* and sixty-one *Bulinus sp*). Sogakofe, Alorkpeme and Agator had marginal infestation (Fig. 17.2).

![Snail vector density along communities of the Lower Volta in March 2014](image)

Salinity level was zero in upstream communities and increased to 2ppt (parts per thousand grams) in communities closer to the estuary (Fig. 17.3). Similar trends are observed with electrical conductivity as it is a measure of nutrients and salts in water (Fig. 17.4). Many of the heavy metals tested for were also undetected except for iron, nickel, magnesium and cadmium. Iron and nickel levels were low in the water column while magnesium and cadmium were found to be much higher within the water column of sampled localities (Fig 17.5).
Fig. 17.3: Water salinity variation in the Lower Volta

Fig. 17.4: Variation in electric conductivity (EC) in the Lower Volta
Discussion

The Volta River, downstream of the Akosombo and Kpong dams, serves as an important resource for many thousands of inhabitants (Barry et al., 2005). It serves as a major source for domestic water supply and water transport, supports fish aquaculture industry and is a location for an emerging sand winning business. The water system also provides a suitable environment for vectors of schistosomiasis and malaria to thrive. While the re-operation of the dams is expected to restore livelihood opportunities lost with damming, it is also anticipated to impact on the public health of communities in close proximity to the dams and along the river downstream. The expected environmental changes in case of re-operation of the dams include periodic increases in river flow rates from increased water releases from the dam mainly in an attempt to restore pre-dam riverine conditions. In the process it is anticipated that this activity will result in downstream washing of aquatic vegetation and schistosomiasis vectors, thereby intermittently disrupting schistosomiasis transmission. While re-operation of the dams is likely to reduce schistosomiasis transmission, it may promote the upsurge of malaria, skin related diseases and water borne diseases...
such as diarrhoea. Previous studies for instance have shown floods to be significantly associated with an increased risk of cases of infectious diarrhoea (Ding et al., 2013; Joshi et al., 2011). Similar evidence has also been shown in the case of malaria and other water related infections (Tempark et al., 2013; Kondo et al., 2002; El Sayed et al., 2000). On the other hand, although dracunculiasis and filariasis were never mentioned during stakeholder assessment, these diseases were found at some point in the Lower Volta Basin (Bene and Russel, 2007). Dracunculiasis (Guinea worm disease) has been eliminated countrywide but filariasis is still endemic in some areas in Ghana. Mosquito species belonging to the Anopheles, Culex and Aedes genera are carriers of the filarial parasite (De Souza et al., 2012). Thus the possibility of filariasis prevailing in the area cannot be ruled out. It is anticipated that surveillance will be enhanced to prevent the upsurge of the disease.

It is envisaged that re-operation of the dams in the short term may disrupt farming activities, thereby impacting negatively on malnutrition. However, in the medium term, re-operation of the dam is anticipated to restore the ecological system by flooding the floodplains, enhancing food production and reviving the clam and fishery industry. Generally, the project is expected to improve food security. However, migration of indigenes out of the area was observed and the remaining youth did not seem interested in agriculture. Interventions to promote youth in agriculture should help restore the interest of the youth in agriculture.

Snail density and physico-chemical parameters will also be impacted by the re-operation of the dams. Locations where high snail density was observed were areas with intense aquatic vegetation at human water contact sites. Thus with re-optimisation, when water is released at a faster rate, it will be expected to wash downstream aquatic vegetation that harbors snails and reduce density in locations where they are established. Also, increased volume of water will dilute the water systems and invariably reduce the levels of heavy metal observed.
Conclusion and Recommendations

The impact of the Kpong and Akosombo dams construction continue to be felt by downstream communities. Over the years, changes in the ecological systems have resulted in the loss of agricultural productivity, increased schistosomiasis, proliferation of aquatic weeds in the river including water hyacinth, and out migration of indigenes in search of better economic opportunities. The concept of re-operation of the dams is intended to mitigate these effects of the dam by restoring the ecological system to improve the socio-economic opportunities that were lost by dam construction. Nevertheless, it is also envisaged that, by re-operating the dams, there will also be some negative effects on the downstream communities.

The following interventions are recommended to help mitigate some of the negative effects of re-operation of the dams on downstream communities:

A. Improvement in water and sanitation in the communities concerned
   - provision of potable water and sanitation infrastructure to reduce anticipated impact on water related diseases
   - health education to improve health facility utilization and promotion of registration for National Health Insurance to improve access to health care
   - hygiene and environmental education
   - construction of dry water holding ponds to minimize the effects of flooding
   - Enforcement of sanitation regulation

B. Sensitization of community members on dam re-operation
   - Development of early warning systems to alert community members about floods and risks associated with dam re-operation
   - Education of community members on potential consequences and mitigating measures
   - Mobilizing communities to provide life savers at vantage points along the river system

391
C. Capacity development and support

- Training of health care workers in anticipation of re-emergence and upsurge of water related diseases of public health concern
- State agencies such as NADMO should be active in the Lower Volta communities to help avert disasters that might occur as a result of dams’ re-operation.

References


Ding, G., Zhang, Y., Gao, L., Ma, W., Li, X., Liu, J., Liu, Q., and Jiang, B. (2013). Quantitative Analysis of Burden of Infectious Diarrhea Associated with Floods in Northwest of Anhui Province, China:


Okoye, J.K., and Achakpa, P.M. (2007). Background study on water and energy issues in Nigeria to inform the national consultative conference on dams and development, *Federal Ministry of Agriculture and Water Resources*.  

393


PART FIVE

ALTERNATE APPROACH TO
RESTORING LIVELIHOOD OF
DOWNSTREAM COMMUNITIES
CHAPTER EIGHTEEN

IMPROVING ACCESS TO POTABLE WATER SUPPLY FOR DOWNSTREAM COMMUNITIES OF THE VOLTA LAKE

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Abstract

This study determines the cost effective water facility needed to improve access to potable water supply to 153 communities downstream of the Volta Lake. The study area of about 8,500 km² covers sections of seven (7) Districts and Municipalities including Ada-East, Shai-Osudoku, North-Tongu, South-Tongu, Central-Tongu, and Asuogyaman Districts and Keta Municipality. The selected communities have either inadequate or no supply of potable water; they depend directly on the River Volta. The Vertical Electrical Sounding (VES) Geophysical method in the Schlumberger Electrode Configuration was used to delineate fractures in bedrock and thicknesses of weathered zones in order to assess the groundwater potential of the terrain. The findings of the geophysical studies indicated that North-Tongu District had very low groundwater potential due to the massive outcrop of the basic gneiss basement rock with micro-fracture development. Over 81% of the study communities indicated high groundwater potential (> 100 lpm) to meet the required water demand. However, the low resistivity values toward the southern section of the study area depicted high salinity. The small roof sizes, averaging 10 x 44 m dimensions, of available public infrastructure (e.g. school block) cannot harvest adequate rainwater to
meet the water demand of the beneficiary communities. In addition, aquatic weeds growing in large portions of the lake make the river unsafe for drinking. This requires treatment of raw water drawn from the river as an alternative means to improve access to safe drinking water for the beneficiary communities. Following a careful cost benefit analysis of the possible water supply and treatment facilities, the cost of supplying treated water from the Volta River appeared quite modest, and the potential users considered this option as a welcome idea. It is, however, necessary to integrate the resources available to provide improved quality water resources to address the prime water related national millennium development goals.

**Keywords**: Downstream, Groundwater Potential, Potable water, Public Infrastructure, Rainwater

**Introduction**

The construction of the Akosombo and Kpong Dams displaced a significant number of indigenous people and they were resettled in 52 townships including Adjena, Senchi, New Senchi, Apeguso and Somanya. The Akosombo Dam alone displaced eighty thousand (80,000) people from 739 villages within an area of 8,500 km² whilst the Kpong Dam displaced seven thousand two hundred (7,200) people over an area of 12 km² (Kalitsi and Associates, 2008). The loss of livelihoods of the people at the downstream of the Akosombo and Kpong Dams is a major concern to the local communities (IWMI, 2015; Asare, 2004). Apart from the most visible impact of the Akosombo and Kpong Dams in the form of the inundation of 8,500 km² (Akosombo Dam) and 400 km² (Kpong Dam) of land, access to safe drinking water also was strongly affected (Kalitsi and Associates, 2008), as occurred with the construction of the Badush Dam in Iraq (Aqeel Al-Adili *et al.*, 2014).

Large volumes of water are available in channels of River Volta and its underlying aquifer system for drinking and for domestic use. However, the quality of the available water sources is very poor. Groundwater at the downstream areas of the Akosombo and Kpong Dams indicates a high salinity level and high total iron concentration above the
WHO Guideline Values as a result of leachate of dissolved iron from existing geology and salt infiltration from the sea (Kumar, 2010). This was enumerated in the preliminary studies conducted under the Re-optimization and Re-operation Project of the Akosombo and Kpong Dams. Under reducing conditions, the iron from quartzite, biotite mica and laterites from the existing rock are leached into solution in ferrous state (Kumar, 2010). According to Moore (2004), as stated in the review report by the Institute of Environmental and Sanitation Studies (IESS) for WRC (2013), there is the need for freshwater systems to maintain the ecological integrity of the society. This implies that rivers, wetlands, aquifers and other water systems within the affected areas require a certain fraction of water in sufficient quantities and of an acceptable standard quality to ensure improved livelihood of affected inhabitants.

Generally, environmental flows are necessary to maintain or partly restore the biophysical components and ecological processes of in-stream and groundwater systems, floodplains and downstream receiving waters (Arthington and Pusey, 2003). Shallow aquifers have a higher risk of vulnerability to pollution than deeper aquifer systems. The groundwater quality varies with depth in shallow and deep aquifers (Kumar, 2010). Application of NPK fertilizer used as plant nutrients also results in increased chloride contamination of recharging shallow groundwater (Bohlke, 2002; Abbasi, 1998; CGWB, 2004). Groundwater with high mineral content can be ‘desalinated’ at a much lower cost and with much less waste than desalinated seawater (EPD Guidance Document, 2007; UNEP, 2008). The common method for the removal of iron from water is by aeration followed by sedimentation as well as filtration (Kumar, 2010), whilst chloride can be removed by desalination by means of reversed osmosis (RO). The use of deeper aquifers for domestic water consumption is sustainable, since the recharge rate is of comparable magnitude. However, deeper aquifers should not be used for irrigation until the hydrological and chemical responses to increased withdrawals are better understood (Zheng et al., 2005).

According to the Water and Development Strategy of USAID, 39% of the population in sub-Saharan Africa did not have access to an improved source of drinking water in 2012 (USAID, 2012; World Economic Forum, 2015). The strategy of USAID emphasized water
as a development priority and highlighted its importance to meeting the development imperatives of improved health and increased food security. A report presented to WRC (2013) concerning Environmental Flow, Livelihood Flow and Adaptive Management indicates that because many poor people do not have access to safe drinking water, they are more exposed to water-borne diseases (Kumar, 2010). A review of rural water system sustainability in eight sub-regions, including sub-Saharan Africa, found an average water project failure rate of 20-40% (WHO and UNICEF JMP, 2015). There is the need to provide innovative solutions that can change livelihood through safe drinking water and sanitation as proposed in the proceedings of a stakeholder consultative meeting (National Public Policy Services for Sustainable Dam Development in Ghana, 2009). Several programmes and projects such as the Global Health Initiative, Feed the Future, and the Water for the Poor Act focus on improved access to potable water especially in sub-Saharan Africa. The GLOWA Volta Project (2000-2009) sought to develop a scientifically sound Decision Support System for the assessment, sustainable use and development of water resources under changing land use, rainfall reliability and increasing water demands in the Volta basin.

An average amount of 28.5 liters per capita per day (l/c/d) is consumed by Volta basin households (Asare, 2004). In order to enhance water security, multiple sources are utilized for multiple purposes depending on season and geographic location (Asare, 2004). It is against this background that rainwater harvesting during the rainy season, water from the river Volta and the groundwater system are deployed to meet the need for essential drinking water for the improved livelihood and socio-economic development of the entire country. In view of the adverse effects of the construction of the Akosombo and Kpong Dams on the livelihoods of indigenous people who depend directly on the Volta River resources, this paper reviews the need to provide water with improved quality for the affected communities.

**Study area**

The study area is located between Latitudes (5°30’0’’ N; 6°30’0’’ N) and Longitudes (0°07’0’’ W; 1°0’0’’ E) as shown in Fig. 18.1. It covers
the most affected areas involving sections of seven (7) Districts and Municipalities including Ada-East, Shai-Osudoku, North-Tongu, South-Tongu, Central-Tongu, and Asuogyaman Districts and Keta Municipality. The study area was demarcated based on the proximity of the communities to River Volta, geological considerations, availability of public infrastructure such as school buildings, location within the inundated region, lack of freshwater supply facility and direct dependence of inhabitants on River Volta for livelihood. Based on these criteria, a total of 153 deprived communities were selected in the study area and the extent of degradation associated with the creation of the dams was assessed.

