

SUSTAINABLE IRRIGATION DEVELOPMENT

IN THE WHITE VOLTA SUB-BASIN



ERIC ANTWI OFOSU



Sustainable Irrigation Development in the White Volta Sub-Basin

DISSERTATION

Submitted in fulfilment of the requirements of
the Board for Doctorates of Delft University of Technology
and of the Academic Board of the UNESCO-IHE Institute for Water
Education

for the Degree of DOCTOR
to be defended in public
on TUESDAY, 13TH DECEMBER 2011 at 12:30 hours
in Delft, The Netherlands

by

Eric ANTWI OFOSU
born in Koforidua, Ghana
MPhil Civil Engineering

This dissertation has been approved by the supervisors
Prof.dr.ir. P. van der Zaag UNESCO-IHE/ TU Delft
Prof.dr.ir. N. C. van de Giesen TU Delft

Members of the Awarding Committee:

Chairman:	Rector Magnificus, TU Delft
Vice-chairman:	Rector, UNESCO-IHE
Prof.dr.ir. P. van der Zaag	UNESCO-IHE/ TU Delft
Prof.dr.ir. N. C. van de Giesen	TU Delft
Prof. S. N. Odai	Kwame Nkrumah University of Science and Technology, Ghana
Prof.dr. L.C. Rietveld	TU Delft
Prof.dr.ir. E. Schultz	UNESCO-IHE / Wageningen University
Prof.dr. L. Vincent	Wageningen University
Prof.dr.ir. T.N. Olsthoorn	TU Delft, reserve member

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

© 2011, Eric Antwi Oforu

All rights reserved. No part of this publication or the information contained herein may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording or otherwise, without written prior permission from the publishers.

Although all care is taken to ensure integrity and the quality of this publication and the information herein, no responsibility is assumed by the publishers nor the author for any damage to the property or persons as a result of operation or use of this publication and/or the information contained herein.

Published by:

CRC Press/Balkema

PO Box 447, 2300 AK Leiden, The Netherlands

e-mail: Pub.NL@taylorandfrancis.com

www.crcpress.com – www.taylorandfrancis.co.uk – www.balkema.nl

ISBN 978-0-415-62103-8 (Taylor & Francis Group)

ABSTRACT

Global efforts aimed at ensuring food sufficiency by increasing staple food production have adopted irrigated farming as one of the main strategies. Sub-Saharan Africa has an irrigation potential of about 42 million hectares of which only 17% is developed. While investments in irrigation have yielded significant impacts in terms of improving food security and reducing poverty in areas such as South-East Asia and East Asia, the same cannot be said for sub-Saharan Africa. Despite several investments in irrigation from governments (colonial and post-colonial), multi-national donor agencies and private investors, irrigation development in Sub-Saharan Africa has been slow. The implications of increasing irrigated agriculture are significant. Knowledge of the hydrological impact of up-scaling irrigated agriculture on downstream users will be essential for decision making and negotiating tradeoffs between competing water uses.

This study tries to understand irrigation development in sub-Saharan Africa, and was conducted in the White Volta sub-basin. Three neighbouring sub-catchments: Yariatanga, Anayari and Atankwidi located in Northern Ghana and Southern Burkina Faso, where both government-led and private-led irrigation developments occurred, were studied. The increasing market for vegetables in the urban areas of southern Ghana has led to the acceleration of private-led irrigation development in the past two decades resulting in several indigenous irrigation technologies which are unknown in literature. This study area presented the opportunity to compare the factors that promote private-led irrigation with those that affect government-led irrigation within the same context.

This study aims at helping to achieve sustainable irrigation in sub-Saharan Africa, through gaining a better understanding of productive irrigation water use and effective management of irrigation development by: (1) drawing lessons from several irrigation systems across sub-Saharan African, (2) assessing the factors that have influenced government-led and private-led irrigation systems in the White Volta sub-basin, (3) conducting a comparative analysis on the productivities of various irrigation technologies, (4) assessing the past and future trends of irrigation development in the White Volta sub-basin and (5) investigating the impact of upscaling irrigation development in the White Volta sub-basin on competing water uses with emphasis on hydropower production at the Akosombo Dam.

The study reviews irrigation development in sub-Saharan Africa, dating from the colonial era till present. The review covers the various types of irrigation

systems developed across sub-Saharan Africa identified in literature. The study is aimed at identifying the challenges that have been associated with irrigation development and success factors for sustainable irrigation development across sub-Saharan Africa. In the review, it was observed that irrigation development in sub-Saharan Africa began in the pre-colonial era and have continued through the colonial and post-colonial era. Irrigation development in sub-Saharan Africa has been both government-led and private-led with the government being the major developer. In the last two decades significant irrigated areas have been developed by private commercial farmers, outgrower farmers, small-holder individuals and communities as well as non-governmental organisations.

The review identified the following as the challenges affecting irrigation development in sub-Saharan Africa: high development cost of irrigation, lack of access to credits for farmers, unreliable and unpredictable markets, ineffective institutions, low productivity, and finally inappropriate technologies coupled with poor infrastructural maintenance. To achieve successful and sustainable irrigation in sub-Saharan Africa, the following factors were identified: (1) secure access to land and water, (2) appropriate technology, (3) predictable and stable input/output markets, (4) reliable farmer support environment, and (5) effective institutions with favourable policies. These success factors function as a chain of shackles, the chain being as strong as the weakest shackle.

In the three catchments studied both government-led and private-led irrigation developments were compared in order to identify the factors underlying the current trends. Two large-scale irrigation schemes managed by a single government company and several small reservoir irrigation systems were studied. Four different irrigation technologies developed by private individuals were also studied.

Records on the two large-scale irrigation schemes from 1985 till 2005 together with observations and interviews showed that both schemes are producing below average, are not financially sustainable and achieve low water use efficiencies. The problems of the schemes (a) originate from unresolved social impacts of the irrigation development leading to long-standing land-tenure issues; (b) ineffective institutions; (c) lack of credit and reliable market for farmers; and (d) weaknesses in irrigation system design. Small-scale private-led irrigation developments give farmers control over resources and decisions, and these do not suffer from the types of problems that large-scale irrigation schemes have. This explains why such innovations have rapidly spread in Northern Ghana during the last two decades.

An extensive field survey conducted in the sub-basin for three consecutive irrigation seasons revealed the details of the small-scale private-led irrigation technologies prevailing in the sub-basin. The following were identified as private-led irrigation technologies in terms of the type of water source: permanent shallow wells, riverine water, temporal shallow wells, and riverine alluvial dugouts. These irrigation technologies have spread in the sub-basin because the direct control of water sources, either through groundwater pumping, drainage reuse or direct pumping from canals and rivers, has brought the flexibility in water delivery to irrigators, which the large-scale surface distribution systems do not offer. Also growing market demand for vegetables in the urban areas of southern Ghana and the transfer of knowledge on irrigation technologies and farming have all contributed to the upscaling of irrigation technologies.

A comparative analysis of the productivities (in terms of food and water) of all the irrigation technologies in the study area was based on a survey of ninety tomato farmers from both Ghana and Burkina sections of the study area during the 2007/2008 irrigation season. The study showed that apart from water being a pre-requisite for successful irrigation, adequate fertilizer application was a major factor in achieving high irrigation productivities. The most productive irrigation technologies were the temporal and permanent shallow wells, followed by the riverine alluvial dugout. Moreover, these highly productive irrigation technologies also achieved high profit margins and provided income opportunities to the wider society in terms of labour and also have higher women participation. Technologies characterised by relatively small farm sizes were better managed by the surveyed farmers because they enabled the farmers to provide adequate water and crop nutrients, resulting in high crop yields. This contrasted with the large irrigation schemes where farm plots were relatively large, but where low productivities (in terms of land, water and profit margin) were achieved.

The findings imply that in order to achieve high impact, irrigation development in sub-Saharan Africa should consider the economic status of the users and their ability to make the best out of the technology in terms of productivity. Moreover, technologies that give farmers full control over the water should be preferred. The ongoing endogenous irrigation development in the study area provides a strong backing that the way forward in sub-Saharan Africa is for governments to create policies that facilitate poor farmers becoming irrigation entrepreneurs. Such policies should aim to enhance the reliability of markets (both input and output) as the driving force, and facilitate people's access to land and water.

The study also investigated the past trend of irrigation development with the aim of projecting possible future irrigation developments in the study area. Based on satellite images from 2003 and ground-truthed data, it was found that irrigated areas have expanded by a rate of approximately 5.6% per year. Private-led irrigation, which comprises about 73% of the total irrigated area, has expanded at faster rates, because government-led irrigation systems (small and large reservoirs) experienced a general decline in irrigated areas.

The factors that have influenced the past trend are likely to sustain the current state of irrigation in the basin. However additional factors such as expanding markets for irrigated products, introduction of new irrigation technologies, government policies and interventions and emerging trends of irrigation management are likely to increase irrigation development beyond the current growth rate in the near future.

The implications for the future expansion of irrigation development in the study area led to the final study which assesses the impact of upscaling irrigation development in the White Volta sub-basin. The study was conducted using WEAP model and validated with a simple water balance approach. The water balance analysis confirmed a weakness of the WEAP model, namely that it considers groundwater to be unconnected to surface water, implying that water abstracted from groundwater for irrigation is not considered to have any impact on streamflow. The lack of long-term streamflow measurements in the studied catchments was a major challenge to the study, which prevented the development of a hydrological rainfall-runoff model.

The current level of irrigation has no significant impact on competing water uses within the sub-basin and downstream of the sub-basin. However, based on a 5%/a irrigation growth rate in the White Volta sub-basin, current irrigation is likely to more than double by 2025. When this occurs, inflows into the Volta Lake could be reduced up to 8.8%. This has potential consequences on hydropower production at Akosombo dam.

The benefits of upstream irrigation to the losses suffered by hydropower production downstream of the sub-basin were compared. Tomato farmers would make a profit of 429million US\$/a while hydropower production at Akosombo would lose 42.5 million US\$/a. The economic benefits of irrigation upstream of the Volta Lake would thus significantly exceed the financial loss to hydropower production. This implies that if current development trends as studied in the three small catchments continue to develop for the coming 15 years, and are upscaled to the entire White Volta, then the negative downstream impacts are relatively small compared to the upstream benefits.

However, these conclusions are made based on reproducing historical electricity generation patterns. A much more detailed investigation is required that would include explicit operating policies of the Akosombo dam, and would be able to optimise operating rules that could minimise electricity losses in the face of reduced inflows.

The study has not considered the possible future developments in other sub-basins and the combined impacts of all upstream developments on the Akosombo dam. To be able to assess that impact, the following are proposed: (1) conduct analysis similar to the present in all other sub-basins; and (2) develop a dynamic water resources model to accurately assess the impact.

There are other challenges to sustainable irrigation development which have not been captured in this study. A typical example is the impact of climate change on future water availability for irrigation and other competitive water uses in the sub-basin. Another scenario is the impact of upscaling irrigation development in Burkina Faso on competing water uses in downstream Ghana. These and other possible future scenarios can be studied towards achieving sustainable irrigation development.

DEDICATION

I dedicate this work to my family: Emmanuel Oforu Baabu, Paulina Amobe, Adelaide Oforu-Antwi, Katriel Oforu-Antwi, Doris Oforu, Seth Oforu, Susanna Oforu, Irene Oforu and Eva Oforu.

ACKNOWLEDGEMENT

Many are the desires of a man's heart but it is the counsel of God that shall stand. I know and believe that God designed this PhD study for me at the right time and at the right institution. I am very grateful to God for granting me grace and success in this very important stage of my life. I owe every success in this study to my maker.

This PhD study is part of the staff development and capacity building project between the Kwame Nkrumah University of Science and Technology, UNESCO-IHE and Technical University of Delft. Discussions on having my PhD at UNESCO-IHE began when I was yet to complete my MPhil at Kwame Nkrumah University of Science and Technology (KNUST). I am very grateful to the Civil Engineering Department of KNUST for this opportunity given to me. I must acknowledge the support from Prof. S. N. Odai, the late Prof. Kwesi Andam, Dr. Anyemedu, Prof. Nemanja Trifunovic and the late Dr. I. K. Nyameche who championed the granting of this PhD award from the department. I pray the Lord Almighty bless you for allowing Him to use you in fulfilling His divine purpose for my life.

I have benefitted a lot from the mentorship and supervision of Prof. Pieter van der Zaag. Pieter, as you like me to call you even though it is not the African style, I pray God bless you everyday. You have been the pillar of this PhD study and have been the best supervisor I can talk of. Your encouragement, advice, corrections and concern for my welfare, peace of mind and health are very much appreciated. I am sure this is the beginning of more things that we can do together.

I must acknowledge the great support I benefitted from Prof. Nick van de Giesen, who happens to be an expert in my study area. You came in when it mattered most and gave me simple solutions to problems which weighed me down. I am grateful. Many thanks to Prof. S. N. Odai my local supervisor for his contributions towards the successful completion of the study.

I want to acknowledge my friends in Ghana who have been very close to me during this period. Nana Boateng, Nana Kwame, Abeku Koomson, Frank Annor, Kwaku Agyei, Mark Assiaw and Nana Bonsu, you are true friends.

Let me finally appreciate my field assistants who were with me in the field: Jacob, Pieter Adongo and Mark, you drove me through the field on the motorbike safely to conduct interviews and collect data. God bless you.

I also acknowledge the various roles played by my PhD colleagues on the staff development project being Emmanuel Owusu Ansah, Sampson Oduro

Kwarteng and Hellen Essandoh. I remember how you guided me and assisted me the first time I stepped in Holland. Not forgetting the great friendship I have enjoyed from other Ghanaian PhD colleagues at UNESCO-IHE, namely, Ebenezer Ansa, George, Salifu and Michael. I cherish the friendship and the support we gave each other.

I appreciate the friendship and moral support I received from the staff of the MAI department. My stay in Holland was made very easy and comfortable because of some valuable friends I met. I remain indebted to Marloes Mul for her beautiful human relation and love for Africans, especially me. I enjoyed staying with you on two occasions and the fact that you made me a little richer. To all the MSc students and fellow PhD colleagues I met I say God bless you for your wonderful friendship. Special appreciation to my *shalamuta* brothers and all the African Night performers I acted with. The three African Nights I enjoyed are cherishable moments I will also remember.

Life in Delft would have been very boring without having friends in other European countries that one could call on skype or cheaper just to release tension and relax the brains after a hard days work. To my cousin Perpetual, Mike and Franci and Homie Schati, I am grateful for the morale and the support.

I made a very wonderful family in Delft with the Mount Zion RCCG membership. Because of you I never wanted to leave Delft. I am grateful to Pastor Hiscent, Helena, leadership and entire membership of the church. My Good God will establish you in abundant joy and peace.

Let me finally descend home and appreciate all my family members for the great and cherishable support you offered. I thank my father (Mr. Ofofu Baabu) and mother (Paulina Amobe) for pushing me to greater heights and encouraging me to keep up despite the numerous challenges. To my siblings (Doris, Seth, Suzzy, Irene and Eva), I remain indebted to you because your numerous pieces of support have all played important roles in bringing me this far.

Special thanks to all Christ Resurrection Church members, especially Rev. C. K. Soso, Rev J. E. Mensah, Rev. Nana Boateng, Rev. E. Y. Ampofo, Rev James Yamoah, Rev Brekorang and Rev. Yiadom-Boakye. I thank you for your prayer support and spiritual backing. My God will bless you for what you have done in my life.

I appreciate the family of Dr. K. B. Nyarko for the wonderful support. I have but few words to tell you. You are God-sent. God enrich your life for the love you've shown me. I pray the Lord almighty bless Prof. Mrs. Esi Awuah for

her encouragement during my PhD studies. I also appreciate the family of Mr. & Mrs. Kyei-Sarpong for supporting me when I was in Bolgatanga to conduct fieldwork.

I remain grateful to my in-laws, Rev J. E. Mensah and wife and children for your love. You took care of my wife and daughter when I was away in Delft. You gave me all the support I needed and were always at the airport to pick me when I returned to Ghana. God bless you.

To my lovely wife and daughter, I love you and will always do. Sweetheart, we got married just after I started my PhD and left you for Delft when you were pregnant. Forgive me for the several days I left you at home to be in Delft or on the field. You gave me all that a wife could do to make her husband happy and successful. You are the best wife I could and will ever have. I love you Katriel.

LIST OF ACRONYMS

ADB	Agricultural Development Bank
ADRA	Adventist Development and Relief Agency
AMVS	Sourou Valley Development Authority
AREDONZE	Associação de Regantes do Distributor 11
CIDA	Canadian International Development Agency
CSIR	Council for Scientific and Industrial Research
CWSA	Community Water and Sanitation
DANIDA	Danish International Development Agency
DAs	District Assemblies
DGEAP	General Directorate for Provision of Potable Water
DGH	General Directorate of Hydraulics
DGHA	General Directorate of Agricultural Hydraulics
DGIRH	General Directorate for Inventory of Hydraulic Resources
DGRH	General Directorate for Fishery Resources
DISCAP	District Capacity Building Project
DWST	District Water and Sanitation Team
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organisation
FBOs	Farmer Based Organisations
FDR	Rural Development Fund
GIDA	Ghana Irrigation Development Authority
GIS	Geographic Information System
GWCL	Ghana Water Company Limited
GWP	Global Water Partnership
GWSC	Ghana Water and Sewerage Corporation
ICOLD	International Commission on Large Dams
ICOUR	Irrigation Company of Upper Region
IFAD	International Fund for Agricultural Development
IUCN	World Conservation Union
IWRM	Integrated Water Resources Management
LACOSREP	Land Conservation and Smallholder Rehabilitation Project
MDGs	Millennium Development Goals
MEE	Water and Environment Ministry
MIA	Moçfer Industrias Alimentares
MMDAs	Metropolitan, Municipal and District Assemblies
MOB	Bagre Development Agency
MOFA	Ministry of Food and Agriculture

NCWSP	National Community water and Sanitation Program
NEPAD	New Partnership for Africa's Development
NGOs	Non-Governmental Organizations
ONBI	National Office of Dams and Irrigation
ONEA	National Water and Sanitation Office
SAP	Structural Adjustment Program
SARI	Savannah Agricultural Research Institute
SONABEL	Burkina Faso Electricity Society
SPPAGIRE	National Council for Water and Permanent Secretariat of National IWRM Plan
TIPCEE	Trade and Investment Program for a Competitive Export Economy
VALCO	Volta Alluminium Company
VBA	Volta Basin Authority
VBTC	Volta Basin Technical Committee
VCR	Value/Cost Ratio
VRA	Volta River Authority
WATSAN	Water and Sanitation Committee
WEAP	Water Evaluationa and Planning
WRC	Water Resources Commission
WUA	Water User Association
WVPP	White Volta Pilot Project

LIST OF FIGURES

Figure 1.1: Everybody lives downstream..., and looks upstream (Van der Zaag, 2007).	6
Figure 2.1: Sub-Basins of the Volta Basin and Location of study area (Source: Liebe et al., 2002).	10
Figure 3.1: Trend of large-reservoir irrigation development in sub-Saharan Africa (Source: Aquastat, available at: http://www.fao.org/nr/water/aquastat/main/index.stm).	43
Figure 3.2: Chain of Success Factors for sustainable Irrigation Development (Source: modified from Vishnudas et al., 2007).	63
Figure 4.1: Location of Vea and Tono Irrigation Schemes in the Volta basin.	83
Figure 4.2: Organisational Structure of ICOUR Management.	86
Figure 4.3: Layout of Tono Irrigation Scheme.	88
Figure 4.4: Layout of Vea Irrigation Scheme.	89
Figure 5.1: Schematic presentation of a small reservoir system (Source: Gyasi, 2005).	114
Figure 5.2: a) pumps used in abstracting water from small reservoirs b) furrows used in irrigating fields of small reservoir irrigation schemes.	115
Figure 5.3: a) Example of private dugout; b) Abstracting Water with motorized pump from a private dugout.	119
Figure 5.4: Farmer using rope and bucket to irrigate from a permanent shallow well.	122
Figure 5.5: a) Diesel pump abstracting water from river b) method of transporting and applying water under riverine irrigation technology.	125
Figure 5.6: a) Shallow well with hip pump b) Rope and Bucket Watering used in Temporal Shallow well farms.	128
Figure 5.7: a) Initial stages of Riverine Alluvial Dugouts b) Latter stages of Riverine Alluvial Dugouts.	130
Figure 5.8: a) Water abstraction method b) Water application method for Riverine alluvial dugouts technology.	131
Figure 6.1: a) Seasonal irrigation water applied; b) Seasonal expenditure on irrigation water.	146

Figure 6.2: a) Average tomatoes yield for 2008; b) Fertilizer input for tomatoes.	147
Figure 6.3: Performance of a regression analysis of crop yield of irrigation technologies.	148
Figure 6.4: a) Water productivity for tomatoes in 2008; b) Value of water for tomato production in 2008.	149
Figure 6.5: a) Farm-gate prices for tomatoes in 2007/2008; b) Trend of farm-gate prices for tomatoes in 2007/2008.	150
Figure 6.6: a) Gross profit margin for tomato production; b) Farmer profit for tomato production.	151
Figure 6.7: a) Cost of hired labour in production; b) Participation of women farmers.	152
Figure 7.1: Irrigated areas in observed in 2003 and 2005 (images taken on 16-01-2003 and 27-01-2005).	162
Figure 7.2: Irrigated areas observed in 2007 and 2010 (images taken on 10-01-2003 and 27-01-2010).	162
Figure 7.3: a) Women from southern Ghana buying tomatoes from the Upper East Region; b) Small reservoir with breached dam wall.	167
Figure 7.4: a) Temporal shallow wells being used for tomato production; b) Motorized pumps being used at small-reservoirs for irrigation.	168
Figure 7.5: a) Rehabilitated Pwalugu Tomato Factory; b) Farmers cultivating vegetables such as cabbage for the urban population.	172
Figure 7.6: Pilot project of drip irrigation systems in the Veia Scheme introduced by TIPCEE.	173
Figure 8.1: Schematic layout of catchment and modelled parameters in WEAP.	185
Figure 8.2: Calibrated streamflow; a) Atankwidi; b) Yarigatanga	188
Figure 8.3: Validated streamflow; a) Atankwidi; b) Yarigatanga	189
Figure 8.4: 45-year annual rainfall deviation from the normal for study area.	190
Figure 8.5: Impact of 5% annual growth of irrigation on groundwater storage	193
Figure 8.6: Impact of scenario 1 on streamflow; a) Atankwidi; b) Yarigatanga	194
Figure 8.7: Impact of scenario 2 on groundwater storage.	195
Figure 8.8: Impact of scenario 2 on streamflow; a) Atankwidi; b) Yarigatanga	196