Fig. 18.1: Geological map of project site showing the location of existing boreholes
Aquifer systems in the study area consist of confined, semi-confined and unconfined types. The semi-confined to confined aquifer system is associated with the hard basement rock (quartzite or gneiss) which dominates Asuogyaman, Shai Osudoku and North-Tongu Districts as well as the unconsolidated loose sandy formation with unconfined aquifer system that occurs in the Ada-East District, Keta Municipal Area and sections of South-Tongu District (Kankam-Yeboah et al., 2013). Typically, the major rock type in the extreme north of the study area is quartzite which weathers to form sand and clay. The quartzite basement covers the upstream portion of the study area from Old Akrade cutting across the NE-SW direction. The greater part of Asuogyaman District is underlain by quartzite (Fig. 18.1). Boreholes in this rock type produce water which is usually associated with high iron and/or manganese concentration above the WHO Guideline Values (WHO, 1996) of normal drinking water. Borehole yield mostly varies between 0.72 – 24.3 m$^3$/h with an average yield of 9.2 m$^3$/h.

The success rate of drilling a productive borehole within the Togo Series formation is about 87.9% (Dapaah-Siakwan and Gyau-Boakye, 2000). The major rock type is the gneiss (acidic and basic forms), which weathers to form sand and clay (Kesse, 1985). This rock covers the entire middle portion (about 50%) of the study area. It stretches from Old Akrade to Kpotame covering North-Tongu and portions of Asuogyaman, Central-Tongu and Shai-Osudoku Districts. The central portion of this rock around North-Tongu District (Fodzoku, Aforkpakope, etc.) is extremely massive with only micro-fractures. As a result, groundwater potential is low in the central portion of the study area. The success rate of drilling a productive well within the gneiss basement is 36% with yielding capacity ranging between 1-3 m$^3$/h (Dapaah-Siakwan and Gyau-Boakye, 2000).

The recent and tertiary formation is made up of unconsolidated loose sand covering the southern portion of the study area (Fig. 18.1). It stretches from Atrobinya along the river channel, which increases into an alluvium-fan towards the sea. Groundwater potential is high at the southern sector of the study area; however, its high salinity level due to infiltration from the sea makes the groundwater unsafe for drinking without treatment. The terrain is generally low-lying towards the coast with elevation of less than 50 m above mean sea level (amsl). From
Agbeve stretching to Gbadakope, the terrain rises slightly above 50 m amsl and areas around the mountain ranges at Atimpoku towards the north-western portion in the upstream rises up to about 350 m amsl.

The dry equatorial climate prevails in the upper portion of the area, which has a remarkably dry season with mean annual rainfall values ranging between 740 mm/yr and 890 mm/yr at regional scale, and which is considered to be amongst the driest in the country. The southern part of the study area is marked by annual rainfall between 500 mm/yr and 700 mm/yr at a mean monthly temperature between 22°C in August and 28°C in March/April. The average monthly relative humidity ranges from 60% to 75% (Dickson and Benneh, 2001). The vegetation of the coastal savanna comprises mainly mangrove with coastal shrub and grassland. It is marked by dense scrub west of Accra and mainly grass with isolated patches of scrubs and occasional trees east of Accra. Baobab and neem trees are common, and the wetter parts, particularly east of the Volta River are made up of fan palms and wild oil palms. The coastal savanna climate favours the cultivation of pineapple and pawpaw in the grassland.

As illustrated in Fig. 18.2[A], the majority of inhabitants, who form 50% of the 153 communities depend on the river Volta for access to drinking water. About 46% of the people in 47 communities depend solely on river sources whilst the others rely on alternative sources such as boreholes and rainwater harvesting systems (Fig. 18.2B).
Baseline information indicated a high level of total iron concentration in groundwater towards upstream and increasing salinity in both groundwater and surface water towards the downstream up to the coastline of Ghana. Total Dissolved Solids (TDS) in groundwater optimized from 1,079 mg/l at the upstream to 1,810 mg/l in the mid portion and up to 13,310 mg/l at the downstream towards the coast (WRC, 2013). A reasonable number of existing boreholes within the northern sector of the study area were fitted with hand pumps coupled with iron removal chambers, however, the filtration media had not been renewed or backwashed since its installation, and this had reduced its efficiency in performance. Furthermore, raw water from the Volta Lake is highly contaminated with bacteria as a result of effluent and runoffs from various anthropogenic activities within the catchment, especially with the advent of uncontrolled growth of water weeds and environmental sanitation problems such as open-defecation, which lead to total coliform (TC/100 ml) in the major drinking water source, the Volta River, of between 100 and 1302 (WRC, 2013).

**Methods**

Liaising with the seven (7) District / Municipal Assemblies to observe protocol, permission was sought for entry into communities of the various electoral areas to conduct informant interviews on the situation of water related challenges using the chiefs, elders and opinion leaders of the communities. The reconnaissance survey also aimed at locating target areas for geophysical investigations to assess the groundwater potential of the area as well as rig accessibility for borehole drilling. Furthermore, available public infrastructure was identified to assess its rainwater harvesting potential. During the period, public infrastructure (e.g. school buildings) available were identified and the roof sizes measured to assess their suitability for harvesting rainwater. Finally, information on the drinking water source available, general health status, population and prevailing sanitation situation was obtained from the Chief/Elders and/or Opinion Leaders of the communities visited. Moreover, the state of the Volta River was assessed locally to affirm its usefulness as an alternative source of water supply. The closeness of the communities to the main Volta River was observed.
The Vertical Electrical Sounding (VES) resistivity technique was employed in the field investigations, with the aim of detecting fracture zones, as well as thickness of weathered zones. The Signal Averaging System (SAS) 1000C ABEM Terrameter of precision ±0.5% was used (ABEM, 2006). Ensuring quality control against minimum human error, the equipment was used with an error margin of ±0.38% (Okrah et al., 2012). The RES1DINV software was used to iteratively model each measured VES data to obtain the number of geological layers in the sub-surface, and their corresponding resistivity values and thicknesses, with the view to detecting fractures within the underlying rock. The groundwater potential of communities along the Volta River was assessed using Surfer 10.1 software in order to classify the terrain to propose the appropriate water scheme to mitigate the poor quality drinking water in the downstream communities of the Volta Lake.

Results

Geophysical Survey to assess groundwater potential

The upper portion of the study area, mostly characterized by quartzite dominated basement rock type included Asuogyaman District, which is underlain by 4 to 5 lithological strata with overburden thickness of less than 5 m. The aquifer horizon of the bedrock tomography depicted low resistivity values of less than 100 Ωm around Ghanakpoe and the Marine areas. The associated basement rock is marked with high resistivity values up to a maximum value of 3,000 Ωm whilst Abume recorded above 3,000 Ωm (Fig. 18.3). Within the quartzite basement rock terrain, the lowest resistivity value computed was 40.1 Ωm of 9.6 m thick underlying the topsoil. The trend of decreasing resistivity variation in the upper part of the study area occurs towards Ghanakpoe and Small London as shown in Fig. 18.4, which also indicated the base-flow trend. Abume and its environs have a shallow aquifer section between 4 and 25 m whilst the others have a deep-seated aquifer system between 23 and 75 m thick.
Fig. 18.3: Comparing resistivity tomography of quartzite terrain within Asuogyaman District showing aquifer thickness and poorly weathered hard basement rock located at the Abume, Ghanakpoe, Marine and Gyakiti communities.

Fig. 18.4: Classification of bedrock resistivity and base flow direction of Asuogyaman District.
The middle portion of the study area, involving North-Tongu, is dominated by crystalline gneiss basement rock of the Dahomeyan Formation, which is mostly massive with only micro-fractures. This terrain is underlain by about 3 layers with a less than 4 m thick overburden. The bedrock resistivity varied from high values above 500 Ωm in the southwestern to low values below 500 Ωm in the northeastern corridor of North-Tongu District.

The fractured gneiss aquifer system of the Shai-Osudoku, Central and South-Tongu Districts of the southern sector is underlain by 3 to 4 layers of 8-10 m depth-to-bedrock. In the South-Tongu District, however, the aquifer zone is located beyond 20 m depth with relatively low bedrock resistivity below 9 Ωm. Similarly, Ada-East District and Keta Municipal area are made up of 4 to 5 layers with low resistivity values.

**Rooftop Rainwater-Harvesting Potential**

The existing public infrastructure was mainly public school buildings, which were mostly located within a cluster of communities. The schools with Primary and Junior High School (JHS) served at least three nearby cluster of communities with an average population of 1500 people in each community. Agbeve in South-Tongu District, for instance, had a Primary School Block of dimensions 10.4 x 44.2 m covering a receptacle area of 459.68 m² (Appendix 18.1).

**Water supply from River Volta**

The communities were located on the banks of the river Volta, except a few which were about 300 m away from the river bank. According to the informant survey, 96% of the communities complained of common cases of bilharzia, skin itches, and diarrhea among others as a result of swimming, bathing and drinking raw water from the Volta River.
Discussion

Interview

From the informant interviews of chiefs/elders/opinion leaders conducted, 96% of respondents expressed their concern about the occurrence of health challenges with notable common cases of bilharzia, skin itches and diarrhea associated with body contact and drinking raw water from the Volta Lake. According to the survey, a ratio of over one (1) out of every three (3) communities depended solely on River Volta for drinking water whilst the others combined water from River Volta with other sources such as hand-dug wells and/or boreholes, which are associated with quality problems (i.e high iron concentration and/or salinity).

Geophysical Survey to construct borehole

Groundwater potential of the study area varies as a result of the heterogeneity of the rock formation and the associated geological structure variations. A well-developed fracture matrix in the bedrock and thick permeable overburden promoted groundwater development to improve groundwater potential, as interpreted based on the findings. The northern sector of the study area contributes about 11% of the total groundwater potential liable to produce moderate-to-high yielding boreholes, which could be harnessed to support the water supply system of beneficiary communities along the Volta River. However, the quality is associated with high iron concentration, which could be treated to obtain fresh drinking water.

As a result of the minimal fracture characteristics of the gneiss basement of the mid portion of the study area, the aquifer horizon is mainly shallow within the overburden, which requires consistent recharge from a reliable source. The underlying rock in communities located on the banks of the Volta River, such as Aforkpakope and Zortikpo, are predicted to have moderate-to-high groundwater potential as a result of reliable recharging capacity from the river. The gneiss bedrock of Dahomeyan Formation is moderately weathered to support groundwater development. At Shai-Osudoku District, the aquifer is a
semi-confined to confined system with yielding capacity expected to be between 20 and 100 lpm (Fig. 18.5), which is adequate to meet the water demand of the people. The aquifer system in the Central-Tongu District which is mostly confined between 12 and 45 m deep represents 12% of the total moderate groundwater potential of 53% in the study area (Fig. 18.6).

The southern sector of the study area, on the other hand, is dominated by loose sand of recent/tertiary formation with patches of a hard rock aquifer system. The loose sandy aquifer comprised Keta Municipal, Ada-East District and certain portions of Shai-Osudoku, Central-Tongu and South-Tongu Districts. The generally low bedrock resistivity values (<9 Ωm) of the South-Tongu District indicated moderate-to-high yielding groundwater potential; however, the groundwater quality is expected to be saline. South Tongu District contributed about 38% of the moderate-to-high groundwater potential of the entire project site. The aquifer system of Ada-East District with multiple layers includes unconsolidated loose sand with unconfined sediment and semi-confined limestone aquifer systems. The groundwater yielding capacity is high, but the water is saline, which could be treated. The communities selected in the enclave of Keta Lagoon are marked with reliably high groundwater potential. The groundwater tapping the second limestone aquifer system is expected to provide freshwater. The shallow-to-intermediate aquifer systems at Anyako and Seva areas are saline but can be desalinated by means of reverse osmosis.
Fig. 18.5: Bedrock resistivity variation of the study area showing groundwater potential zones and groundwater flow direction based on variations in apparent resistivity of bedrock (negative values depict salinity)

Fig. 18.6: Groundwater potential categories based on bedrock resistivity assessment of Communities in the study area
Rooftop Rainwater-Harvesting System with Treatment

Notwithstanding the average annual precipitation of about 1000 mm/yr, the average volume of rainwater harvested during the year is 459.68 m³/yr. If the per capita water consumption per person is assumed to be as low as 20 l/day, the water demand for Agbeve community of 1,500 people is estimated to be 30,000 l/day (or 30 m³/day). Thus, Agbeve community alone is expected to consume the total storage of 459.68 m³ for the entire year within 15 days. This leaves a huge deficit in water availability. An alternative source is required to augment the rainwater supply to meet adequate water demand by the cluster of communities in order to prevent water stress in the area.