Figure 8.9: Impact of scenario 3a on streamflow; a) Atankwidi streamflow; b) Yarigatanga	198
Figure 8.10: a) Impact of scenario 3a on groundwater storage; b) Impact of scenario 3b on groundwater storage.	199
Figure 8.11 Impact of scenario 3c on groundwater storage	201
Figure 8.12: a) Impact of reducing groundwater recharge by 10% on groundwater irrigation; b) Impact of reducing groundwater recharge by 20% on groundwater irrigation	201
Figure 8.13: Water Balance of the catchment.	202
Figure 8.14: Impact of change in inflow into Lake Volta on water level, storage and electricity production, given historical operating policies.	212
Figure 8.15: Impact of reduction of inflow into Lake Volta on hydropower generation at Akosombo.	213

LIST OF TABLES

Table 3.1: Common challenges affecting irrigation development in sub-Saharan Africa	54
Table 3.2: Measure of Success Factors on Some Irrigation Systems in Sub-Saharan Africa.	68
Table 4.1: Some large-scale irrigation schemes in the White Volta sub-basin of Burkina Faso.	81
Table 4.2: Features of the Vea and Tono Irrigation Schemes.	82
Table 4.3: Priorities and Rules for Land Allocation at Vea and Tono.	91
Table 4.4: Cropped areas in the Vea and Tono Irrigation Schemes from 1986-2007.	94
Table 4.5: Comparison between recorded crop yields at Vea and Tono irrigation schemes and the potential yields (FAO) for semi-arid and arid regions.	97
Table 4.6: Range of Global water productivity values for selected crops.	100
Table 4.7: Credits provided for rice farmers in Tono scheme and repayment records.	103
Table 5.1: Summary of Description of Irrigation Technologies.	137
Table 6.1: Tomato farmers surveyed and analysed for the 2007/2008 season.	141
Table 6.2: Cost of water-use for irrigation technologies in Upper East Region and Burkina Faso.	143
Table 6.3: Comparison of irrigation technologies using productivity factors.	153
Table 7.1 Small and Large Reservoir Irrigation systems in the entire study area	160
Table 7.2: Estimated irrigated areas from satellite images	163
Table 7.3: Extrapolated irrigated areas from satellite images	164
Table 7.4: Government and private-led irrigated areas in the study area.	165
Table 8.1: Irrigation water demand data for WEAP modelling.	181
Table 8.2: Modelled parameters for the three catchments.	186
Table 8.3 Rainfall-Runoff coefficient obtained after calibration.	187
Table 8.4: Range of rainfall and modifying factors for climatic variations	191
Table 8.5: Input values for 5% annual growth in irrigation at 2025	192
Table 8.6: Input values for 10% annual growth in irrigation at 2025.	194
Table 8.7: Current groundwater irrigation and potential expansion up to 10% of catchment area.	197
Table 8.8: Current surface water irrigation and potential expansion up to 2% of catchment area	198
Table 8.9: Input values for Improving Irrigation Efficiency to 70%.	200
Table 8.10: Monthly Evaporation from reservoirs	203

Table 8.11 Total Evaporation from surface (ESI) and groundwater irrigation (EGI) and Evaporation from reservoirs (ER)	204
Table 8.12: Comparison of Water losses between WEAP results and water balance analysis	205

TABLE OF CONTENT

Abstract	v
Dedication	x
Acknowledgement	xi
List of Acronyms	xv
List of Figures	xvii
List of Tables	xxi
Table of Content	xxiii
Chapter 1 Introduction	1
1.1 Background	1
1.2 Review of Irrigation Development in sub-Saharan Africa	3
1.3 Irrigation Development in the White Volta sub-basin	4
1.4 Sustainable Irrigation Development in the context of Integrated Water Resources Management	5
1.5 Research Objectives	7
1.6 Thesis Outline	7
Chapter 2 The White Volta sub-basin	9
2.1 The Volta Basin	9
2.2 Water Governance in the Volta Basin	11
2.3 The White Volta sub-basin	13
2.4 Water uses in the White Volta sub-basin	14
2.5 Water Governance in the White Volta sub-basin	15
2.5.1 Ghana	16
2.5.2 Burkina Faso	32
2.5.3 Transboundary Water Management	37
2.5.4 Description of Study Sites	38
2.6 Conclusion	40
Chapter 3 Review of Irrigation Development in Sub-Saharan Africa	41
3.1 Introduction	41
3.2 Trend of Irrigation Development in sub-Saharan Africa	42
3.3 Types of Irrigation Development in sub-Saharan Africa	44
3.3.1 Government-Led Irrigation Development	45
3.3.2 Non-Government led Irrigation Systems	48
3.3.3 Non-Government Initiated but later supported/partnered by Government	51
3.3.4 Joint Ventures	52
3.4 Challenges of Irrigation Development in Sub-Saharan Africa	53
3.4.1 High Irrigation Development Cost	55
3.4.2 Lack of Access to Credit	55
3.4.3 Marketing and Access to Markets	57
3.4.4 Ineffective Institutions	58
3.4.5 Choice of Technology and Maintenance of Infrastructure	59

3.4.6	Low Productivity	60
3.5	Success Factors for Achieving Productive and Sustainable Irrigation Development in Sub-Saharan Africa	61
3.5.1	Background	61
3.5.2	Success Factors for Sustainable Irrigation Development	62
3.5.3	Impact of Success Factors on some Irrigation Schemes/Systems in sub-Saharan Africa	66
3.6	Conclusions	66
Chapter 4 Is Large-Scale Public Irrigation the way-forward for sub-Saharan Africa?		72
4.1	Introduction	72
4.1.1	Background	72
4.1.2	Objective	74
4.2	Large-Scale Irrigation Development in sub-Saharan Africa	75
4.2.1	Socio-Economic Impact of Large-Scale Irrigation in sub-Saharan Africa	77
4.2.2	Environmental Impact of Large-Scale Irrigation in sub-Saharan Africa	78
4.2.3	Challenges facing Large-Scale Irrigation in Africa	78
4.2.4	Large-Scale Irrigation Development in the White Volta sub-basin	80
4.3	Case Study on the Vea and Tono Irrigation Schemes	81
4.3.1	Methodology and Data Collection	81
4.3.2	Description of Vea and Tono Irrigation Schemes	82
4.4	Data Analysis	93
4.4.1	Productivity of the schemes	93
4.4.2	Financial Sustainability of the Irrigation Schemes	101
4.5	Discussion of Results	104
4.5.1	Challenges	104
4.5.2	Lessons from Vea and Tono Irrigation Schemes for Future Irrigation Development	106
4.6	Conclusions	108
Chapter 5 Description of Irrigation Technologies in the White Volta sub-basin		109
5.1	Introduction	109
5.2	Structure of Chapter	110
5.3	Definition of Irrigation Schemes and Technologies	110
5.3.1	Small Reservoir Irrigation Technology	111
5.3.2	Dugout Irrigation Technology	118
5.3.3	Permanent Shallow Well Irrigation Technology	120
5.3.4	Riverine Water Irrigation Scheme	124
5.3.5	Temporal Shallow Well Irrigation Scheme	127

5.3.6	Riverine Alluvial Dugout Irrigation Technology	129
5.4	Evolution from one technology to another	134
5.5	Conclusion	135
Chapter 6	Productivity of Irrigation Technologies in the White Volta sub-basin	139
6.1	Introduction	139
6.2	Methodology and data collection	140
6.3	Field Results	141
6.3.1	Investments in water and seasonal expenditure on water	142
6.3.2	Plot size and fertilizer use	145
6.3.3	Amount of water applied by irrigation technologies	145
6.3.4	Crop productivity	146
6.4	Data Analysis	147
6.4.1	Analysis of crop yield of irrigation technologies	147
6.4.2	Water productivity	149
6.4.3	Economic impact of irrigation technologies	150
6.4.4	Social impact- employment/labour and women participation	151
6.5	Conclusion	155
Chapter 7	Past and Future Trend of Irrigation Development in three catchments of the White Volta sub-basin	157
7.1	Introduction	157
7.2	Methodology	158
7.3	Past Trend of Irrigation Development in the White Volta sub-basin	159
7.3.1	Data Analysis of Irrigation Development in the study area	160
7.3.2	Satellite Image Analysis of Irrigation Development in the Study Area	161
7.3.3	Past Trend of Irrigation Development in the study area	164
7.3.4	Factors Influencing Past Trend	166
7.4	Variables Influencing Future Irrigation Development	169
7.4.1	Irrigation Potential of the Study Area	169
7.4.2	Drivers for the Upscaling of Irrigation Development	170
7.5	Future Irrigation Development in the White Volta sub-basin	175
Chapter 8	Impact of Intensifying Irrigation Development and Implications for Sustainable Water Resources Management in the White Volta sub-basin	177
8.1	Introduction	177
8.2	Methodology and Data Collection	179
8.2.1	Domestic, Livestock and Urban water demand	180

8.2.2	Irrigation water demand	180
8.2.3	Groundwater characteristics	182
8.2.4	Rainfall-Runoff Co-efficient	182
8.3	Model Development	183
8.3.1	Overview of WEAP Model	183
8.3.2	Model setup	184
8.3.3	Parameterization of the study area	186
8.3.4	Current accounts/Calibration	187
8.3.5	Validation	188
8.3.6	Reference scenario	189
8.4	Scenarios Development and Analysis	191
8.4.1	The situation in 2025 if irrigation should have expanded at a rate of 5%/a	192
8.4.2	The situation in 2025 if irrigation should have expanded at a rate of 10%/a	194
8.4.3	Investigating sustainable groundwater and surface water use for irrigation	196
8.4.4	Impact of variations in groundwater recharge on model results	201
8.4.5	Water Balance Analysis of Scenarios	202
8.5	Discussion of the Results	206
8.5.1	Current Level of Exploitation of Water Resources for Irrigation	206
8.5.2	Impact of Intensifying Irrigation on Water Resources and Competing Water Uses	207
8.6	Managing tradeoffs between upscaling Irrigation and Hydropower Production	209
8.6.1	Benefits of Irrigation Development in the White Volta sub-basin	209
8.6.2	Benefits of Hydro-power production at Akosombo	210
8.6.3	Managing trade-offs between irrigated agriculture upstream and hydropower production downstream at Akosombo	211
8.6.4	Implications for Sustainable Water Resources Management	214
8.6.5	Conclusions and Recommendations	214
Chapter 9		216
Conclusions and Recommendations		216
9.1	Conclusions	216
9.1.1	Irrigation Development in sub-Saharan Africa	216
9.1.2	Irrigation Development in the White Volta sub-basin	217
9.1.3	Impact of Upscaling Irrigation Development in the White Volta sub-basin	218

9.1.4 Sustaining Irrigation Development in the White Volta sub-basin	219
9.1.5 Implications of results for other regions of sub-Saharan Africa	220
9.2 Recommendations	221
9.3 Limitations of the Study	221
9.4 Innovations made by the Study	222
References	224
Appendix A – data for cropwat	241

Chapter 1

INTRODUCTION

1.1 BACKGROUND

The extreme variability in rainfall, long dry seasons, recurrent droughts, floods and dry spells pose a key challenge to food production. The sole dependence of farming on rainfall has been a major cause of low food productivity, food shortages, undernourishment and famine in sub-Saharan Africa. The world's hotspots for hunger and poverty are concentrated in the arid, semiarid and dry subhumid regions of the world which depend solely on rainfall for food production (Faurès et al., 2007). In large parts of Africa, the fight against poverty and the prospects to reach the Millennium Development Goals (MDGs) has been the focus of governments (Birner et al., 2005).