Supplying Treated Water from River Volta

The communities have attached cultural value to the use of the Volta River and according to informants interviewed, nothing could replace the water from this river. Their cultural belief indicated that the Volta River is a legacy from their ancestors and they need to preserve it for posterity and utilization. They would prefer the water from River Volta be treated for them, in line with their perception. Volo is a community within the Shai-Osudoku District, which is using such treatment facility, dubbed ‘VOLO WATER HEALTH CENTRE’, donated by USAID. The raw water is pumped from the Volta River, chlorinated and runs through multiple filtration systems before it is distributed to the inhabitants of Volo community.

Cost-Benefit Analysis

Prices of goods and services are dynamic depending on the prevailing economic trend and bargaining strategy in the open market, amongst others. It is necessary to address the choice of water system with prudence and critical judgment. Following the estimates of providing about 10,000 L capacity of treated water per treatment process from available alternative water supply sources, rainwater harvesting turns out to be the cheapest means at a unit cost of GH¢9,310.00, but the challenge of inadequate amount of water harvested due to small sizes of available roofs still remains. The cost estimates to provide the same volume of potable water per system for each cluster of communities from alternative sources are itemized below:
<table>
<thead>
<tr>
<th>Item</th>
<th>Water Facility</th>
<th>Cost Estimate per System (GHC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>Rainwater harvesting</td>
<td>9,310.00</td>
</tr>
<tr>
<td>Option 2</td>
<td>Borehole fitted with hand-pump</td>
<td>30,700.00</td>
</tr>
<tr>
<td>Option 3</td>
<td>Mechanized borehole with treatment</td>
<td>71,850.00</td>
</tr>
<tr>
<td>Option 4</td>
<td>Treated water from Volta River Source</td>
<td>54,360.00</td>
</tr>
</tbody>
</table>

Borehole fitted with hand-pump (option 2) comes next after the cost of rainwater harvesting system; however, a desalinating plant cannot operate as auxiliary to the hand-pump for the treatment of high chloride concentration in groundwater. In such treatment, therefore, it is necessary to mechanize the borehole (option 3), which appears to be the most expensive amongst the available systems. The cost of supplying treated water from the Volta River (option 4) to each cluster of communities is quite modest. The indigenous people of the beneficiary communities expressed a desire for the latter option as they considered the river as their cultural heritage.

Conclusion

Groundwater potential is high, yielding above 100 lpm, with rich aquifers covering over 81% of the entire study area. However, the quality of the available sources of water is poor. Though, the quantity of groundwater in the aquifer system exceeds the water demand per the population figures, the quality remains a challenge. The mid portion of the study area involving North-Tongu District recorded relatively low groundwater potential due to the poor weathering condition of basic gneiss bedrock. It is recommended that these areas draw treated water from the Volta River rather than have boreholes provided, as almost all existing boreholes are either dry or marginal with a yielding capacity below 13.5 lpm throughout the year. Existing public infrastructure (e.g. School Buildings) has small roof sizes of average dimensions 10 x 44 m. Subsequently, the volume of rainwater that could be harvested within the rainy period would not meet the expected water demand of the beneficiary communities. The estimated cost of providing rainwater harvesting systems is the lowest followed by boreholes fitted with hand-pumps, then followed by supplying water from the Volta River, and finally mechanized boreholes. However, considering adequacy
of available water supply vis-à-vis optimal water demand per cluster community, it is proactive to adopt the option of tapping raw water from the Volta River to ensure sustainability of potable water supply,

**Recommendation**

1. The rooftop rainwater harvesting system could be provided for the schools only or integrated with other water facilities for the communities.

2. The cost estimates should be used to help proactive decision making on cost-effective water facility needed to improve access to potable water supply to the downstream communities of the Volta Lake. The estimates should further be reviewed to match the prevailing economic trend in order to arrive at a finite decision.

3. Adopting community classification (i.e.: clusters) for the provision of water facility would reduce the cost involved.

4. The study should be replicated in the Bui dam as 168 households of 859 people in 7 villages were affected by the Dam construction.

5. There is a prime need to strengthen effective collaboration among riparian countries in partnership to address issues pertaining to the Volta Basin on a common platform.

6. Programmes and Projects should focus on capacity building and leveraging local partners to minimize over-reliance on donor partners to nurture sense of ownership in the local sector.
## Appendix 18.1: Public Infrastructure (22 schools) identified for rainwater harvesting

<table>
<thead>
<tr>
<th>District</th>
<th>Community</th>
<th>Population (GSS, 2010)</th>
<th>Long</th>
<th>Lat</th>
<th>Public infrastructure</th>
<th>Latrine</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-Tongu</td>
<td>Avegoeme</td>
<td>500</td>
<td>0.61188</td>
<td>5.87930</td>
<td>nil</td>
<td>KVIP(1)</td>
</tr>
<tr>
<td>South-Tongu</td>
<td>Agbeve</td>
<td>1000</td>
<td>0.62590</td>
<td>5.85665</td>
<td>Prim (10.4x44.2m)</td>
<td>pit in community, KVIP in school</td>
</tr>
<tr>
<td>South-Tongu</td>
<td>Agorme</td>
<td>600</td>
<td>0.62322</td>
<td>5.92801</td>
<td>nil</td>
<td>pit</td>
</tr>
<tr>
<td>South-Tongu</td>
<td>Tsatsukope</td>
<td>650</td>
<td>0.63226</td>
<td>5.85145</td>
<td>nil</td>
<td>open defecation along river bank</td>
</tr>
<tr>
<td>Central-Tongu</td>
<td>Mafi-Devime</td>
<td>1500</td>
<td>0.47169</td>
<td>6.05885</td>
<td>Prim (7x56.2m); JHS (13.6x45.9m)</td>
<td>open defecation in town, KVIP for school</td>
</tr>
<tr>
<td>Central-Tongu</td>
<td>Mafi-Dove</td>
<td>3000</td>
<td>0.47323</td>
<td>6.02802</td>
<td>Prim (11.4x53.2m); JHS (11.4x53.2m); Private School (lower Prim)</td>
<td>pit</td>
</tr>
<tr>
<td>Central-Tongu</td>
<td>Mafi-Zortikpo</td>
<td>550</td>
<td>0.51037</td>
<td>6.04274</td>
<td>nil</td>
<td>pit</td>
</tr>
<tr>
<td>Central-Tongu</td>
<td>Mafi-Dugame</td>
<td>600</td>
<td>0.50310</td>
<td>6.04950</td>
<td>Prim (13.2x32.3m); JHS (12.5x36.2m)</td>
<td>pit</td>
</tr>
<tr>
<td>Asuogyaman</td>
<td>Old Akrade</td>
<td>1361</td>
<td>0.10209</td>
<td>6.20301</td>
<td>School Prim, JHS under tree</td>
<td>KVIP (1) full but not dislodged</td>
</tr>
<tr>
<td>Asuogyaman</td>
<td>South Senchi</td>
<td>4631</td>
<td>0.08759</td>
<td>6.19872</td>
<td>School</td>
<td>KVIP (11) full but not dislodged</td>
</tr>
<tr>
<td>Shai-Osudoku</td>
<td>Kortorkor</td>
<td>350</td>
<td>0.28744</td>
<td>6.06761</td>
<td>School (rainwater harvesting installed for the school)</td>
<td>pit</td>
</tr>
<tr>
<td>Shai-Osudoku</td>
<td>Volivo</td>
<td>0.25164</td>
<td>6.09841</td>
<td></td>
<td>School (Prim and JHS)</td>
<td>KVIP (1), Open defecation</td>
</tr>
<tr>
<td>North-Tongu</td>
<td>Torgorme</td>
<td>1532</td>
<td>0.13799</td>
<td>6.11751</td>
<td>School (Prim and JHS)</td>
<td>KVIP (6) but full, open defecation</td>
</tr>
<tr>
<td>North-Tongu</td>
<td>Fodzoku</td>
<td>1969</td>
<td>0.12449</td>
<td>6.16321</td>
<td>School (Prim and JHS)</td>
<td>KVIP (12) but full, open defecation</td>
</tr>
<tr>
<td>North-Tongu</td>
<td>Aforkpakope</td>
<td>226</td>
<td>0.11646</td>
<td>6.15253</td>
<td>nil</td>
<td>KVIP (1), needs dislodgement</td>
</tr>
<tr>
<td>District</td>
<td>Community</td>
<td>Population (GSS, 2010)</td>
<td>Long</td>
<td>Lat</td>
<td>Public infrastructure</td>
<td>Latrine</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>---------</td>
<td>----------</td>
<td>-----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Keta</td>
<td>Seva</td>
<td>838</td>
<td>0.94017</td>
<td>5.98434</td>
<td>school</td>
<td>KVIP (2)</td>
</tr>
<tr>
<td>Keta</td>
<td>Konu</td>
<td>2184</td>
<td>0.92196</td>
<td>5.99469</td>
<td>school (Prim, JHS)</td>
<td>KVIP (2)</td>
</tr>
<tr>
<td>Keta</td>
<td>Anyako</td>
<td>4604</td>
<td>0.91088</td>
<td>5.99633</td>
<td>school (Prim=5, JHS=4 and SHS=1)</td>
<td>KVIP (1), WC</td>
</tr>
<tr>
<td>Keta</td>
<td>β Anyako-Kpota</td>
<td>470</td>
<td>0.90214</td>
<td>6.00890</td>
<td>school (Prim, JHS and SHS)</td>
<td>KVIP (2)</td>
</tr>
<tr>
<td>Ada East</td>
<td>Azizanya</td>
<td>2830</td>
<td>0.64913</td>
<td>5.77560</td>
<td>Lower Prim</td>
<td>WC (not commissioned), open defecation and directly into Volta</td>
</tr>
<tr>
<td>Ada East</td>
<td>¶ Kewunor</td>
<td>1146</td>
<td>0.65701</td>
<td>5.77283</td>
<td>School</td>
<td>Open defecation and on river bank</td>
</tr>
<tr>
<td>Ada East</td>
<td>Kudjragbe</td>
<td>6864</td>
<td>0.61690</td>
<td>5.82168</td>
<td>nil</td>
<td>KVIP (2)</td>
</tr>
<tr>
<td>Ada East</td>
<td>§ Salem-Agorkpo</td>
<td>947</td>
<td>0.61587</td>
<td>5.82486</td>
<td>School</td>
<td>WC, KVIP</td>
</tr>
<tr>
<td>Ada East</td>
<td>β Teye Mensah Panya</td>
<td>2644</td>
<td>0.63707</td>
<td>5.78340</td>
<td>School</td>
<td>WC(2), Manhole leaks, System abandoned, open defecation and directly into Volta</td>
</tr>
</tbody>
</table>

**FOOTNOTE:** | ¶ Communities without electricity; § Communities with clinic on chief’s compound; β Communities with CHPS Centre; CHPS means “Community-based Health Planning and Services”; GSS means “Ghana Statistical Service”
Reference


CHAPTER 18


CHAPTER NINETEEN

HIGH SPATIAL RESOLUTION MAPPING AND MANAGEMENT OPTIONS OF AQUATIC WEEDS AT THE LOWER VOLTA

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Abstract

The altered flow regimes and aquatic ecosystem conditions consequent to the damming of the Volta River have increased the rates of aquatic weed infestation at the Lower Volta. Effective management of aquatic weed infestation and restoration of favourable socio-economic and sound environmental conditions require baseline information that reflects the actual patterns of infestation intensities and a reference for monitoring. A high spatial resolution mapping using GeoEye (46cm) and Pleiades (50cm) imagery was carried out. The aquatic weeds were categorized into three broad classes: 1) Water hyacinth 2) Vossia sp. association and 3) Submerged macrophytes. These were mapped in four sections of the Lower Volta using image segmentation techniques, including: Artificial Neural Networks (ANNs), Histogram Thresholding Segmentation (HTS), Principal Component Analysis (PCA) and Classification. Definite infestation distribution and intensification patterns of aquatic weeds emerged. An estimated 1574.25 ha of floating and emergent aquatic weeds were mapped. This constituted 12.55% of the entire water surface area of the Lower Volta. The highest level of infestation occurred in the Atimpoku-Kpong reservoir and the delta.
areas of the Lower Volta. *Vossia* sp. association occurred closest to the river banks, followed by Water hyacinth. Submerged ones occurred in the open waters. An estimated 230.39 ha and 69.70 ha of *Vossia* sp. association occurred in the Kpong reservoir and Atimpoku area respectively. The highest water hyacinth infestation occurred in the delta area, with an estimated coverage of 54.40 ha. Aquatic weed infestation declined towards the estuary of the Lower Volta. Submerged plants, especially *Ceratophyllum* sp. occurred in extensive massive mats in the estuary area. Options of aquatic weed control strategies are proposed for management and policy considerations.

**Keywords**: Remote sensing, Spatial Resolution, Water hyacinth, Aquatic weed infestation.

**Introduction**

Aquatic plants are key components of freshwater ecosystems. However, high infestation and invasion of aquatic weeds are a major global challenge that requires urgent action (Xu *et al*., 2012). Excessive aquatic weed infestation disrupts aquatic ecosystem structures, functioning livelihood systems of dependent communities, promotes water-related diseases (Hejda *et al*., 2009; Rands *et al*., 2010, Yirenya-Tawiah *et al*., 2011; Hill *et al*., 2012), and interferes with water transport.

Since the construction of the Akosombo and Kpong hydroelectric dams on the Volta River in the early 1960s and 1980s respectively, the resultant regulated discharge and flow regimes have significantly modified the ecological conditions of the Lower Volta River, resulting in the proliferation of aquatic weeds, with adverse socio-economic impacts. High infestation and invasion of aquatic weeds are a major global challenge which requires urgent action (Xu *et al*., 2012). Consequently, an important objective of the Volta Re-operation and Re-optimization project was to reduce the aquatic weed infestation to levels for maintaining aquatic ecological conditions conducive to deriving optimal socio-economic benefits for local communities. An effective management regime requires accurate baseline information on infestation levels and nature of weed distribution at the Lower Volta (Baker *et al*., 2012). Such information will enable identification of
hot spots for priority interventions and provide reference information for monitoring and evaluation activities.

Yet, a comprehensive up-to-date high resolution data/information on weeds at the Lower Volta is unavailable. Available data cover only isolated localities, thus failing to reflect a complete picture of the situation. Accurate maps allow resource managers to assess the composition of plant beds and the abundance of species either directly or indirectly for targeted management (EPPO, 2012).

Hitherto, the challenge has been how to generate comprehensive information at a suitable scale and resolution. Standard methods of mapping aquatic macrophyte beds involve surveys of vegetation using sampling and field observations in quadrats or transects. These methods are often expensive, time consuming and tend to spread the aquatic weeds to new areas (Vis et al., 2003; Nelson et al., 2006). Additionally, field sampling and mapping techniques can disturb the vegetative beds and wildlife (Shuman and Ambrose, 2003), and are impractical for inventorying larger waterbodies (Nelson et al., 2006).

Emerging geo-information technologies and tools have made it possible to generate timely data and information that enhance decision-making processes in time and space (Cavalli et al., 2009; Schmidt and Witte, 2010). High resolution satellite imagery is a potentially cost-effective way to gather information about aquatic macrophyte communities. In particular, remote sensing can be used to economically map aquatic vegetation in lakes spread out over a large area as they cost as little as one half of the expenditure for traditional surveying methods (Valta-Hulkkonen et al., 2005).

A number of studies have shown that remote sensing is effective for mapping aquatic macrophytes (Ciraolo et al., 2006; Underwood et al., 2006; Laba et al., 2008). Remote sensing is most effective in mapping emergent, floating and submerged macrophytes (Nelson et al., 2006; Underwood et al., 2006; Laba et al., 2008). Aerial photography has been the most widely used method in mapping aquatic vegetation (Marshall and Lee, 1994; Valta-Hulkkonen et al., 2005). Yet, as high spatial resolution satellite images have become available, there has been a shift in preference for such imagery in aquatic vegetation mapping (Everitt et
al., 2005; Nelson et al., 2006; Everitt et al., 2008; Laba et al., 2008). Satellite data-based mapping is more effective when a wider geographic area has to be mapped and regularly monitored (Madden, 2004).

This mapping exercise of the Lower Volta River was designed to make extensive use of remote sensing and geographic information technologies to map the dominant aquatic weed distribution, intensity, nature and patterns of infestation. This is a requirement for a better appreciation of aquatic weed infestation. It provides reference information for monitoring and evaluation and for formulating relevant strategies for managing aquatic weeds and associated ecological and socio-economic impacts.

Materials and Methods

The Study Area

The section of the Lower Volta mapped stretches across the Asuogyaman District, through the North, Central and South Tongu districts, to the Lower Manya, Shai-Osudoku and Ada East Districts. The Kpong Dam forms an important feature of the Lower Volta (Fig. 19.1). The creation of the dam at Akuse has modified the hydrological conditions, resulting in regulated flow throughout the year. Flooding, which occurred during raining seasons, and which brought with it a high load of sedimentation, has been curtailed. Changes in the aquaric ecology have promoted the growth and invasion of aquatic weeds. Also, high human activity such as open defecation, fertilizer run-offs from nearby farms and siting of refuse dumps along the banks of the river have led to nutrient pollution of the river, which encourages the prolific growth of aquatic weeds.

The study operationally defines the Lower Volta River as the entire stretch from the Akosombo Dam to the estuary at Ada. For the mapping exercise, the area was divided into four sections; this was to ensure design validity, convenience and ease of presenting information on areas with similar characteristics, levels of general aquatic weed infestation, and intensity of water hyacinth infestation. The Kpong reservoir and areas towards Atimpoku constitute Section A; Section
B comprises the area immediately below the Dam at Akuse to Volo in the North Tongu District; Section C spans the area between Volo and Sogakope; whereas the southern sections – from Sogakope to the estuary form Section D (Fig. 19.1).

**Fig. 19.1: The Lower Volta and the Adopted Mapped Sections**

### Sub-division of the Lower Volta

- **SECTION A:** The zone from Atimpoku to the site of the Kpong Dam. The section has the Kpong reservoir, an important feature that influences the entire lower hydrology.

- **SECTION B:** Torgome to Battor Dugame. This is considered the first part of the middle section which is relatively narrow in cross-section.
CHAPTER 19

- SECTION C: Battor Dugame to Sogakope. This forms the second part of the middle section, with a similar characteristic as Section B.
- SECTION D: Sogakope to the Volta Estuary. This forms an important part of the Lower Volta, with a complex structure of many islets of different sizes and water channels with wider sections. The southern portion (estuary) has a direct contact with the sea.

**Methodology**

**Remote Sensing-based aquatic weed mapping: challenges and solutions**

The presence of populations of different species in a pixel, even at high spatial resolutions, poses a challenge in aquatic weed mapping (Peng et al., 2016; Jones et al., 2014; Selkowitz, 2014). Also, absorption of usable reflectance of Electromagnetic Radiation (EMR) by water constrains the identification and discrimination of aquatic plants, especially submerged ones. Suspended and dissolved materials vary over geomorphological gradients, meteorological conditions, flow conditions, and land use practices. These influence remote sensing of submerged aquatic systems by limiting the detection of submerged aquatic plants as light attenuates with depth, altering the water-leaving reflectance.

To minimize these challenges, very high spectral and spatial resolution images were used. Different segmentation algorithms with higher discriminating power were employed as indicated below. An intensive ground-truthing exercise was undertaken for identification and verification. Channels with high capacity for portraying features below the surface of water bodies were used. In addition, a simple classification scheme of fewer categories of mappable aquatic weed formations was adopted.
Aquatic plant survey and adopted mapping classification scheme

Field surveys were undertaken to identify and geo-reference key aquatic weed populations and communities. Areas where the CSIR-Water Research Institute (WRI) was commissioned to undertake studies on biological controls of aquatic weeds received higher priority attention to ensure the availability of adequate data/information for future monitoring and evaluation of the outcome of the weed control activities. Photographs of plant species and communities were taken for illustrative purposes and supervised classification processes.

Weed population and communities of mappable coverage were targeted for the mapping. Species with socio-economic and ecological importance were prioritized. Three classes of aquatic weed formations/assemblages in mappable quantities were adopted and mapped. These were:

1. Water hyacinth (*Eichhornia crassipes*).
2. *Vossia* sp. association: a mixed population of aquatic weeds dominated by *Vossia* sp. *Vossia* sp. association occurred mostly along the banks of the rivers and creeks. Some plants that formed part of the class included: *Aponogeton pectinatus, Commelina diffusa, Cyclosorus striatus, Ipomoea aquatica, Ludwigia stolonifera, Neptunia oleracea and Typha domingensis*.
3. Submerged aquatic weeds: These were either rooted or floating. *Vallisneria* sp. and *Ceratophyllum* sp. were the commonly found species. The submerged class was sub-divided into deeply submerged aquatic weeds (found is comparatively deeper water) and partially submerged aquatic weeds (whole plants found in shallow waters, just beneath the surface of the water, or partially exposed above the surface of water).

**Satellite data, Software and Digital Processing**

A careful search of satellite data was conducted based on spatial and spectral resolutions, availability, data recency and quality in terms of reduced cloud cover and haziness. Two satellite data types: GeoEye and Pleiades met the established criteria, and hence were chosen. Software used for the data processing and analysis were ArcGIS, ENVI and Erdas Imagine.
Image segments were merged by mosaic techniques to form seamless larger ones that covered larger sections of the lower Volta. Pansharpening, a process of fusing high-resolution panchromatic and lower resolution multispectral imagery to create a single high-resolution colour image to increase spatial resolutions of multispectral channels, was carried out. The panchromatic channels for the Pleiades (50cm) and GeoEye (46cm) were used to pansharpen the multi-spectral channels. Geometric correction and geo-referencing of the image were undertaken by the use of the UTM coordinate system to enable quantitative spatial analysis. Radiometric correction was done. Image enhancement was undertaken to improve visual interpretation of the composite image. Spectral analysis of identifiable features was conducted for sampled localities. Spectral profiles were examined to determine the relative spectral characteristics of the various weed aggregation types and environmental entities such as water, land vegetation and bare lands.

**Aquatic weed segmentation and mapping accuracy**

The study acknowledged the existence of different segmentation techniques based on the level of automation and human control. There are manual, semi-automated and fully automated procedures. The study employed a mixture of these techniques in different locations and situations. These are noted to ensure that future image processing and analysis employ similar procedures for harmonization for valid comparative analysis. The following is an outline of procedures employed in the study.

Classification: it is the clustering of similar objects, and it has been a commonly employed technique for grouping similar objects and differentiating dissimilar ones. In this exercise, both supervised (semi-automated) and unsupervised (automated) classification techniques were applied. However, the outputs were not satisfactory: in most cases, the unsupervised classification procedures returned outputs far fewer than the stipulated number of classes.

Normalized Difference Vegetation Index (NDVI): this is an index that provides indicative information on chlorophyll content and photosynthetic activity. It varies depending on season, species, amount of vegetation and radiation reaching plants, as in the case of submerged aquatic plants (Becker *et al.*, 2013; Schneider and Fernando, 2010).
Principal Component Analysis (PCA): this is a multivariate statistical technique that summarizes or reduces information content of data sets into a few uncorrelated information components or mathematical functions. In this exercise, the information content in the satellite channels was used.

Histogram Thresholding Segmentation Techniques (HTST): this was developed in the field of Computer Vision for image processing, and is normally introduced as a second step in the typical workflow of satellite image analysis in order to improve the classification results. Different configurations and numbers of these techniques were combined and applied in different areas, based on their suitability in different situations.

Artificial Neural Networks (ANNs): Object recognition consists of locating the positions and possibly orientations and scales of instances of objects in an image. The purpose may also be to assign class labels to detected objects, in this case aquatic weeds. In this application, ANNs were trained to locate aquatic weeds and other objects based directly on pixel data (Fukumi et al., 1997).

Validation and Accuracy of some segmentation procedures were based on field information and segmented classes. Different levels of scales were adopted for the whole and parts of the area for different details of information.

**Results**

In the current mapping exercise, the plants were generally smaller in size, with the majority of the populations occurring in smaller pure aggregations. A mixture of different plant species occurred at the same location, making it practically impossible to differentiate them by existing technologies. The senescence stage of plants with minimal photosynthetic activity limited their remotely-sensed value for the analysis. For example, *Aponogeton sp.* was at the stage of senescence at the time of the imagery in November 2015. The presence of extensive mats of deeply submerged plants (e.g. *Ceratophyllum* sp.) was difficult to determine for mapping.
The categories of aquatic weed populations and communities occurred in different infestation intensities and definite distribution patterns of coverage and associations. A clear relative abundance in spatial occurrence emerged; there was dominance of some of the categories in sections of the river. Fig. 19.2 illustrates the types of aquatic weeds that were identified and mapped.

Spectral Characteristics

Generally, different classes of aquatic weeds reflected unique patterns of spectral characteristics. Water hyacinth recorded the highest spectral reflectance mean value (1842.548) in infra-red, followed by the *Vossia* sp. association and then the slightly submerged macrophytes. The deeply submerged plants recorded the lowest reflectance mean value (267.515) in infra-red. With channel 3 (red), the *Vossia* sp. association recorded the highest mean reflectance value (645.560), followed by water hyacinth (587.783). Distinct spectral patterns were observed for the different identifiable aquatic weed formations. In the raw data of the reflectance values, the infrared separated the different classes to a greatest extent. Water had lowest values for R, G and Infra-red. The NDVI (Table 19.1) output indicated that water hyacinth had the highest values, with water having the lowest values. The ANNs similarly extracted the *Vossia* sp. association with a very high segmentation accuracy of 99.89% and a Kappa coefficient of 0.98.