Irrigated agriculture has been a major solution used in addressing water challenge affecting food production in areas of unreliable rainfall patterns. Global efforts aimed at ensuring food sufficiency by increasing staple food production have adopted irrigation farming as one of the main strategies. Approximately 70% of the world's irrigated land is in Asia, where it accounts for almost 35% of cultivated land. Of the total cultivated area in Africa, estimated at 198 million ha, just 4% (slightly above 7 million ha) is equipped with irrigation infrastructure (Svendsen et al., 2009).

According to the FAO (1995) sub-Saharan Africa has an irrigation potential of about 42 million hectares of which only 17% is developed. The average rate of expansion of the irrigated area over the past 30 years was 2.3%/a. Expansion slowed to 1.1% per year during 2000–2003 but has since picked up as a result of renewed investments by multilateral and bilateral donors and foundations (You et al., 2010). In sub-Saharan Africa there is thus great potential for expansion of irrigated agriculture.

Irrigation has historically had a large positive impact on poverty reduction and livelihoods, in both urban and rural areas, producing relatively cheap food for everyone and providing employment opportunities for the landless poor (Hussain, 2005). Through increased productivity irrigation produces secondary benefits for the economy at all levels, including increased productivity of rural labour, promotion of local agro-enterprises, and stimulation of the agricultural sector as a whole (Faurès et al., 2007). About 46% of the gross value of global agricultural production comes from irrigated

areas, which makes up 28% of the total harvested area (de Fraiture et al., 2007). Many expect that the contribution of irrigated agriculture to food production and rural development will increase in the coming decades (Seckler et al., 2000a; Bruinsma, 2003).

While investments in irrigation have yielded significant impacts in terms of improving food security and poverty reduction in areas such as South-East Asia and East Asia, the same cannot be said for sub-Saharan Africa (Rosegrant et al., 2001; Hussain 2005). Regions such as South-East Asia have almost exhausted their irrigation development potential, making the potential irrigable land in Sub-Saharan Africa a major hope for the world in terms of feeding the future population (FAO, 2006).

Due to the far reaching benefits of irrigation farming, several investments in sub-Saharan Africa have been directed towards irrigation development. These investments have been driven by government policies (colonial and post-colonial), multinational donor agencies, private investors, markets, and by technological innovations such as, drip, motorized pumps and treadle pumps. It has therefore resulted in several types of irrigation systems in sub-Saharan Africa over time. International donors have shown renewed interest in irrigation investments, particularly in sub-Saharan Africa, where irrigation development has remained well below its physical potential. The Commission for Africa (2005) and the New Partnership for Africa's Development (NEPAD) have described the need to doubling the irrigated area in Sub-Saharan Africa to achieve the MDGs (de Fraiture et al., 2007). Meanwhile, irrigation development in sub-Saharan Africa has been slow, resulting from several unresolved factors.

To improve irrigation development in sub-Saharan Africa the following is required: (1) an assessment of the factors that have influenced past trends of irrigation development, (2) identification and application of lessons from successful irrigation systems in the sub-Saharan African context, (3) discovery of additional interventions needed to accelerate the future expansion and the potential influence of such interventions, and (4) promotion of policies that ensure productive and sustainable irrigation development.

The implications for increasing irrigation development are enormous. Expansion of irrigated agriculture increases consumptive water use which obviously reduces available water for other competing water uses. Increased cultivation in recent decades has resulted in increased diversion of freshwater, with some 70% of water now being used for agriculture and

reaching as high as 85%-90% in parts of Africa, Asia and the Middle East (Shiklomanov and Rodda, 2003).

The increasing competition for water as a result of increasing agricultural production needs to be managed efficiently. Recent trends in managing competing water uses have been to promote river basin organisations where water is managed at the basin level. There is general agreement on the long-term benefits of effective integrated management of river basins, especially with increasing competition and environmental degradation (Merrey et al., 2007). In many developing countries small-scale irrigation farmers are under threat from other sectoral demands for water considered of higher economic value. This threatens the livelihoods of millions of small farmers in economies with few alternative sources of employment (Svendson, 2005). An externally imposed “one-size-fits-all” strategy for managing such complexity is unlikely to be effective. Policies emphasizing public management, community-level collective action and private sector roles follow different institutional approaches, but share several tendencies (Merrey et al., 2007). Knowledge of the hydrological impact of up-scaling irrigated agriculture on downstream users will be essential for decision making and negotiating tradeoffs between competing water uses.

This study aims at helping to achieve sustainable irrigation in sub-Saharan Africa, through gaining a better understanding of productive irrigation water use and effective management of irrigation development.

1.2 REVIEW OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

Irrigation systems in many developing countries were established with the assumption that enhanced financial gains from improvements in productivity levels would be sufficient to meet the operation and maintenance costs. This assumption has very often proved unfounded; public irrigation systems in developing countries have seldom performed to their design potential (Shah et al., 2002).

Reviews help in assessing past and existing situations which inform decision making to achieve improvement. Review of irrigation development can (1) confirm some earlier findings and disprove some popularly-held notions and incorrect perceptions; (2) provide empirical support to some existing irrigation investment policies and suggest reconsidering others; and (3)

provide some specific recommendations for future irrigation investments (Inocencio et al., 2007).

Irrigation development in sub-Saharan Africa started in the colonial era. This was intensified in the period of decolonization and was motivated by strong nation building (Siebert et al., 2002). Governments have been the major investors in irrigation with assistance from international donor agencies. Irrigation schemes developed by governments are mostly publicly managed. Private involvement in irrigation development across sub-Saharan Africa is also significant. There is a wide range of private-led irrigation systems which have resulted in different management systems.

This study reviews irrigation development in sub-Saharan Africa, dating from the colonial era till present. The review covers the types of irrigation systems developed across sub-Saharan Africa and the trends of development of these irrigation systems. It identifies the challenges that have been associated with irrigation development with specific examples from some irrigation systems. Success factors for sustainable irrigation development are identified based on an analysis of various irrigation systems across sub-Saharan Africa.

1.3 IRRIGATION DEVELOPMENT IN THE WHITE VOLTA SUB-BASIN

The practice of traditional irrigated agriculture going back several centuries in some arid regions south of the Sahara, the availability of significant water, land, and labour resources in many areas, good and growing domestic and regional export markets for irrigated food crops, and appropriate low-cost manual and mechanized irrigation equipment promise a bright future for irrigation in sub-Saharan Africa (Perry, 1997).

A typical example is the increasing vegetable irrigation observed in the Upper East Region of Ghana and southern parts of Burkina Faso all in the White Volta sub-basin. The demand for vegetables in the urban centres of southern Ghana has triggered the upscaling of irrigation development in the White Volta sub-basin during the past two decades. Studying this positive development is expected to bring out some of the strategies that are needed in boosting irrigation development across sub-Saharan Africa.

The study is conducted in three neighbouring transboundary catchments located in the Upper East Region of Ghana and southern Burkina Faso. Six different irrigation technologies are identified and researched in the study area. Whereas small reservoirs and large reservoir irrigation schemes are well

covered in the literature (Liebe et al., 2005; Faulkner et al., 2008), other irrigation technologies, which rely on permanent shallow wells, riverine water, temporal shallow wells and riverine alluvial dugouts, are uncommon in the literature (Ofosu et al., 2010).

Lessons from irrigation development in the White Volta sub-basin begin with the performance assessment of two large-scale irrigation schemes over the past thirty years. This is followed by a detailed description of the less known irrigation technologies. Following two years of data collection on these irrigation technologies, a comparative analysis is performed on the productivities of irrigation technologies. The results throw more light on the reason why private-led irrigation has been increasing within the past two decades. A historical analysis is also performed on the trend of irrigation development in the study area. Factors influencing the historical trend and other identified factors are used to forecast the future of irrigation in the White Volta sub-basin.

1.4 SUSTAINABLE IRRIGATION DEVELOPMENT IN THE CONTEXT OF INTEGRATED WATER RESOURCES MANAGEMENT

Increase in consumptive water use (e.g. irrigated agriculture) is driven by the development policies of governments on irrigated agriculture and other economic factors such as market demand which will expand the irrigation activities in the White Volta. The increase in water consumption obviously reduces available water to downstream users.

The implications are significant due to the fact that the Volta basin is of economic importance to the six riparian countries. For example, the importance of the Volta basin to the socio-economic development of Ghana is underscored by the fact that the basin, through its two hydroelectric power stations (located downstream of the White Volta at Akosombo and Akuse), has a potential of generating 1072MW of electricity and supplies energy to Togo and Burkina Faso. The Volta Lake is also used for the transportation of people and goods, particularly petroleum products from the seaport of Tema via Akosombo to Northern Ghana.

Upstream water use influences the flow regime and has impacts downstream, both in terms of quantity and water quality. As stated by van der Zaag and Savenije (2005), my water use always implies “looking upstream” in order to assess water availability, and “looking downstream” in order to assess possible third party effects of my activity (Figure 1.1).

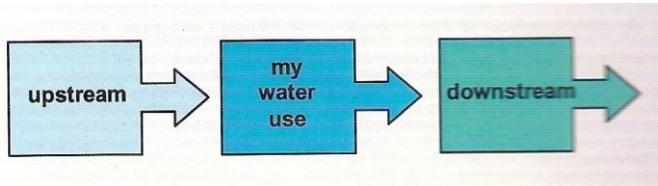


Figure 1.1: Everybody lives downstream..., and looks upstream (Van der Zaag, 2007).

The vital nature of water gives it characteristics of a public good. Its finite nature confers to it properties of a private good, as it can be privately appropriated and enjoyed. The fugitive nature of water, and the resulting high costs of exclusion, confers to it properties of a common pool resource. Water resource management aims to reconcile these various attributes of water. This is obviously not a simple task. The property regime and management arrangements of a water resources system are therefore often complex (Van der Zaag and Savenije, 2005). At the heart, Integrated Water Resources Management aims to reconcile economic efficiency, equity, and environmental preservation goals (Molle et al., 2007). This is reflected in the first Dublin Principle, formulated at the International Conference on Water and the Environment, held in Dublin in January 1992, which states that “since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer” (ICWE, 1992).

Catchment management is based on the recognition of the catchment area as the spatial integrator and appropriate unit for the management of land and water resources based on hydrological principles of upstream-downstream linkages. Thus, catchment management generally aims at establishing an enabling environment for the integrated use and management of water and land resources of a watershed to accomplish resource conservation and biomass production objectives (Jensen, 1996).

Although frequently advocated as a key to achieving effective water management (Rogers and Hall 2003), stakeholder participation in river basin management is not straightforward and actually including the poor and achieving substantive stakeholder representation has proven elusive in practice (Wester et al., 2005). A major lesson learned, relevant to all scales (field, farm, village, catchment and basin), is that the realisation of a conservation or environmental objective can be achieved by paying particular attention to upstream developments, that is, conservation through use. Thus, balancing environment and production objectives and the interests and roles

of various stakeholders of the socio-political hierarchy, based on the principles of collective action and management at the lowest appropriate level, has become a core approach of watershed management (Molle et al., 2007).