Table 19.1: NDVI Statistics for features. (Water has the lowest values, with water hyacinth having the highest values).

<table>
<thead>
<tr>
<th>Feature Class</th>
<th>No. of Pixels</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water hyacinth</td>
<td>2568</td>
<td>0.360740</td>
<td>0.588704</td>
<td>0.512460</td>
<td>0.041863</td>
</tr>
<tr>
<td>Water</td>
<td>26075</td>
<td>-0.504660</td>
<td>-0.427056</td>
<td>-0.464889</td>
<td>0.010405</td>
</tr>
<tr>
<td>Vossiasp Association</td>
<td>6470</td>
<td>0.142049</td>
<td>0.426144</td>
<td>0.302662</td>
<td>0.041434</td>
</tr>
<tr>
<td>Submerged (Deep)</td>
<td>3595</td>
<td>-0.436548</td>
<td>0.115821</td>
<td>-0.382751</td>
<td>0.040984</td>
</tr>
<tr>
<td>Submerged (Close to surface)</td>
<td>4053</td>
<td>-0.386010</td>
<td>0.289709</td>
<td>-0.168271</td>
<td>0.111821</td>
</tr>
</tbody>
</table>

Figures 19.2b and 19.2e illustrate *Vossia* sp. association which were consistently oriented against the flow of the water flow at Atimpoku, the northern part of Section A. The coverage of aquatic weeds at Atimpoku area in Section A (Fig. 19. 3a) was estimated at 69.70 ha. In the Kpong Reservoir of Section A, the area closer the Kpong township was the most infested, with an estimated 230.39 ha of *Vossia* sp association mapped.
Figure 2: Aquatic weed types mapped in the study. These were distributed in distinct patterns of coverage.
a) Mapped *Vossia sp* Association by ANNs in Atimpoku in section A. The higher coverage of infestation is more against the flow of water.
b) High Aquatic weed infestation at the upper sections of the Kpong Reservoir. The intensity of infestation may have been driven by relatively low depth and pollution of water in the area.

*Fig. 19.3: Aquatic weed maps in/at the Atimpoku and Kpong Reservoir(s) in Section A*

Common submerged aquatic plants identified included *Vallisneria* sp. and *Ceratophyllum* sp (Figures 19.2d, 19.2c and 19.2f). The Kpong reservoir and the estuary area in Section D had the most extensive coverage of the submerged plants. *Vallisneria* sp. was widely distributed, and in many instances it was found in association with *Ceratophyllum* sp. The deeply and partially submerged ones were mapped differently, based on their NDVI values (Table 19.1). The partially submerged were found closer to the Water hyacinth, especially closer to the river banks.
Water hyacinth occurred closer to the banks of the Volta River and in the creeks, mostly in pure stands (Fig. 19.4 and 19.5). The most extensive coverage of Water hyacinth occurred in Section D (Fig. 19.5). A total of 54.40 ha was mapped in the area. Some populations were detected in Section C, though not in mappable quantities. In Section D, variability in distribution pattern occurred: the banks of the islets and the eastern banks of the mainland had the highest Water hyacinth infestation. In most cases, it formed a ring-like formation around the islets. The western side, from Agorkpo to the estuary in Section D, had comparatively sparse coverage of Water hyacinth (Fig. 19.5). According to discussions with some inhabitants along the river, Water hyacinth invaded the area some five years ago, and already has gained significant coverage in the area.
Fig. 19.4: Submerged and free floating weeds at the centre of image from NDVI. Dark and light brown patches are submerged plants closer to the surface. Green patches are deeply submerged plants.
Fig. 19.5: Overview of Water hyacinth coverage at the delta of the Lower Volta. To the Left is detailed cross-section of the different classes of aquatic weeds. Note the sequence of aquatic weed organization from the open waters to the banks: from the submerged, water hyacinth and Vossia sp. association.
From the open waters to the banks, submerged plants occurred first, followed by water hyacinth, and finally the *Vossia* sp. association (Figures 19.2a and 19.5). This was the usual definitive pattern, rather than a random occurrence. The boundary between the water hyacinth and the *Vossia* sp. association was not abrupt, but was a gradual transition of a mixture of the two classes, with reducing numbers of the water hyacinth as it got closer to the banks, beyond which the *Vossia* sp. association dominated. *Vossia* sp. association was the most widely distributed aquatic weed in all the sections of the Lower Volta. This was followed by the submerged plants, then the water hyacinth (Figures 19.4 and 19.5). All the aquatic weeds, including the water hyacinth, had limited coverage where trees were closer to the water body.

**Discussion**

The success of the remote sensing technology in discriminating and isolating the different types of aquatic weeds in this exercise justifies and adds to the evidence that has informed the shifts from the use of manual and aerial photo mapping techniques to high resolution remote sensing data (Nelson *et al*., 2006; Everitt *et al*., 2008; Laba *et al*., 2008). This exercise avoided direct contact with aquatic weeds that results in new infestations and further spread, a drawback normally associated with the traditional manual methods (Bossard *et al*., 2000). The basis of discrimination may be attributed to the distinct spectral patterns of unique differences in plant leaf biochemistry that greatly influenced reflectance (Ustin *et al*., 2004; Ustin *et al*., 2009), and the internal leaf arrangement (Ustin *et al*., 2009).

Challenges encountered included the mapping of *Aponogeton* sp. That was in the senescence stage with low chlorophyll content, and hence offered limited remote sensing value. We also acknowledge the inability of this exercise to accurately map the actual infestation coverage of submerged plants at different depths. Thus, information provided is indicative. As already indicated, remote sensing signals become degraded due to the progressive variation of light intensity with depth, bathymetric variability, water quality, tidal variability, reflection from water surface etc. (Morel and Bélanger, 2006; Underwood *et al*., 2006; Dogan *et al*., 2009). All these affect the coverage of submerged aquatic weeds under different conditions.
Aquatic weeds infestation has been found to be associated with specific sections or types of water bodies, including deltas (Underwood et al., 2006; Zhu et al., 2007). At the Lower Volta, areas closer to the banks of the mainland or the islets were locations of the highest aquatic weed infestation (Figures 19.3-19.5). Possibly, these locations provided suitable lotic conditions for rooted, submerged and floating macrophytes for anchorage and photosynthesis. Whereas the emergent Vossia sp. association prefers very shallow locations adjacent to the banks for anchorage in the soil, the submerged types were found in fairly shallow, but more open and sun-lit sections of the water body where they can effectively photosynthesize. The conditions between the Vossia sp. association and the submerged plants appeared ideal for the growth of water hyacinth. The Vossia sp. association was found along the entire stretch of the Lower Volta, except at locations with many trees, where limited sunlight may account for this pattern of distribution.

Water hyacinth, which is one of the most noxious invasive species, was visible in the satellite data used. It has a notably high capacity for rapid propagation by both sexual and asexual means (Téllez et al., 2008; Villamagna and Murphy, 2010; Zhang et al., 2010; Patel, 2012; Patel et al., 2012). In the Lake Victoria system, water hyacinth spread was estimated as growing at 3 hectares per day at its peak (Ayodo and Jagero, 2012). This may explain its rapid spread within the short period of its invasion at the Lower Volta as indicated by the communities.

Villamagna and Murphy (2010) and Ndimele et al. (2011) have identified lakes, estuaries, wetlands, marshes, ponds, dambos and slow flowing rivers as aquatic systems with high occurrence of water hyacinth. The observed distribution of water hyacinth in this study seemed to follow the pattern identified in the Nile system, which spread southwards to the estuary due to the construction of the Aswan Dam (Dagno et al., 2007). The distinct pattern of coverage of Water hyacinth at the Volta delta area should provoke investigations for developing early warning systems and management control before a massive and uncontrolled infestation occurs.

The distribution of submerged aquatic weeds is limited by sunlight since light energy rapidly attenuates as it penetrates water columns
and suspended materials (Madsen et al., 2006). Thus, the productivity and growth, and hence the invasion of aquatic weed, is limited by light. The observed pattern of the spread of submerged macrophytes confirms this principle. They were found closer to the banks, where water was shallow, and also in the open waters where sunlight was adequate for photosynthetic activities. Madsen (2009) has indicated that in eutrophic waters, submerged weeds are found within 3m, but could be found at the depth of 10m in oligotrophic waters.

**Conclusions**

The level of aquatic weed infestation is significantly high in cover and intensity. This could disrupt the normal ecological functioning of the Lower Volta aquatic ecosystem, with negative implications for socio-economic conditions. Reduced quantity and quality of drinking water and increased incidence of water-borne and water-related diseases (Hill et al., 2011) have been reported. Clear patterns of aquatic weed infestation emerged. The pattern of spatial infestation varied along the entire Lower Volta, with locally differentiated intensities of different classes of aquatic weed occurrence. The well-defined patterns could reflect specific local human-ecologically induced processes that could be further explored for managing the aquatic weeds (Schmidt and Witte, 2010; Baker et al., 2012; EPPO, 2012). The definitive evidence of the presence of aquatic weed provides a basis for developing the requisite effective strategies for managing them. It is proposed that the under-listed broad principles drive the development of management actions for the control of aquatic weed infestation and spread at the Lower Volta: avoidance of infestation in areas with limited or no significant infestation, preventing further spread of aquatic weeds to new areas and destroying them in areas with significant aquatic weed infestation.
CHAPTER 19

Management options for aquatic weed control

The following specific suggestions are intended to inform the development of policy and management strategies for the re-operation and optimization implementation, as well as other intervention programmes.

- Considering the importance of aquatic weeds, their current levels of infestation, intensities and patterns, the re-optimisation actions must consider the Kpong reservoir and the delta area between Agbeve and Big Ada as the primary targets for aquatic weed infestation control interventions.

- Water hyacinth must be targeted in Section D where infection levels were significantly high. They were closely associated with emergent and rooted plants such as *Vossia* sp. and *Typha* sp., but rare in areas at river banks with tree cover. Therefore it is suggested that trees are cultivated along the banks to control their growth.

- Given its subdued visibility, the problem of submerged aquatic weed infestation may be downplayed. The re-optimisation must prioritize the management of these weeds, especially in Sections A and D. Submerged aquatic weeds must be targeted in the open, well-lit shallow waters, especially close to areas where water hyacinth and other emergent aquatic weeds may be present. Also, it will be expedient to dredge these areas to limit light penetration and remove nutrients and roots of plants in the river bed.

- Notably, aquatic weed population is low towards the estuary of the Volta River. Obviously, salt content plays a critical role in controlling the aquatic weed populations. Removal of sandbars at shorter regular internals could enhance salt water influx upstream.

- Develop an early warning system to detect the onset of weed infection for early and proactive containment. Online and mobile phone technologies could be adopted to map and transfer information to a central collection point for monitoring, evaluation and management decisions for control interventions.
• Since aquatic weed infestation is not uniform in all localities, it is important to avoid the spread of specific invasive species to new areas. The fishermen and other users of the water body must be educated to desist from spreading the invasive water hyacinth, especially to new areas.

• WRC and VRA must promote centralized GIS invasive species reporting with auto-alert capability. They should establish reporting protocols in concert with response protocols for confirming, assessing, and responding to new detections. Professionals and volunteers must be trained in identifying, detecting, mapping, reporting, assessing and monitoring emerging invasive plants for early reporting.

• Scientists must closely study and find explanations for the existing spatial patterns of aquatic weed infection. This will aid the development of evidence-based and effective management interventions that address the causes rather than symptoms of aquatic weed infestation.

References


CHAPTER TWENTY

THE ANTI-SCHISTOSOMA CERCARIAL PENETRATION PROPERTIES AND SAFETY OF TOPICAL HERBAL FORMULATION FOR CONTROL OF SCHISTOSOMIASIS

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Abstract

Schistosomiasis continues to affect several populations, so that globally in 2013 at least 261 million people required preventive treatment, which is the main means of control. This situation calls for urgent and comprehensive control of schistosomiasis, which includes the control of intermediate snail hosts in water bodies. An effective alternative option to snail host control is the prevention of cercarial penetration of the human skin. Currently, there is limited information on formulations from orthodox or herbal medicine that is topically applied for such prevention. As part of the Re-operation and Re-optimization of the Akosombo and Kpong dams Project in Ghana, the need for developing a topical anti-schistosomal product from medicinal plants was identified. This product, if successfully developed and used by endemic communities, would contribute to the reduction of schistosomiasis. This work aimed at exploring the anti-cercarial properties of stem bark extracts obtained from Balanites aegyptiaca
and assessing the efficacy of topical formulation from these extracts in preventing schistosomal cercariae skin penetration. Three crude (aqueous, 70% and absolute ethanol) extracts of *Balanites aegyptiaca* were prepared using maceration, rotary evaporation and freeze drying techniques. The extracts were tested for anti-cercarial, anti-proliferation and cytotoxic activities by *in vitro* assays. A preliminary topical was prepared and tested for anti-penetrant properties using the mouse skin model. The major findings were that the crude extracts demonstrated considerable anti-schistosomal activity by killing the cercariae within 5 to 36 min depending on extract concentration. The absolute ethanol extract showed the highest anti-proliferative activity against MCF-7 and CHANG cell growth but was weak on PC-3 with IC$_{50}$ values of 31.76, 26.57 and >1000 µg/ml, respectively. The products from the absolute ethanol (EE10 and EE8) and aqueous extracts (QE10 and QE8) showed significant anti-skin-penetrant properties in mice. This suggests that the products could be useful in preventing cercariae penetration. Further studies are needed to isolate the active compounds as well as pre-clinical and clinical evaluations of the final products.

**Keywords:** Anti-cercarial, *Balanites aegyptiaca*, Formulation, Re-optimization, Schistosomiasis

**Introduction**

Schistosomiasis is a parasitic disease caused by schistosomes which manifests mainly in two forms in humans: intestinal schistosomiasis caused by *Schistosoma mansoni, S. japonicum, S. intercalatum* and *S. mekongi* which is associated with blood in stool (Silmara *et al.*, 2012; Boamah *et al.*, 2012) and urinary (urogenital) schistosomiasis caused by *S. haematobium* characterized by the presence of blood in urine (Yirenya-Tawiah *et al.*, 2011) and other significant pathological issues (Sanaa *et al.*, 2011). Schistosomiasis persists in many endemic communities along freshwater bodies worldwide, with at least 261 million people requiring preventive treatment in 2013, out of which more than 40 million people were treated (WHO, 2015; Bosompem *et al.*, 2004). In some countries in sub-Saharan Africa including Ghana, schistosomiasis is caused mainly by *S. haematobium* and *S. mansoni* (WHO, 2002). In Ghana, the intermediate snail hosts for *S. haematobium* are *Bulinus*
truncatus and B. globosus and that for S. mansoni is Biomphalaria pfeifferi. Schistosomiasis is widespread in Ghana and control has mainly been by mass drug administration (MDA) using a single dose of praziquantel (PZQ). Control of intermediate snail hosts in water bodies has not been a desirable option due to the major challenges that come with it. Successful control of schistosomiasis in endemic communities would, therefore, largely depend on effective prevention of cercarial penetration of the human skin at the water contact site.

Studies have demonstrated that some medicinal plants possess schistosomicidal and/or anti-cercarial activities (Mshana et al., 2000; Koko et al., 2005; El-Rigal et al., 2006; Ahmed et al., 2014). However, there is no formulation from medicinal plants that is topically applied to prevent schistosomal cercariae from penetrating the skin of human hosts. It has therefore become expedient to explore and screen medicinal plants that possess anti-cercarial penetration properties using an in vitro experiment and formulating the promising extract into a topical product. Such products would be effective when used by endemic communities in reducing the prevalence and morbidities of schistosomiasis.

One of such plants is Balanites aegyptiaca (Linn) which has shown considerable activity against other pathogens (Mshana et al., 2000; Koko et al., 2005). It is commonly known as ‘desert date’ in English and widely distributed in dry land regions of Africa, South Asia and the Middle East and traditionally used in the treatment of various ailments including jaundice, intestinal worm infection, malaria, syphilis and stomach aches. Its phytochemical constituents include protein, lipid, carbohydrate, alkaloid, saponin, flavonoid and organic acid (Chothani and Vaghasiya, 2011). This work therefore explored the anti-cercarial properties of stem bark obtained from Balanites aegyptiaca and also assessed the efficacy of topical formulation in preventing schistosomal cercariae skin penetration.
CHAPTER 20

Methods

Plant materials and extract preparation

The candidate medicinal plant was obtained from the Plant Development Department, Centre for Plant Medicine Research (CPMR), Mampong-Akuapem, Ghana. Three crude extracts were prepared from the stem bark of \textit{B. aegyptiaca}. The air-dried stem bark was milled and then extracted with 96% ethanol, 70% ethanol and distilled water. To prepare the ethanol extracts, 200 g of the pulverized material was macerated in 2 L of 70% or absolute ethanol in plastic containers for 72 hrs at room temperature, after which they were filtered with Whatman filter paper No. 1. In the case of the aqueous preparation, 200 g of the pulverized stem bark was boiled in distilled water contained in a stainless steel pan for 45 min on a hot plate cooled to room temperature and then filtered in a similar manner. Each of the ethanolic aqueous extracts was rotary-evaporated and freeze-dried. The aqueous extract was reconstituted in double de-ionized water, while 5% (v/v) of Dimethyl Sulfoxide (DMSO) was used in the case of the 70% and the absolute ethanol extracts. However, in the final working concentrations of 10,000, 8,000, 6,000, 4,000, 2,000 and 1,000 ppm for each of the extracts prepared, the quantity of the DMSO did not exceed 1%. The remaining lyophilized and the reconstituted extracts were stored at 4°C until used.

Obtaining schistosome cercariae

Survey for infected schistosomiasis snail hosts

The \textit{Bulinus truncatus} and \textit{ Biomphalaria pfeifferi} snails were collected using scoop nets at the human contact sites of the Weija Lake at Tomefa, a schistosomiasis endemic community. Snails were picked by a pair of forceps, placed into containers filled with water from the Lake, transported to the snail laboratory and maintained in snail breeding aquaria at the Noguchi Memorial Institute for Medical Research. The snails were kept in appropriately labeled aquaria containing aged-tap water for a minimum of 24 hrs and examined for cercariae shedding.
Cercariae shedding by snails

Snails were singly placed in wells of 24-well microplates (Corning, Tewksbury, USA), each containing 1 ml of de-ionized water, and then exposed to white light for no more than 2 h in order to stimulate cercariae shedding. The microplates were observed under an inverted microscope and the snails that had shed cercariae were pooled into a beaker and kept in the dark to avoid continuous shedding. The non-cercariae shedding snails were returned to the aquaria and maintained there for subsequent exposure for 2 hrs under the same exposure conditions to confirm them as uninfected. After about 24 hrs, a total of 8 cercariae-shedding snails, five *B. truncatus* and three *B. pfeifferi* snails were transferred into separate test tubes containing 5 ml of de-ionized water to continue the exposure for cercariae. To estimate the density of shed cercariae in the tube, 50 µl of the cercariae suspension was linearly spread on a slide and a cover slip carefully placed on it followed by counting cercariae present using a laboratory counter under a light microscope. The cercariae suspension was appropriately divided into a 24-well microplate to be used in testing the plant extracts for their anti-cercarial activity.

In vitro anti-cercarial activity testing of the plant extracts

The anti-cercarial effects of the three extracts were assessed on *S. mansoni* and *S. heamatobium* cercariae obtained from the wild snails. After an estimation of the cercarial density, the appropriate volume of the cercariae suspension was transferred into the respective wells in the 24-well microplates using a slant-cut pipette tip. The number of cercariae obtained for each test varied depending on the total cercariae shed by each snail group at a time. However, the number of cercariae obtained ranged from approximately 22 – 82 /well excluding ones already dead. The wells were observed under an inverted microscope (Olympus, CK40-SLP, Japan) and the numbers of active and dead cercariae in each well were recorded. To evaluate the effect of the extract on the cercariae, an equal volume of the appropriately diluted extracts (10,000, 8,000, 6,000, 4,000, 2,000 and 1,000 ppm) was added one at a time to each well and then incubated on the bench. This was monitored every 5 min under the inverted microscope and the numbers of dead or active cercariae counted using a laboratory counter. The dead cercariae
were determined by the appearance of a protruding sucker, lost or detached tails, the presence of a visible dark pigmentation on the tegument and the loss of motor activity as described by earlier studies (Haas 1984; Rug and Ruppe, 2000).

The incubation was continued for about 1 to 2 hrs with monitoring where the cercariae were observed to be active. Tests were conducted in triplicate. Control experiments were set up using only de-ionized water or 5% DMSO. Since the activity of cercariae reduces over time, incubation and monitoring of the cercariae in the experiment was carried out within 2 hrs.

Anti-proliferative and cytotoxicity activity testing of the extracts

The effect of the three extracts of *B. aegyptiaca* on the viability of PC-3 (human prostate cancer cells), MCF-7 (human breast cancer cells) and CHANG (normal human liver cells) cell lines (all obtained from NMIMR) were evaluated *in vitro* using the MTT assay as described by Uto *et al.* (2013) and using curcumin (C1386,Sigma-Aldrich) as positive control. The PC-3 cells were cultured in an RPMI-1640 medium (GIBCO), while the MCF-7 and CHANG cells were maintained in a DMEM medium. All cell cultures were supplemented with 10% fetal bovine serum (FBS) (PAN Biotech) and 1% Penicillin-Streptomycin-L-Glutamine, and incubated at 37°C in a 5% CO₂ under humidified atmospheric conditions. Here, the extracts and curcumin were dissolved in 1% DMSO. The DMSO concentrations in the cell culture medium did not exceed 0.1% (v/v), and the controls were always treated with the same amount of DMSO as that used in the corresponding experiments.

The growth inhibition of the cell lines due to the presence of the extract and curcumin was determined using the tetrazolium-based colorimetric assay (MTT Assay) (Uto *et al.*, 2013) to assess the cytotoxicity of the extracts. These monolayer adhesive cells (PC-3, MCF-7 and CHANG) cultured in flasks (TPP, 90026) were washed with PBS, detached with trypsin solution and transferred into centrifuge tubes. Tubes were centrifuged at 1000 rpm (Eppendorf Centrifuge, 5415C) for 5 min and the pellets re-suspended in growth media. The cells were counted using a haemocytometer (Marienfeld, Germany) and a cell suspension of 1 x
10^5 cells/ml was prepared by further dilution in growth media. Then 100 µl of the cell suspensions (1 × 10^5 cells/ml) was seeded into 96-well plates (TPP, 92096) and incubated overnight at 37°C in a 5% CO_2 under humidified atmospheric conditions for activation before treatment.

Ten microlitres (10 µl) of five different concentrations prepared for each extract were added sequentially to the wells containing the cell suspensions and incubated for 72 hrs similarly. Curcumin was used as a positive control in all assays and a colour control plate was also setup for each compound. About 20 µl of a 2.5 mg/ml MTT solution was added to the wells and incubated further for 4 hrs in the CO_2 incubator. Then 150 µl of acidified isopropanol containing Triton-X was added to stop the reaction. The reaction plates were incubated in the dark at room temperature overnight and absorbance read at 570 nm using a microplate spectrophotometer (Tecan Infinite M200 Pro plate reader, Austria).

The percentage cell viability was determined as:

\[
\% \text{ Cell viability} = \left( \frac{A_\alpha - A_\beta}{A_\gamma - A_\beta} \right) \times 100
\]

\(A_\alpha\) = Mean absorbance of extract-treated cells
\(A_\beta\) = Mean absorbance of blank
\(A_\gamma\) = Mean absorbance of extract-untreated cells

The percentage cell viability determined for each concentration was plotted as a dose response curve using Microsoft Excel. The inhibition concentration at fifty percent (IC_{50}) values, that is, concentration of extracts or curcumin inducing 50% inhibition of cells, was determined from the dose response curve by linear regression analysis.

**Formulation of the extract**

The preliminary *B. aegyptiaca* extracts formulations were prepared by a proprietary procedure to develop an oil-base topical ointment that would not readily emulsify in water. This was performed in order to conform to the standard protocols, as the form of the final anti-
cercarial product should be stable in a water environment. Four topical formulations were developed: EE10 (from 10,000 ppm absolute ethanol extract), QE10 (from 10,000 ppm aqueous extract), EE8 (from 8,000 ppm absolute ethanol extract) and QE8 (from 8,000 ppm aqueous extract). The formulations were tested for anti-penetrant properties using the mouse skin model.