Van de Giesen et al. (2001) identify irrigation development in the upstream sections of the Volta Basin and hydropower generation at Akosombo as the main competing water uses. This research quantifies the downstream impact of irrigation development and provides some recommendations concerning future development of the water resources in the White Volta sub-basin.

1.5 RESEARCH OBJECTIVES

In sub-Saharan Africa the best option to enhance food security is investment in both rainfed and irrigated agriculture. Both Governments and the private sector will continue to invest in irrigation development; however their policies need to be informed by empirical evidence and comparative analysis.

The purpose of this research, then, is to enhance the understanding of effective and sustainable irrigation development in the White Volta sub-basin in the wake of increasing small-scale irrigation development taking into account other important economic benefits produced by downstream uses.

The objectives of the study are listed as follows:

1. To produce a comprehensive description of irrigation technologies in the White Volta sub-basin
2. To compare the productivities of the prevailing irrigation technologies in the White Volta sub-basin
3. To determine the past trend and forecast the future of irrigation development in the White Volta sub-basin
4. To assess the impact of upscaling irrigation development in the White Volta sub-basin on competing water uses, including those downstream, and evaluate the implications for sustainable water resources management.

1.6 THESIS OUTLINE

This thesis is presented in nine chapters. The present chapter has introduced the research.

Chapter 2 describes the study area from the Volta Basin, the White Volta sub-basin to the selected catchments within the White Volta sub-basin. The

description covers existing water governance, water resources, and competing water uses.

Chapter 3 reviews irrigation development across sub-Saharan Africa. The review focuses on the trend of irrigation development, types of irrigation development, challenges affecting irrigation development and finally identifies success factors for sustainable irrigation development.

Chapter 4 provides a case-study on the performance of two large-scale public irrigation schemes aimed at contributing to better understanding the potential of this type of irrigation development in sub-Saharan Africa.

Chapter 5 describes the indigenous small-scale irrigation technologies identified in the White Volta sub-basin which are rarely found in literature.

Chapter 6 presents a comparative analysis of all six irrigation technologies identified in the study area. The comparative analysis covers food productivity, water productivity and the economic impacts of these irrigation technologies.

Chapter 7 analyses historical trends of irrigation development in the study area and attempts to forecast future irrigation developments in the White Volta sub-basin.

In Chapter 8 a hydrological analysis is performed to assess the impact of upscaling irrigation development on competing water uses including the Akosombo dam and implications for water resources management in the Volta basin.

Chapter 9 presents the conclusions of the research.

Chapter 2

THE WHITE VOLTA SUB-BASIN

2.1 THE VOLTA BASIN

This chapter describes the study area. The research was conducted in three sub-catchments (Anayari, Atankwidi and Yarigatanga) of the White Volta sub-basin. The White Volta is a major tributary of the Volta basin. The description entails the location, climate, hydrology, hydrogeology, water governance and water uses at the three levels: beginning with the Volta Basin, followed by the White Volta and lastly the three sub-catchments.

The Volta River Basin is located in West Africa and covers an estimated area of 400,000 km². The Volta basin stretches from approximately latitude 5° 30' N in Ghana to 14° 30' N in Mali. The widest stretch is from approximately longitude 5° 30' W to 2° 00' E but the basin becomes more narrow towards the coast of the Gulf of Guinea. The Volta basin is spread over six West African countries (43% in Burkina Faso, 42% in Ghana, 6% in Togo, 3% in Benin, 3% in Cote d'Ivoire and 3% in Mali) (Barry et al., 2005).

The Volta Basin is drained by several major rivers: the Black Volta, the White Volta with the Red Volta as its tributary, the Oti River and the Lower Volta. The mean annual flows of the Black Volta, White Volta, Oti River and Lower Volta are 7.7, 9.6, 11.2 and 9.8 x 10⁹ m³/a, respectively (MWH, 1998). A dominant feature in the basin is Lake Volta, which covers about 4% of the total area in Ghana, and which was formed by the construction of Akosombo dam in 1965. Inflows into Lake Volta average 38 x 10⁹ m³/a. Hydropower is generated at Akosombo and Kpong (1072MW installed capacity).

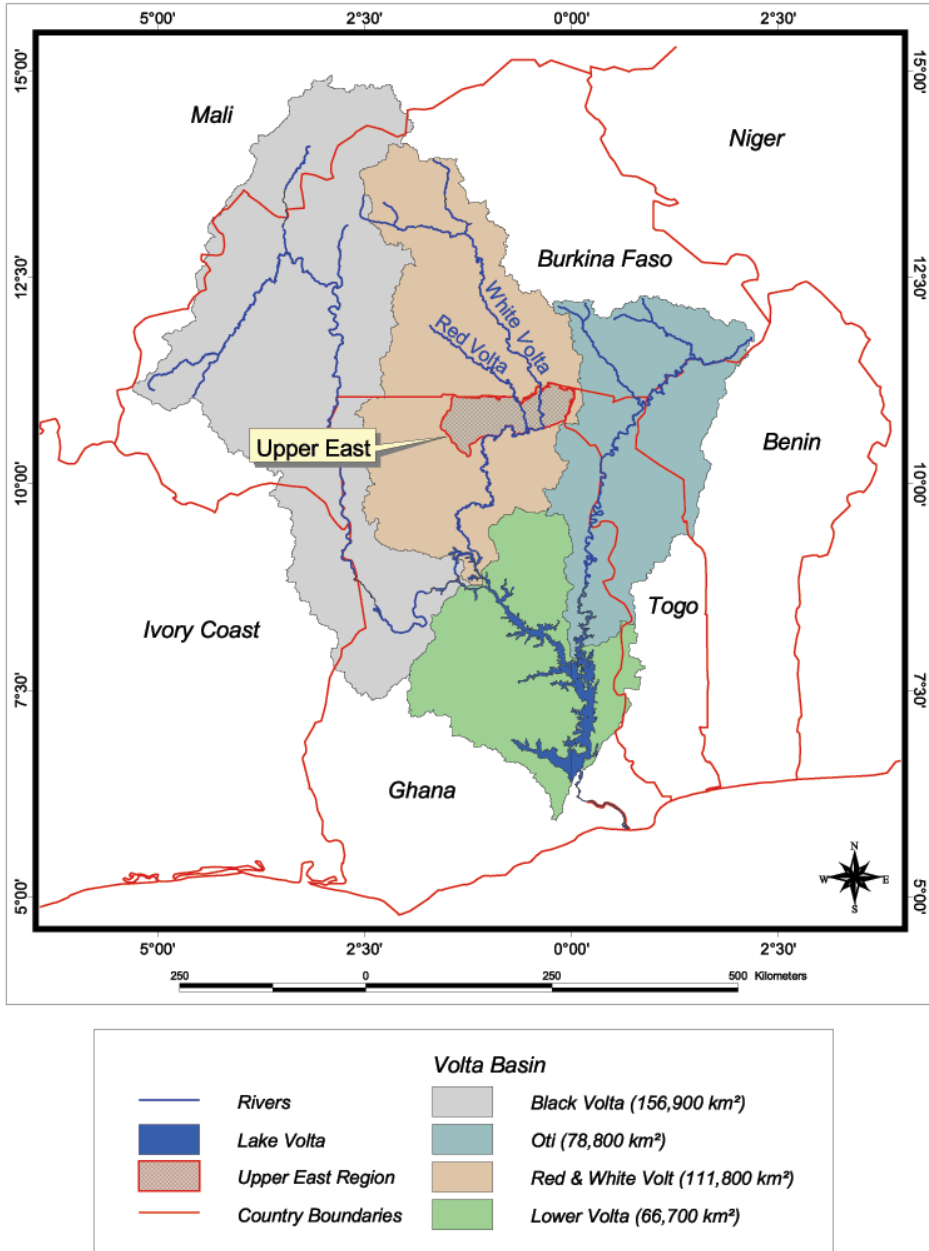


Figure 2.1: Sub-Basins of the Volta Basin and Location of study area (Source: Liebe et al., 2002).

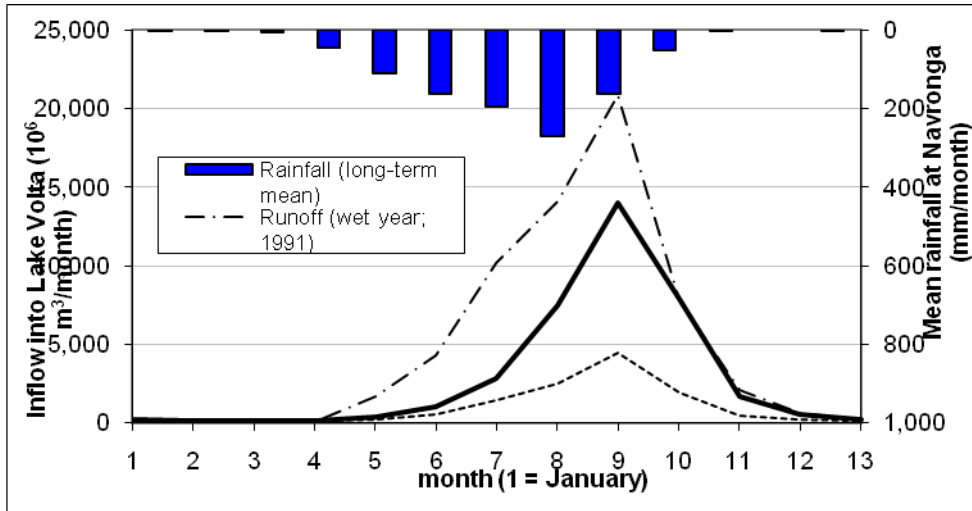


Figure 2.2: Hydrograph of the Volta River and Rainfall at Navrongo (Data source: Obeng-Asiedu, 2004)

The geographic distribution of the population within the basin is highly variable with a density ranging from 8 to 104 persons/km². The total basin population is expected to grow significantly from an estimated 18.6 million in 2000 to approximately 33.9 million in 2025. This represents a growth rate of 2.5 % per year. Population in the Volta Basin is generally rural (64-88 %) and most people depend to a large extent on the exploitation of the natural resources for their livelihood, which may not be environmentally sustainable in the future (Barry et al., 2005).

The major uses of water in the Volta Basin are rainfed-agriculture, hydro-power generation, irrigation, fisheries, domestic water uses, industrial and mining water uses, livestock and water transport.

2.2 WATER GOVERNANCE IN THE VOLTA BASIN

Joint water governance of the Volta Basin emerged out of collaborations between Ghana and Burkina Faso on the Volta Basin. In April of 2004, the Ministers in charge of water resources of Ghana and Burkina Faso signed the Ghana-Burkina Joint Declaration, which acknowledged common water and environmental issues and stated a desire to collaborate on management of shared water resources through a Volta Basin Technical Committee (VBTC), involving all riparian countries.

The process of establishing the Volta Basin Authority began with the ministerial endorsement and signing of an agreement to form the Volta Basin Technical Committee (VBTC) in November of 2004 (WRC, 2004). On 6 December 2005, in Ouagadougou, the Ministers in charge of water from Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali and Togo signed a "Memorandum of Understanding to establish a Volta Basin Authority (VBA)" (Opoku-Ankomah et al., 2006). On the 17th of July 2006, the Ministers in charge of water at a meeting in Lomé, approved a Convention and Statutes for the Volta Basin Authority (VBA), with its headquarters in Ouagadougou, and appointed an Interim Executive Directorate. The first Assembly of Heads of State of the Volta Basin was held on the 19th of January 2007 at Ouagadougou where the VBA convention was signed. On the 16th of November 2007, the first meeting of the Council of Ministers in Ouagadougou signed the statutes of the VBA. The Volta Basin Authority Convention has been ratified by all riparian states except Cote d'Ivoire (source: <http://www.abv-volta.org/about/historique>, accessed 17-10-2010).