**In vitro assessment of the formulation against cercariae using the mouse skin model**

The extracts screened had shown considerable anti-cercarial activity and therefore it was important to assess their effectiveness when formulated into ointment products. To evaluate how effective the products would be in inhibiting the cercariae from penetrating the skin, the mouse skin model as described by Lim et al. (1999) was used with slight modification. Briefly, 18 female Balb/c mice (8 weeks old) were obtained from the Animal Experimentation Unit of the Centre for Plant Medicine (CPMR) and carefully shaved to the bare skin before euthanization using chloroform. The epidermal skin was excised from the body of the mice. Three excised epidermal skins were used per each set up. The ointment was applied to the outer portion of the skin using cotton swabs to obtain a uniformly coated film. Two control groups (one group receiving no ointment treatment while the other received only the ointment base (the petroleum jelly without any extract formulation) were included. Each skin was stretched over the circular opening of the respective well of a 24-well plate filled with a 1 ml RPMI 1640 medium supplemented with 10% FBS and 50 µg/ml gentamycin that had been warmed to 38°C, ensuring that the inner portion of the epidermal skin stayed in contact with the medium in the well. A cercarial suspension (180 cercariae/240 µl) was dispensed onto the surface of the outer epidermal skin, then covered and incubated at room temperature for 24 hrs. After that, the remaining suspension on the outer surface was transferred into a new well. In addition, the medium underneath the skin was transferred into a 15 ml tube and centrifuged at 2000 rpm to sediment any schistosomula (transformed cercariae after penetrating through the skin) present. Most of the supernatant was removed by pipetting, leaving about 800 µl with the sediment. Each tube’s contents were re-suspended by tapping and then pipetted and transferred into a
new well. All wells were microscopically examined for whole cercaria and/or schistosomulae and then counted using a laboratory counter.

Phytochemical Screening

The three extracts (aqueous, 70% and absolute ethanol extracts) were screened for plant secondary metabolites by phytochemical qualitative analysis. The screening procedures were performed following the protocols described by Haborne (1998). Each lyophilized extract was prepared for screening by refluxing 10 mg with 100 ml of 80% ethanol in a beaker for 4 hrs. The cool solution was filtered using Whatman filter paper No. 1 and the extracted filtrate used for the various phytochemical tests. The screening was performed for saponins, phytosterols/triterpenes, alkaloids, reducing sugars, phenolic acids, cyanogenic glycosides, polyamides, anthracenosides and flavonoids. The color intensity or the precipitate formation after each reaction was used as analytical results to these tests.

Statistical Analysis

Microsoft Excel was used for the data entry and simple statistical analyses such as mean, standard deviation (SD) and linear regression analyses. Values were presented as means ± SD, percentages or sum totals to assess the extent of the effectiveness of the plant extracts on the cercariae.

Results

Snail Survey and shedding of cercariae

All the snails collected during the survey were exposed to light and the number of infected snails obtained was counted. As shown (Table 20.1), there were 4,139 Bulinus and 718 Biomphalaria snails collected with the percentage infectivity rate of 0.53 and 6.12% respectively.
Table 20.1: Number of snails collected during the snail survey activities and the number of infected snails.

<table>
<thead>
<tr>
<th>Snail Species</th>
<th>Total number collected</th>
<th>Uninfected</th>
<th>Infected</th>
<th>Percentage infectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulinus sp.</td>
<td>4,139</td>
<td>4,117</td>
<td>22</td>
<td>0.53</td>
</tr>
<tr>
<td>Biomphalaria sp.</td>
<td>718</td>
<td>674</td>
<td>44</td>
<td>6.12</td>
</tr>
</tbody>
</table>

Anti-cercarial activity of the extracts

The anti-cercarial (cercaricidal) activity of *B. aegyptiaca* stem bark extracts against *Schistosoma mansoni* and *S. haematobium* cercariae is reported below.

Activity of aqueous extract on cercariae

The results obtained from the anti-cercarial activity of the aqueous extract of *B. aegyptiaca* stem bark against *S. mansoni* and *S. haematobium* cercariae are shown in Table 20.2. At a concentration of 10,000 ppm of the aqueous extract, mortality of the *S. mansoni* was observed at 5 min and 100% mortality at 7 min. Similarly, 100% mortality was found at 6 to 7 min for 8,000 ppm. Again, the 6,000 ppm had 100% mortality at 8 min. The various concentrations used exhibited cercaricidal effect, with the minimum concentration (1,000 ppm) recording 100% mortality at 36 min. The onset of activity of the aqueous extract on *S. haematobium* cercariae was relatively slower since it took a longer incubation period before 100% mortality was observed. At a concentration of 10,000 ppm of the aqueous extract, 100% mortality was observed from 16 to 35 min, whereas the 8,000 and the 6,000 ppm both recorded 100% mortality in a similar time of 16 to 25 min and 17 to 25 min, respectively. At a concentration of 1,000 ppm of the aqueous extract, the activity on *S. haematobium* cercariae took a much longer time. Mortality started after 76 min and by 115 min, 100% mortality was observed.
Table 20.2: Anti-cercarial activity of aqueous extract of *Balanites aegyptiaca* stem bark on *Schistosoma mansoni* and *S. haematobium*

<table>
<thead>
<tr>
<th>Test</th>
<th>Active cercariae</th>
<th>Dead cercariae</th>
<th>Extract conc. (ppm)</th>
<th>Duration of exposure (min)</th>
<th>Post-exposure no. and condition of cercariae*</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>80 ± 4.2</td>
<td>4.0 ± 0.0</td>
<td>10,000</td>
<td>5 – 7</td>
<td>0.0 ± 0.0</td>
<td>80 ± 4.2</td>
</tr>
<tr>
<td>C2</td>
<td>22.5 ± 2.1</td>
<td>0.5 ± 0.7</td>
<td>8,000</td>
<td>6 – 7</td>
<td>0.0 ± 0.0</td>
<td>22.5 ± 2.1</td>
</tr>
<tr>
<td>C3</td>
<td>34 ± 1.4</td>
<td>1.0 ± 0.0</td>
<td>6,000</td>
<td>7 – 8</td>
<td>0.0 ± 0.0</td>
<td>34 ± 1.4</td>
</tr>
<tr>
<td>C4</td>
<td>41 ± 0.0</td>
<td>3.0 ± 1.4</td>
<td>4,000</td>
<td>10 – 11</td>
<td>0.0 ± 0.0</td>
<td>41 ± 0.0</td>
</tr>
<tr>
<td>C5</td>
<td>30 ± 0.7</td>
<td>2.0 ± 0.0</td>
<td>2,000</td>
<td>11 – 12</td>
<td>0.0 ± 0.0</td>
<td>30.5 ± 0.7</td>
</tr>
<tr>
<td>C6</td>
<td>27 ± 2.8</td>
<td>3.0 ± 0.0</td>
<td>1,000</td>
<td>20 – 21</td>
<td>5.0 ± 2.8</td>
<td>22 ± 5.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Active cercariae</th>
<th>Dead cercariae</th>
<th>Extract conc. (ppm)</th>
<th>Duration of exposure (min)</th>
<th>Post-exposure no. and condition of cercariae*</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>27.5 ± 0.7</td>
<td>3.5 ± 2.1</td>
<td>10,000</td>
<td>16 – 35</td>
<td>24.0 ± 2.8</td>
<td>27.5 ± 0.7</td>
</tr>
<tr>
<td>C2</td>
<td>26.5 ± 5.0</td>
<td>0.5 ± 0.7</td>
<td>8,000</td>
<td>16 – 25</td>
<td>0.0 ± 0.0</td>
<td>26.5 ± 5.0</td>
</tr>
<tr>
<td>C3</td>
<td>31.5 ± 2.1</td>
<td>0.5 ± 0.7</td>
<td>6,000</td>
<td>17 – 25</td>
<td>0.0 ± 0.0</td>
<td>31.5 ± 2.1</td>
</tr>
<tr>
<td>C4</td>
<td>35.5 ± 3.5</td>
<td>2.0 ± 1.4</td>
<td>4,000</td>
<td>16 – 95</td>
<td>33.5 ± 2.1</td>
<td>35.5 ± 3.5</td>
</tr>
<tr>
<td>C5</td>
<td>25.5 ± 2.1</td>
<td>3.0 ± 0.0</td>
<td>2,000</td>
<td>46 – 105</td>
<td>0.0 ± 0.0</td>
<td>25.5 ± 2.1</td>
</tr>
<tr>
<td>C6</td>
<td>27.5 ± 7.8</td>
<td>2.5 ± 0.0</td>
<td>1,000</td>
<td>76 – 115</td>
<td>0.0 ± 0.0</td>
<td>27.5 ± 7.7</td>
</tr>
</tbody>
</table>

*C1 – C6: series of tests ran; for the control (de-ionized water), the mean active cercariae were 24 ± 1.4 and percentage mortality at 120 min was 10.4% (2.5 ± 0.7).*
It was also observed that the majority (83.3%) of the dead cercariae treated with 10,000 ppm showed remarkable morphological alterations including detached tails, the appearance of visible dark pigmentation on the tegument and loss of motor activity when compared to the de-ionized water control.

Activity of absolute ethanol extract on cercariae

Table 20.3 shows the activity of the absolute ethanol (96%) extract on the *S. mansoni* and *S. haematobium* cercariae. The 10,000 ppm recorded 100% mortality on *S. mansoni* between 11 and 20 min while the 8,000 ppm had 100% mortality from 9 to 14 min, which was quite different from what was made for the aqueous extract, where the 10,000 ppm had stronger activity than the 8,000 ppm. Again, onset of the anti-cercarial activity at 1,000 ppm was found to be relatively faster (21 – 27 min) as compared with that of the aqueous extract (20 – 36 min). The anti-cercarial activity in terms of 100% mortality of the 10,000 ppm absolute ethanol extract on *S. haematobium* cercariae was from 6 to 10 min. The 8,000 ppm recorded a much shorter time of 5 min while the 1,000 ppm took a longer time of 15 to 30 min to achieve a 100% mortality.
Table 20.3: Anti-cercarial activity of absolute ethanol extract of *Balanites aegyptiaca* stem bark on *Schistosoma mansoni* and *S. haematobium*

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-exposure no. and condition of cercariae*</th>
<th>Extract conc. (ppm)</th>
<th>Duration of exposure (min)</th>
<th>Post-exposure no. and condition of cercariae*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active cercariae</td>
<td>Dead cercariae</td>
<td></td>
<td>Active cercariae</td>
</tr>
<tr>
<td><strong>S. mansoni cercariae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>42.5 ± 6.4</td>
<td>1.0 ± 0.0</td>
<td>10,000</td>
<td>11 - 20</td>
</tr>
<tr>
<td>C2</td>
<td>34.0 ± 0.0</td>
<td>2.0 ± 1.4</td>
<td>8,000</td>
<td>9 - 14</td>
</tr>
<tr>
<td>C3</td>
<td>38.0 ± 11.3</td>
<td>1.0 ± 1.4</td>
<td>6,000</td>
<td>15 - 18</td>
</tr>
<tr>
<td>C4</td>
<td>39.0 ± 1.4</td>
<td>0.0 ± 0.0</td>
<td>4,000</td>
<td>12 - 19</td>
</tr>
<tr>
<td>C5</td>
<td>38.0 ± 5.7</td>
<td>0.5 ± 0.7</td>
<td>2,000</td>
<td>15 - 20</td>
</tr>
<tr>
<td>C6</td>
<td>29.5 ± 4.9</td>
<td>1.0 ± 0.0</td>
<td>1,000</td>
<td>17 - 27</td>
</tr>
<tr>
<td><strong>Schistosoma haematobium cercariae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>50.4 ± 6.4</td>
<td>7.5 ± 0.7</td>
<td>10,000</td>
<td>6 - 10</td>
</tr>
<tr>
<td>C2</td>
<td>72.5 ± 5.0</td>
<td>2.5 ± 3.5</td>
<td>8,000</td>
<td>0 - 5</td>
</tr>
<tr>
<td>C3</td>
<td>82.5 ± 7.8</td>
<td>3.0 ± 1.4</td>
<td>6,000</td>
<td>5 - 10</td>
</tr>
<tr>
<td>C4</td>
<td>51.0 ± 1.4</td>
<td>3.5 ± 2.1</td>
<td>4,000</td>
<td>5 - 10</td>
</tr>
<tr>
<td>C5</td>
<td>68.5 ± 17.7</td>
<td>2.5 ± 0.7</td>
<td>2,000</td>
<td>5 - 15</td>
</tr>
<tr>
<td>C6</td>
<td>55.0 ± 5.7</td>
<td>4.5 ± 2.1</td>
<td>1,000</td>
<td>15 - 30</td>
</tr>
</tbody>
</table>

*C1 – C6: series of test ran; for the control (5% DMSO), the mean active cercariae were 24 ± 1.4 and percentage mortality at 120 min was 0.0% (0.0 ± 0.0).*

*Values are mean ± standard deviation (SD).
CHAPTER 20

Activity of 70% ethanol extract on cercariae

The anti-cercarial activity of the 70% ethanol extract on *S. mansoni* cercariae was similar to that of the aqueous extract. As shown in Table 20.4, in between 5 and 7 min the 10,000 ppm had a 100% mortality, unlike the activity on *S. haematobium* cercariae taking a considerably longer incubation time of 11 to 35 min. Again, the 1,000 ppm of the 70% ethanol extract took between 5 and 25 min to achieve a 100% mortality as compared with the absolute ethanol extract taking 15 to 30 min and that of the aqueous 76 to 115 min.