Mandate and Organisation of the Volta Basin Authority

The mandate of the VBA is to:

1. Promote permanent consultation tools among the parties for the development of the basin;
2. Promote the implementation of integrated water resources management and the equitable distribution of the benefits resulting from their various utilizations;
3. Authorize the development of infrastructure and projects planned by the stakeholders and which could have substantial impact on the water resources of the basin;
4. Develop joint projects and works;
5. Contribute to poverty alleviation, the sustainable development of the Parties in the Volta basin, and for better socioeconomic integration in the sub-region.

The permanent administrative organs are:

1. The Assembly of Heads of State and Government;
2. The Council of Ministers in charge of Water Resources;
3. The Forum of the Parties involved in the Volta basin development;
4. The Committee of Experts;
5. The Executive Directorate of the Authority.

The VBA is in its infant stages, as the Volta Basin office in Ouagadougou is currently being setup. The VBA has therefore not shown any impact on the Water Resources Management in the Volta Basin since its inception.

2.3 THE WHITE VOLTA SUB-BASIN

The total catchment area of the White Volta is 107,417km² distributed in Ghana, Burkina Faso and Togo. Its main tributaries are the Nakambé, Red Volta, Morago, Nasia, Kulpawn and Tamne. The area of the catchment outside Ghana is 58,207km² which is about 54% of the total basin area. The area of the catchment in Togo is less than 5% of the total.

The White Volta begins as the Nakambé River in Burkina Faso. The Red Volta, referred to as Nazinon in Burkina Faso, and Sissili are tributaries of the White Volta and have their source in Burkina Faso. In the White Volta sub-basin, the following rivers originate from within Ghana: Nasia, Kulpawn and the latter's tributary Sisili (WRRI, 1975).

The surface water resources in the basin consist of flows generated inside Burkina Faso as well as flows from within Ghana. The mean annual flow of the White Volta sub-basin is about 300 m³/s, of which 36.5% is generated in upstream Burkina Faso (Barry et al., 2005). The discharges entering Ghana are estimated from the border gauging stations. The border station on the Red Volta is Nangodi with a measured average annual flow of 30m³/s and the gauging station on the White Volta is Yarugu with a measured average annual flow of 80m³/s (Opoku-Ankomah and Amisigo, 1997). The White Volta sub-basin contributes about 25% of the annual total flows to the Volta Lake. The mean monthly runoff varies from a maximum flow of 1,216m³/s to a minimum of about 0.1m³/s (Barry et al., 2005).

Climate: The White Volta sub-basin stretches into three climatic zones:

1. The Sudan zone with an annual rainfall between 900 and 1,200mm/a distributed on average over 74 rainy days. It is located South of the 11° 30'N parallel. The mean temperature in this climatic zone is always below 28°C.
2. The Sudano-Sahelian zone with an annual rainfall between 600 and 900mm/a on average over 43 rainy days, located between the 11° 30'N and 14°N parallels. In this zone the mean temperature lies between 28°C and 29°C.
3. The Sahelian zone located North of the 14°N parallel with a mean annual rainfall between 300 and 600mm/a over 38 rainy days. The mean temperature in this climatic zone is always higher than 29°C.

Hydrogeology: The White Volta sub-basin is composed of about 45% crystalline rocks comprising the Birimian system and its associated Granitic Intrusives and isolated patches of Tarkwaian formations. The remaining 55%

of the White Volta sub-basin is composed of Voltaian Systems consisting of the Upper Voltaian Sandstone, Obosum and Oti beds and Lower Voltaian (Barry et al., 2005).

Aquifers: Two types of aquifers exist in the White Volta sub-basin. These are the weathered zone aquifers and the fissured zone aquifers. These aquifers are either phreatic semi-confined or confined depending on the clay and mica content of the upper weathered layer (Kortatsi, 1997). The fractured zone aquifers are normally discontinuous and limited in area. Due to the sandy clay nature of the weathered overburden, the groundwater occurs mostly under semi-confined or leaky conditions (Ministry of Works and Housing, 1998).

Generally the yield of boreholes vary from $0.03\text{m}^3/\text{h}$ to $24.0\text{m}^3/\text{h}$ with a mean value of $2.1\text{m}^3/\text{h}$ suggesting that most of the aquifers are low yielding (Kortatsi, 1997). Yields from boreholes are highly variable because of the lithological varieties and structural complexities of the rocks (Dapaah-Siakwan and Gyau-Boakye, 2000).

Studies (Kortatsi, 1994; Ministry of Works and Housing, 1998) revealed that the quality of groundwater in Ghana is generally good for multi-purpose use except for the low pH (3.5-6.0) values, and the presence of high level of iron, manganese and fluoride in certain localities.

2.4 WATER USES IN THE WHITE VOLTA SUB-BASIN

Agriculture is the main economic activity in the sub-basin. The agricultural activities include rainfed agriculture, irrigated agriculture, livestock production and fishing. Other notable water uses are domestic water supply (for both rural and urban settlements), industrial water supply and hydropower generation. Current surface water uses in the sub-basin are estimated at about $0.11\text{m}^3/\text{s}$ for domestic water supply and about $2\text{m}^3/\text{s}$ at numerous small-scale irrigation projects (Barry et al., 2005).

In Ghana there are about 200 small reservoirs and 800 dugouts developed in the White Volta sub-basin for the purposes of livestock, fishing, domestic, construction and irrigation farming. In addition there are three large-scale irrigation schemes with a sum of 3790ha of developed irrigable area for irrigation farming. Unmeasured areas of informal irrigation using various irrigation technologies are spread within the basin along rivers and streams. These irrigation developments are private-led and have been intensifying during the past two decades.

In the Nakambé sub-basin alone (in Burkina) more than 400 dams and small reservoirs have been built over the past years to develop irrigation and generate electricity. About 47 irrigation schemes have been identified with 2,620ha developed and out of that 1,000ha are irrigated from the Bagre dam. An estimated 2,175ha of inland valleys are to be added to the irrigable land in the basin. Irrigated land in the Nakambé sub-basin is relatively small compared to the vast potential for irrigation that the large volumes of water stored behind the numerous dams can offer (Barry et al., 2005).

The rich savannah grassland provides good fodder for livestock production in the sub-basin. In Ghana, data show that animal husbandry in four regions, the Upper-East, Upper-West, Northern and Volta, which fall exclusively in the Volta Basin, account for 83.5% of cattle, 57.7% of sheep, 64.1% of goats, and 68.8% of pigs produced in Ghana annually (Barry et al., 2005).

Fish production is also an important activity in the sub-basin. The developments of dams have enhanced fish production extensively. In Ghana, the Volta Lake created by the Akosombo Dam produced about 87,500 metric tons of fish in 2000. The Volta Lake produces about 98% of the inland fresh water fish in Ghana (Barry et al., 2005).

Bagre and Kompienga are the largest reservoirs in the Nakambé sub-basin and are used for power generation, irrigation and environmental purposes in Burkina Faso (Barry et al., 2005).

Development potentials have been identified in the Ghana section of the White Volta sub-basin which includes a total of 63 megawatts of hydroelectric power generating capacity, 360,000 hectares of irrigation, flood control, domestic water supply, navigation and recreation (Wiafe, 1997).

2.5 WATER GOVERNANCE IN THE WHITE VOLTA SUB-BASIN

This section looks at the water governance structures and institutional arrangement within Ghana, Burkina Faso and at the transboundary level, in so far as they relate to the White Volta sub-basin.

2.5.1 Ghana

Stakeholder Organisations in Water Resource Management of Ghana

This section describes the role of the stakeholders in the water resources management of Ghana. The stakeholders can be grouped into government agencies, data collection and research/training institutions, local actors, non-governmental organisations (NGOs) and donor agencies.

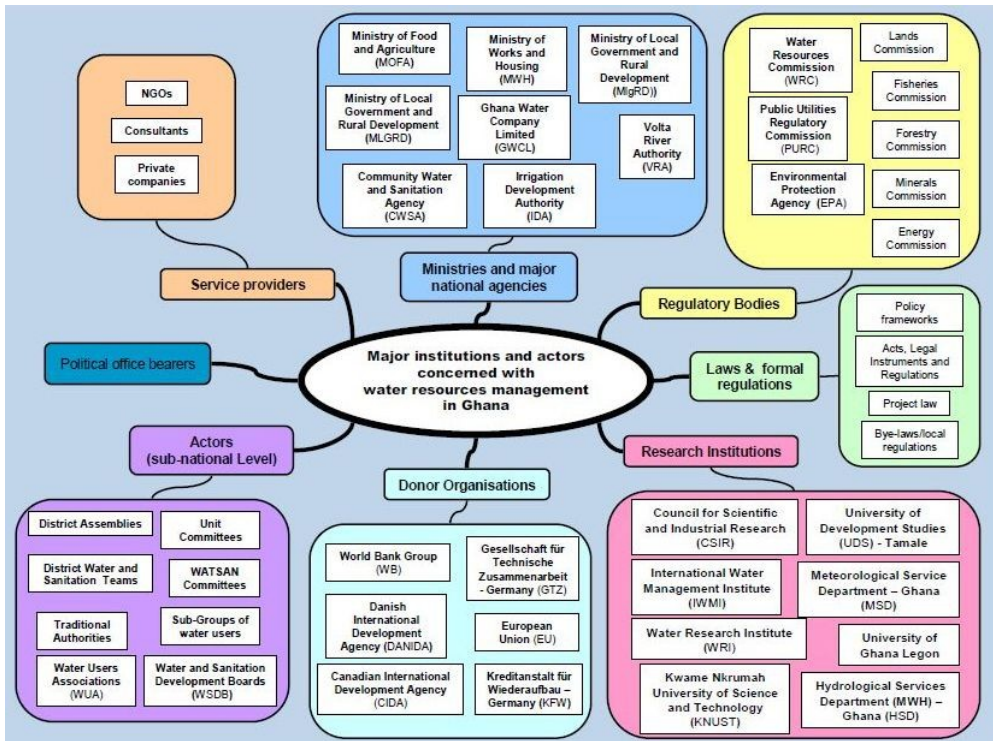


Figure 2.3: Stakeholders of Ghana’s water resources management (Source: Fuest et al., 2005).

Government Agencies

The government agencies with major stakes in water resources development and management in Ghana include the Water Resources Commission, the Ministry of Food and Agriculture, Ministry of Local Government and Rural Development, Ministry of Health, Community Water and Sanitation, Ghana Water Company, Irrigation Development Authority, Volta River Authority, Environmental Protection Agency and Forestry Commission, Lands

Commission, Minerals Commission, Department of Cooperatives and Local Development. Their roles will be briefly discussed.

Water Resources Commission (WRC): In Ghana a significant step was taken to address the diffused state of functions and authority in the water resources sector with the creation of the Water Resources Commission (WRC) through an Act of Parliament (Act 522 of 1996). The Act clearly defines the WRC as the overall responsible body for coordination, regulation and management of the nation's water resources (Opoku-Ankomah et al., 2006). The WRC serves as an umbrella organization to coordinate the different government agencies involved in water management and development. According to Act 522, the WRC has the following responsibilities:

- to propose comprehensive plans for the utilization, conservation, development and improvement of water resources;
- to initiate, control and co-ordinate activities connected with the development and utilization of water resources;
- to grant water rights;
- to collect, store and disseminate data or information on water resources,
- to monitor and evaluate programs for the operation and maintenance of water resources,
- to advise the government on any matter likely to have an adverse effect on the water resources of Ghana; and
- to advise pollution control agencies on the management and control of the pollution of water resources.

The WRC Act allows for decentralized governance of the commission and to this end the WRC has established sub-commissions. The WRC uses this as legal bases for the development of basin boards that are supposed to implement the functions of the WRC at the lower level. The basin boards are not tied to administrative boundaries but rather to hydrological boundaries. One of these basin boards relevant to this study is the White Volta sub-basin Management Board (WVBMB). The WVBMB was established to handle trans-boundary water issues especially between Ghana and Burkina Faso.

Ministry of Food and Agriculture (MOFA): MOFA supports agricultural development, including livestock development at the district level through the regional directorate. One of its main tasks is to provide agricultural and veterinary extension services for farmers (both rainfed and irrigated). The

extension agents are the main channel of information flow between the farmers and MOFA and vice versa.

MOFA has been involved in major water resources development projects in the White Volta sub-basin such as the Upper East Region Land Conservation and Smallholder Rehabilitation Project (LACOSREP). LACOSREP was an International Fund for Agricultural Development (IFAD) funded project which supported the construction and rehabilitation of small reservoirs and vegetable irrigation. MOFA has also been responsible for ensuring increased crop production by promoting crop diversification, soil conservation, exploring water harvesting techniques and promoting irrigation technologies for farmers through pilot projects.

Ministry of Local Government and Rural Development: The Ministry of Local Government and Rural Development was established by the Local Government Act of 1993 (Act 462) with the prime aim to empower people to participate in the development process and to have access to decentralized services. This led to the formation of Metropolitan, Municipal and District Assemblies (MMDAs). The MMDAs are the legislative and the administrative branches at the MMDAs level. Since the MMDAs have the authority for development planning at the local level, the decisions on the investment for the infrastructure required for drinking water supply (bore holes) and for irrigation (small dams, dugouts) have to be part of the MMDAs Development Plans. Together with the respective line agencies, the MMDAs are in charge of supporting the local communities in managing the infrastructure for domestic water supply and for irrigation (Birner et al., 2005).

Ghana Irrigation Development Authority (GIDA): GIDA is responsible for irrigation development in Ghana. It is a semi-autonomous agency which operates under MOFA. GIDA exercises management control over government-developed irrigation dams, associated catchment areas and the drainage areas.

The passing of Legislative Instrument LI 1350, in 1987, legalized and streamlined the management role of GIDA and also incorporated farmer participation in project management. GIDA provides technical expertise for the construction and rehabilitation of dams. This includes both supervision and construction. GIDA is also responsible for managing some of the major dams developed by them. GIDA had in 2003, 22 formal irrigation schemes under its jurisdiction. The small reservoirs developed by GIDA are community managed. In the White Volta sub-basin, there are three large irrigation schemes (Ve, Tono and Bontanga) developed under the

supervision of GIDA. The Bontanga irrigation scheme is managed by GIDA while the Vea and Tono irrigation schemes are managed by the Irrigation Company of Upper Region (ICOUR) (see below).

Ghana Water Company Limited (GWCL): GWCL was previously known as the Ghana Water and Sewerage Corporation (GWSC), which was established in 1965 under Act 310. Among the functions of GWSC were the provision, supply, distribution and conservation of the nation's water resources for public, domestic and industrial purposes (Opoku-Ankomah et al., 2006).

GWCL was created in 1999, taking over the tasks of the former public GWSC. GWCL is in charge of urban water supply for towns with populations above 20,000. In 2004, about 70 urban water supply systems were under GWCL management. GWCL is mandated to produce potable water at various headworks/treatment plants, transmit the water to tanks and reservoirs and further distribute the water to customers through pipelines (Fuest et al., 2005).

Community Water and Sanitation Agency (CWSA): CWSA is the core government agency at the regional level concerned with the provision of potable water to rural communities and small towns. The CWSA was formed under the National Community Water and Sanitation Program which was launched in 1994. The National Community Water and Sanitation Program (NCWSP) is aimed at providing sustainable supply of drinking water and sanitation, following the principles of community ownership, beneficiary capital cost contribution, private sector participation and cost-recovery water tariffs. GWCL has handed over most of the water supply systems (about 208) of the former GWSC to the CWSA/the District Assemblies (DAs) under the NCWSP.

The District Water and Sanitation Team (DWST) is the major partner of the CWSA in the District Assemblies. Most of the CWSA projects are donor sponsored (World Bank, African Development Bank, etc). CWSA facilitates the provision of boreholes, sanitation facilities and water supply systems to communities and small towns following a demand-driven approach. The CWSA selects and supervises consultants for providing consultancy services for the provision of water supply and sanitation for communities and small towns. During the provision of such services the DWST guides the process, monitors the consultants and contractors and reports to CWSA. The DWST is also responsible for monitoring the use of facilities after the consultants and contractors have fulfilled their contracts.

Ministry of Health/Ghana Health Service: The Ministry of Health is responsible for the provision of public health services delivery in Ghana. The Ghana Health Service is the implementing agency of the Ministry of Health. The role of the Ghana Health Service with regard to water is the control of water-related diseases. These are diseases caused by unsafe drinking water, such as cholera and diarrhoea; and vectors that rely on water, such as malaria, schistosomiasis, guinea worm and elephantiasis. The Health Service collaborates with MOFA and GIDA to investigate some of these diseases caused by irrigation developments. They are also engaged in providing health education on water-related diseases to communities, especially in areas where small reservoirs and dugouts are developed (Birner et al., 2005).

Environmental Protection Agency (EPA): The Environmental Protection Agency Act of 1994 (Act 490) turned the Environmental Protection Council into an Agency having, inter alia, regulatory and enforcement roles. The Environmental Protection Agency operates under the Ministry of Environment, Science and Technology and is responsible for enforcing and compliance of pollution prevention and control, ecosystem management, environmental justice and environmental education. EPA is in charge of conducting Environmental Impact Assessments (EIA) for several types of projects. For example, the construction of dams requires an EIA. The EPA receives EIA applications for proposed new projects, conducts inspection and social assessment for verification and grants permits for the projects. For major projects an EIA may involve public hearings.

Volta River Authority (VRA): The Volta River Authority (VRA), a state-owned entity, is responsible for the production of electricity in Ghana through the Akosombo and Kpong Hydropower Plants, located downstream of the White Volta sub-basin. VRA also exports energy to neighbouring countries such as Togo, Benin and Burkina Faso. Due to the water needs of the Akosombo Dam, VRA is concerned with all upstream water uses since these have direct impacts on the water availability downstream for hydropower generation. In the past VRA has provided funding for planting trees to protect river banks with the aim of conserving the water body.

Minerals Commission: The Commission's primary responsibility is to foster the efficient and effective regulation and management of the utilization of Ghana's mineral resources. The minerals commission has an involvement in the water resources management due to the possible adverse effects of mining on water quality and availability.

Forestry Commission: The Forestry Commission of Ghana is responsible for the regulation of utilization of forest and wildlife resources, the conservation

and management of those resources and the coordination of policies related to them. The Forestry Commission is also a stakeholder in water resources management because of the importance of forest belts in erosion control and the micro-climatic hydrological impact.

Lands Commission: The Lands Commission was established by the Lands Commission Act of Parliament 1994 (Act 483) to manage public lands efficiently through proper documentation and good records keeping. In general, agricultural land has not been registered in the White Volta sub-basin of Ghana by individual farmers, except for large-scale commercial farming enterprises. MOFA has been pursuing the approach to register the land resources to be irrigated by small-scale irrigation schemes in the name of the District Assemblies (Birner et al., 2005).

Department of co-operatives and community development: The Department of Co-operatives is a government agency charged with the administration of the Co-operative Societies Decree NLCDC 252 of 1968. The main statutory functions include:

1. Registration of groups into Co-operative Societies
2. Audit and inspection of Co-operative Societies
3. Arbitration of disputes among Co-operative Societies
4. Liquidation of Co-operative Societies

The department exists to facilitate the development of Co-operatives and Farmer-Based Organizations that are capable of contributing positively to sustainable employment generation and agricultural growth, poverty reduction and community development through capacity building, policy implementation, monitoring, evaluation and regulation through farmer groups. The department of co-operatives is also responsible for organizing water user associations and farmer groups.

Data Collection and Research Institutions

Hydrological Service Department and Ghana Meteorological Agency: The Hydrological Services Department is the government agency responsible for hydrological data collection and has regional branches across the country. They collect data mainly on surface water but not groundwater. They do not collect information on surface water quality. They are involved in flood assessments and advise government on technical mitigation measures.

The Ghana Meteorological Agency is the government agency responsible for climate data collection and also has regional branches within the country. It maintains a network of meteorological measuring stations all over the

country. It is a semi-autonomous organisation and depends largely on the sale of data for research activities and others.

Research Institutions: There are several research institutions which have direct stake in the water resources of the Volta Basin. In Ghana the main research institute is the Council for Scientific and Industrial Research (CSIR) which operates under the Ministry of Environment, Science and Technology. It has several research institutes. The institutes related directly to water resources of the Volta Basin are the Water Research Institute (WRI) and the Savannah Agricultural Research Institute (SARI).

The Water Research Institute conducts research into both groundwater and surface water resources (quality and quantity) and their related resources including their sustainable management. SARI is located in the Volta Basin and conducts research into rainfed and irrigated agriculture in the savannah areas of Ghana. SARI researches innovations for harvesting water, and improvement in agricultural productivity.

Local Actors

Traditional Authorities: In Ghana a mixture of customary law and modern law coexists creating a mixed governance system (legal pluralism) which affects water resources management. Traditional institutions are recognised in Ghana's constitution and are represented by the House of Chiefs at the National and Regional levels. Even though they are not represented at the district level, they play major roles in decision making at their traditional level.

Birner et al. (2005) found that according to the customs of the people in the Upper East Region, chiefs are responsible for the rivers and streams that flow through their traditional areas. Traditional authorities are major stakeholders in water resources management in the sub-basin. In the Upper East Region the *tendanas* or earth priests are responsible for the earth shrine and for the distribution of agricultural land. They play major roles in allocating land for irrigation development in the region. The *tendanas* are the spiritual heads of the region.

Community Water User and Management Organizations: There are three main organizations identified in Ghana that are responsible for water management at the community level. The Water User Associations (WUAs) are responsible for small reservoirs (irrigation, livestock and fishing) but not for all irrigation technologies in the community. The Water and Sanitation Committees (WATSAN) are responsible for drinking water supply from boreholes and Water Boards in the case of small town water supply systems.

These community level organizations were promoted by MOFA and CWSA and are part of the project package for every new development.

Both WUAs and WATSANs are responsible for maintaining the water systems. The WATSAN and Water Boards set water tariffs for the community and sell water at point sources to the community members. They are responsible for maintaining the water supply system and also extending supply to newly developing areas of the community. The members of the WATSAN and Water Board are appointed by the community through elections. The WATSAN and Water Board are accountable to the entire community. Major decisions such as tariff changes need to be discussed with the community for approval.