Anti-proliferative and cytotoxicity activity of the extracts

The results obtained for the cell proliferation assay are represented in Fig. 20.1. All the extracts suppressed cell growth in the cell lines tested with the exception of the absolute ethanol extract which did not suppress the PC-3 cell line growth. The IC₅₀ values obtained for the absolute ethanol extract on PC-3, MCF-7 and CHANG cell lines were >1000, 31.76 and 26.57 µg/ml respectively. The 70% ethanol extract had IC₅₀ values of 40.01, 60.80 and 64.25 µg/ml to the same cell lines respectively, while the IC₅₀ values of the aqueous extract on PC-3, MCF-7 and CHANG cells were 44.96, 40.90 and 32.45 µg/ml respectively. The curcumin (positive control) recorded 4.69, 15.22 and 11.67 µM IC₅₀ values for the respective cell lines.
### Table 20.4: Anti-cercarial activity of 70% ethanol extract of *Balanites aegyptiaca* stem bark on *Schistosoma mansoni* and *S. haematobium*

**S. mansoni** cercariae

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-exposure no. and condition of cercariae</th>
<th>Extract conc. (ppm)</th>
<th>Duration of exposure (min)</th>
<th>Pre-exposure no. and condition of cercariae</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active cercariae</td>
<td>Dead cercariae</td>
<td></td>
<td>Active cercariae</td>
</tr>
<tr>
<td>C1</td>
<td>48.5 ± 6.4</td>
<td>4.5 ± 0.7</td>
<td>10,000</td>
<td>5 – 7</td>
</tr>
<tr>
<td>C2</td>
<td>70.0 ± 0.0</td>
<td>2.5 ± 2.1</td>
<td>8,000</td>
<td>7 – 9</td>
</tr>
<tr>
<td>C3</td>
<td>66.5 ± 6.4</td>
<td>1.5 ± 2.1</td>
<td>6,000</td>
<td>8 – 11</td>
</tr>
<tr>
<td>C4</td>
<td>77.5 ± 1.4</td>
<td>1.5 ± 2.1</td>
<td>4,000</td>
<td>10 – 12</td>
</tr>
<tr>
<td>C5</td>
<td>57.5 ± 14.8</td>
<td>1.5 ± 2.1</td>
<td>2,000</td>
<td>11 – 13</td>
</tr>
<tr>
<td>C6</td>
<td>69.5 ± 12.0</td>
<td>2.0 ± 0.0</td>
<td>1,000</td>
<td>12 – 15</td>
</tr>
</tbody>
</table>

**Schistosoma haematobium** cercariae

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-exposure no. and condition of cercariae</th>
<th>Extract conc. (ppm)</th>
<th>Duration of exposure (min)</th>
<th>Pre-exposure no. and condition of cercariae</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active cercariae</td>
<td>Dead cercariae</td>
<td></td>
<td>Active cercariae</td>
</tr>
<tr>
<td>C1</td>
<td>41.0 ± 0.0</td>
<td>0.5 ± 0.7</td>
<td>10,000</td>
<td>11 – 35</td>
</tr>
<tr>
<td>C2</td>
<td>41.5 ± 9.2</td>
<td>0.0 ± 0.0</td>
<td>8,000</td>
<td>0 – 5</td>
</tr>
<tr>
<td>C3</td>
<td>32.0 ± 9.9</td>
<td>0.5 ± 0.7</td>
<td>6,000</td>
<td>5 – 10</td>
</tr>
<tr>
<td>C4</td>
<td>36.0 ± 5.7</td>
<td>6.5 ± 4.9</td>
<td>4,000</td>
<td>5 – 10</td>
</tr>
<tr>
<td>C5</td>
<td>42.0 ± 0.0</td>
<td>4.5 ± 0.7</td>
<td>2,000</td>
<td>5 – 15</td>
</tr>
<tr>
<td>C6</td>
<td>32.5 ± 0.7</td>
<td>14.5 ± 0.7</td>
<td>1,000</td>
<td>5 – 25</td>
</tr>
</tbody>
</table>

C1 – C6: series of test ran; for the control (5% DMSO), the mean active cercariae were 24 ± 1.4 and percentage mortality at 120 min was 0.0% (0.0 ± 0.0)  

*Values are mean ± standard deviation (SD).*
Fig. 20.1: Effects of the aqueous and ethanol extracts of *Balanites aegyptiaca* stem bark on proliferation of human normal and cancer cell lines compared with effect of curcumin in vitro at 72 hrs using the MTT assay.
Test of blocking effect of topical extract formulations on cercariae invasion in mouse skin

As shown (Table 20.5), the anti-cercarial penetrant activity of the 4 formulations (EE10, QE10, EE8 and QE8) to *S. haematobium* cercariae invasion of the mouse skin was successful. There were considerably less numbers of schistosomulae recovered in the wells as compared to the controls. The EE10 and QE10 ointments had the majority of cercariae, 40 and 43 whole active cercariae respectively, that could not penetrate the epidermal skin layer; only 1 schistosomulum was able to penetrate and was recovered in its respective wells. For the EE8 and QE8 ointments, 10 and 6 whole cercariae were found on skin and no schistosomula could penetrate the skin, likely being hindered by the ointment coated skin surface. However, for the two controls; Group 1 revealed 10 whole cercariae on the skin and 8 schistosomulae were found in the well, whereas Group 2 showed 59 cercariae on skin and 2 schistosomulae in the well.

Table 20.5: Cercariae and schistosomulae recovery after 24 hrs ointments treatment of Balb/c mice skin

<table>
<thead>
<tr>
<th>Skin groups</th>
<th>Treatment</th>
<th>Cercariae that did not enter the skin</th>
<th>Schistosomulae recovered from the well</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control 1 (no ointment)</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Control 2 (ointment base without extract)</td>
<td>59</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>EE10</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>QE10</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>EE8</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>QE8</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

EE10: Ointment containing 10,000 ppm absolute ethanol extract; QE10: Ointment containing 10,000 ppm aqueous extract; EE8: Ointment containing 8,000 ppm absolute ethanol extract; QE8: Ointment containing 8,000 ppm aqueous extract.

Phytochemical properties of the extracts

The study identified the phytochemical constituents of the three *B. aegyptiaca* extracts. As shown (Table 20.6), the phytochemicals identified were mainly saponins, reducing sugars, phenolics and phytosteriols which might contribute to the anti-cercarial properties of the extracts.
Table 20.6: Phytochemicals identified in the extracts of *Balanites aegyptiaca* stem bark.

<table>
<thead>
<tr>
<th>Phytochemicals</th>
<th>Extract</th>
<th>Absolute (95.7%)</th>
<th>70%</th>
<th>Aqueous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saponins</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Reducing sugars</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Phenolics</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Cyanogenic glycosides</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
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-; not present; +; present

**Discussion**

Schistosomiasis persists in endemic communities worldwide, requiring regular treatment using praziquantel, the only drug of choice which is orally administered. Treatment options for schistosomiasis are limited, a situation that can induce the emergence of drug resistance (Wang et al., 2012). Therefore, it is important that as part of efforts to develop affordable and sustainable schistosomiasis control programmes in endemic communities, research be intensified to identify and develop equally affordable anti-schistosomal products from medicinal plants.

In this work, efforts were made to develop an anti-penetrant schistosomal cercariae herbal product which may prevent cercaria penetration of human skin. The data obtained in this work demonstrate a considerable anti-schistosomal activity of *B. aegyptiaca* stem bark (aqueous, 70% and absolute ethanol) extracts to Ghanaian strains of *S. mansoni* and *S. haematobium* cercariae (Tables 20.2, 20.3 and 20.4). Importantly, the in vitro activities of the extracts resulted in the killing of both sources of cercariae which affected both the muscular function (loss of motor activity) and tegumental changes. The potential anti-schistosomal activity of *B. aegyptiaca* has also been reported by Koko et al. (2005). In an in vivo experiment the efficacy of the fruit mesocarp was
compared with that of praziquantel in mice infected with *S. mansoni* where significant worm burden reduction was observed.

In cytotoxic screening, the three crude extracts showed varying anti-proliferative activity against PC-3, MCF-7 and CHANG cell lines (Fig. 20.1). Among the extracts, the absolute ethanol extract showed the highest anti-proliferative activity against MCF-7 and CHANG cell growth but was inactive on PC-3, with IC\(_{50}\) values of 31.76, 26.57 and >1,000 µg/ml, respectively, which is considerably weak compared with the curcumin which showed IC\(_{50}\) values of 15.22 µg/ml and 11.67 µg/ml on these cell lines, respectively. The 70% ethanol extract and the aqueous extract showed similar inhibition of growth on the PC-3, while the 70% ethanol extract showed less inhibition of growth on the MCF-7 and CHANG cells in comparison with the aqueous extract. The strong anti-cell proliferation activity observed in the extract against MCF-7 and CHANG cells might be due to the presence of saponins in the extracts which has been shown to possess a cytotoxic effect associated with anti-cancer activity (PC-3) (Chothani and Vaghasiya, 2011; Sparg *et al*., 2004).

In evaluating the ability of the ointments formulated from the extracts to prevent mice skin penetration by the cercariae, representative cercariae (*S. haematobium*) were studied. No schistosomulae were recovered in QE8 and EE8 experiments and only 1 cercaria was found for QE10 and EE10 ointments, accordingly suggesting better anti-cercarial activity (Table 20.5). Group 1 had 8 schistosomulae recovered from the well whereas Group 2 had only 2 schistosomulae recovered. This indicates the ability of the cercariae to freely penetrate the skin without the extract ointment (Ingram *et al*., 2002) but much more difficult to do so where the skin was treated with the extract ointments. In each group, the total number of recovered cercariae and schistosomula was less than the number of cercariae in the original suspension applied to the skin surface. This could be because some of the cercariae might have penetrated the skin but failed to exit through the skin (Bartlett *et al*., 2000). This study suggests that the ointments of the aqueous and absolute ethanol extracts of *B. aegyptiaca stem bark* could be promising anti-cercarial penetrant agents against cercariae (*S. haematobium*).
In conclusion, the project supported a promising research work which is an off shoot of the main Re-optimization and Re-operation study of the Akosombo and Kpong dams Project. The three extracts prepared from *B. aegyptiaca* and screened against schistosome cercariae have shown considerable anti-cercarial activity. The absolute ethanol extract promises to be the preferred sample among the three due to its high anti-cercarial activity as well as its anti-cercarial skin penetrant property. The preliminary products formulated from *B. aegyptiaca* stem bark extract may be useful in preventing human skin penetration by the schistosome parasite.

**Recommendation**

It is important that further studies be conducted to isolate the active phytochemicals for analysis, and to evaluate the pre-clinical and clinical effects of the formulated products by the research team in collaboration with the appropriate agencies toward product registration and patent. Commercial production may then be pursued for use by humans in schistosomiasis endemic communities.

**References**


Ghana’s Akosombo and Kpong dams were constructed on the Volta River primarily for hydropower generation, but they also provided additional benefits such as flood protection, irrigation, navigation and lake fisheries. There is no doubt that the Akosombo and Kpong dams have contributed and continue to contribute immensely to economic development of Ghana. However, the creation of the Volta Lake in the 1960s impacted hugely on the downstream riverine ecosystem processes and communities, resulting in collapse of the shellfish industry, loss of agricultural potential and livelihoods, leading to intense poverty and movement of people. This was compounded by the construction of the Kpong Headpond in the 1980s which further changed the freshwater ecology of the lower Volta. The current thinking is that by managing the flow of water from impoundments, it is possible to obtain some of the pre-dam ecosystem services that have been lost as a result of impoundment. The project “Re-operation and Re-optimisation of the Akosombo and Kpong Dams”, on which this book is based, was conceived to explore technically and economically feasible plans for re-operation of the Volta dams that would retain and possibly enhance the existing benefits, while improving downstream livelihoods and ecosystems. The book brings together the results of wide ranging, multidisciplinary research that address all the key components and implications of dam re-operation. Starting with the perceptions and concerns of the downstream communities, the book presents four scenarios for re-operation, the implications of each scenario for power generation and people’s livelihoods, flow requirements for fisheries and biodiversity, as well as socio-economic implications. Finally, the studies explore also institutional issues for managing reoperation of the dams, as well as alternative approaches for restoring livelihoods of downstream communities. We believe that the studies reported in this book provide valuable baseline information and essential considerations that will inform not only future plans for re-operation and re-optimisation of the Volta dams, but dams world-wide.

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