Water User Associations are responsible for small reservoirs developed for the communities and its members are made up of the irrigators, fishermen and livestock owners. In most instances, the irrigators double as fishermen and/or livestock owners. The executive is elected by the members and is responsible for ensuring the following:

- Protection of the reservoir, irrigable area and catchment areas upstream of the reservoir to prevent siltation;
- Irrigation water delivery and control of valves;
- Maintenance of the dam, valves, canals and drains;
- Collection of water levies for maintenance of system;
- Conflict resolution.

Farmer Based Associations: These associations are formed among groups of farmers with common interests. Farmers can form associations based on the fact that they use similar technology, are located within the same area or they use the same water resource. The reasons for forming these associations are for formalizing self-help clubs, improving their market negotiation power and/or seeking financial or technical assistance or both.

Irrigation Company of Upper Region (ICOUR): There are two large-scale reservoir irrigation schemes located in the sub-basin (Tono and Vea) both managed by ICOUR, which is a government agency that operates as a commercial entity under MOFA. ICOUR is partly funded by public funds and partly by internally generated revenue. The management of farmers on the schemes is done through village committees and recently the introduction of Farmer Based Organizations (FBOs) which are likely to take over from the village committee system. ICOUR charges farmers an irrigation water levy every season and maintains the dam, canals, laterals, valves gates and farm mechanization. They also support farmers with ploughing, harrowing

and ridging at a fee. Some farmers, especially rice farmers, receive fertilizer support which the farmers pay by selling their crops to ICOUR which then deducts the cost of inputs supplied.

Non-Governmental Organisations

Several NGOs are involved in the agricultural and domestic water sector in the Upper East Region. Some of them operate from a national or international basis, while others are regional or even local. The most important NGOs active in the water sector are the following (Birner et al., 2005):

- Rural Aid (major player in the construction of hand-dug wells with more than 500 wells constructed in the Upper East Region from 2000 to 2004 with funding from Water Aid and IFAD);
- Action Aid (funding of dam construction);
- Red Cross (funding of dam construction)
- Catholic Secretariat (funding of dam construction);
- World Vision International (construction of boreholes);
- Adventist Development and Relief Agency (ADRA) (funding of boreholes);
- TRAX (training in land and water management, and funding of boreholes).

Donor Agencies

The major sources of funding for water-related infrastructure are donor agencies. Donor-funded projects are either implemented through the existing administrative structures, or through special project implementation units. Some of these donor agencies are the World Bank, International Fund for Agricultural Development (IFAD), Canadian International Development Agency (CIDA), Danish International Development Agency (DANIDA) and the Food and Agricultural Organisation (FAO) (Birner et al., 2005).

The World Bank funded the Village Infrastructure Project (VIP), a four-year program under the Ministry of Food and Agriculture, aimed at the improvement of rural infrastructure. The aim of the Programme was to improve access to roads, transport, tracks and trails, small credit and markets for the rural poor. The programme also engaged in building boreholes, wind pumps, dams and dug-outs in the three Northern Regions of Ghana. Through the Community Water and Sanitation Project, the World Bank acted as the core donor for rural drinking water provision by the CWSA.

The Land Conservation and Smallholder Rehabilitation Project (LACOSREP) financed by the International Fund for Agricultural Development (IFAD) promoted a wide portfolio of agricultural support activities in the Upper East Region, including training, agricultural extension, gender mainstreaming, agricultural credit, water resources development and rural infrastructure development.

The District Capacity Building Project (DISCAP) is funded by CIDA. This US\$7 million project trained and strengthened district governments and their water-related technical units, together with community-based civil-society organizations that manage rural and peri-urban water systems (WATSAN and Water Boards).

DANIDA is the core funding agency of the Water Resources Commission of Ghana. In addition to supporting the National Water Resource Commission in Accra, DANIDA supported the pilot testing of basin boards to allow for a more decentralized approach to Integrated Water Resource Management.

Government Policy on Irrigation

The draft Ghana Irrigation Policy (Final Draft, 2006) is designed to open up the investment space for intensified and diversified irrigated crop production in Ghana where there is clear comparative advantage. The policy is designed to accomplish this by addressing four key ‘problem’ areas concerning the formal, informal and commercial irrigated sub-sectors that have been identified during an extensive consultative review.

- **Performance and Growth.** Realize the productive capacity of existing assets and respond to new demands for irrigated production through a mix of well coordinated public and private initiatives;
- **Socio-economic inclusion.** Remove constraints to a balanced socio-economic engagement with land and water resources;
- **Responsible production:** Raise the environmental performance of all types of irrigation and related agricultural practice;
- **Enhanced Services.** Extend cost-effective, demand driven irrigation services to public and private irrigators.

Water Rights in Ghana

Section 12 of the Water Resources Commission Act of Ghana (1996) stipulates that “the property in and control of all water resources is vested in the President on behalf of, and in trust for the people of Ghana.” The vesting of the water resources in the President is to make water resources management consistent with general natural resources management in Ghana

and the 1992 Constitution. The principle implies that there is no private ownership of water in Ghana, but that the President, or anyone so authorised by him, may grant rights for water use. It also implies that with good governance and practice, the principle is expected to ensure that water allocation for various uses will be beneficial to the public interest and also for the greatest good of society.

The WRC Act, 1996 (Act 552) conferred on the Water Resources Commission the mandate to enact regulations on water use. The Water Use Regulations, 2001 (L.I. 1692) provides procedures for allocating permits for various water uses including domestic, commercial, municipal, industrial, agricultural, power generation, water transportation, fisheries (aquaculture), environmental, recreational and under water (wood) harvesting.

The Irrigation Development Authority Regulations, 1987 (L.I. 1350) provides procedures for managing irrigation projects including water management within such projects. Ghana Irrigation Development Authority's (GIDA) Technical Guidelines for Irrigated Agriculture, 2004, gives further details on how to effectively manage water for irrigated agriculture including water supply, distribution and application management.

Individuals, institutions, NGO's, agencies and authorities are required to apply for and be granted a permit to use water before engaging in surface water or groundwater abstractions for domestic, commercial, industrial and agricultural use.

Categories of water use that are exempted from the permit requirement include:

- Preventive use of water for the purpose of fighting fire; and
- Any water abstraction by manual means.
- Additionally, some water use categories, even though exempted from the permit requirements, have to be registered. These include:
 - Water abstracted by mechanical means for use where abstraction does not exceed 5 liters per second (432 cubic meters in any period of 24 hours);
 - Subsistence agriculture water use for land not exceeding 1 hectare.

Customary water management in Ghana has been in existence before the colonial days (Lautze et al., 2008). Indigenous institutions in the Akan cultures (which occupy much of the southern Volta basin) invariably tie management of natural resources to their religious belief system. According to Akan beliefs, the Earth was accorded a spirit of its own, which could be

helpful if propitiated or harmful if degraded. Land was inherited from the ancestors. Chiefs and priests entrusted with ensuring that ancestors and gods received proper respect, exercised control over the land and its resources to promote conditions which were beneficial to the environment and sustainable for communities (Ministry of Works & Housing, 1998; Opoku-Agyemang, 2001).

In adherence to these rules, surface water was considered a communal good that could be freely and openly accessed. Every individual possessed the right to its use (FAO, 1998; Ministry of Works & Housing, 1998). The overarching customary principle applying to surface water permitted water users to take as much water as they could personally carry so long as enough water remained for others (Opoku-Agyemang, 2004). While there is some uncertainty surrounding the right to consumptive use of groundwater, it appears that in most communities a person with a right to a piece of land was allowed to tap the water beneath that land. Sustainable use of ground and surface water enabled communities to fulfill their livelihoods, which usually consisted of subsistence farming or cattle herding (Lentz, 2006).

The practice of customary water law is still existent in the rural parts of Ghana and is the common knowledge among water users. Even though the religious belief that rivers belong to gods is fading out due to the spread of Christianity and other non-traditional religions into the rural areas, the general perception of water being a communal good is still strong in the fabric of the society. By virtue of this water users believe they have every right to access surface water so far as they are members of the community and tap groundwater beneath any land they have legal access to. Knowledge on the modern water law regarding the ownership of water and regulations regarding water use in Ghana is yet to reach many water users.

Land Rights in Ghana

This section briefly describes the land rights system in Ghana and focuses on Northern Ghana. A plurality of land tenure and management systems (i.e. state/public and customary) prevails in Ghana (Kasanga and Kotey, 2001). Land tenure in Ghana is therefore complex. There are over 80 formal legal instruments regulating land tenure, some of which are contradictory. They co-exist with various forms of customary land tenure (Ministry of Lands and Forestry, 2003). Likewise, the institutions in charge of land administration are manifold. In spite of the decentralization, central government, especially the Lands Commission, is responsible for land administration. Traditional authorities – the Chiefs and the *tendanas* – are also recognized by modern

law as institutions responsible for land management (Birner et al., 2005).¹ There is mutual respect between the traditional authorities and the government institutions concerning the roles of both institutions. There is also effective collaboration between both institutions concerning land management. Traditional authorities consult government institutions for planning of their land and legal documentation of land transactions.

The state's land tenure system distinguishes "stool lands" and "public lands" (Act 27; Act 125). "Stool lands" represent lands belonging to stools, skins and families. Chiefs represent stools (southern Ghana) and skins (northern Ghana). "Public lands" in Ghana fall into two main categories: land which has been compulsorily acquired for a public purpose or in the public interest under the State Lands Act, 1962 (Act 125) or other relevant statute; and land which has been vested in the President, in trust for a landholding community under the Administration of Lands Act, 1962 (Act 123).

Currently all vested and public lands are administered by the Lands Commission at the national level along with 10 regional Lands Commissions and their secretariats, as provided in the 1992 Constitution and in the Lands Commission Act 1994 (Act 483).

The state's land tenure system contrasts with customary practice. To the northern tribes land is a sacred trust of the ancestors, whose labour won it and preserved it for the use of their descendants; it belongs to them and the general belief is that to sell land is a sacrilege. The local customary authority overlooking land issues in Northern Ghana is the *tendana*, the traditional earth priest. Local farmers have "family land": while they do not own this land in a legal way and cannot sell it, they do have secure usufruct rights to this land, which can be inherited within the family (Birner et al., 2005).

The village chief or the *tendana* is in-charge of administrating the land. According to traditional tenure rights, land is only allocated to the farm households. The usufruct rights can be passed on to the descendants so that land tenure is secure as long as the land is cropped. When the land is left fallow the *tendana* can redistribute it. There is no fixed rent paid to the chief or to the *tendana*. A part of the harvest is given to them in recognition of their authority. As the household is not the owner of the land, they cannot sell it. Land transactions are limited to leasing; however the leasing of land is

¹ The Town and Country Planning Offices of the District Assemblies are involved in land administration, too, but their activities, so far, are mostly limited to urban planning.

rare. Land can temporarily be exchanged for bullock or tractor services. When population density rises and land becomes scarcer, the land which is fallow will be reallocated. Thus, smaller households that do not have enough labour to cultivate all the land but who still want to keep the land at their disposal also try to lease the land to neighbours or relatives. Land security is very high as measured by rights over land and low incidence of dispute, except for migrant farmers from other regions. Unlike statutory law, customary law does not recognise the female right of *usufruct* (Barry et al., 2005).

Hydro-Political Water Governance in Ghana

The water governance structures at various levels in the sub-basin are shaped by international treaties, the national water policy, administrative structures and stakeholders of the water resources. This section presents how the above mentioned factors are related in the existing water governance system of Ghana at the various levels.

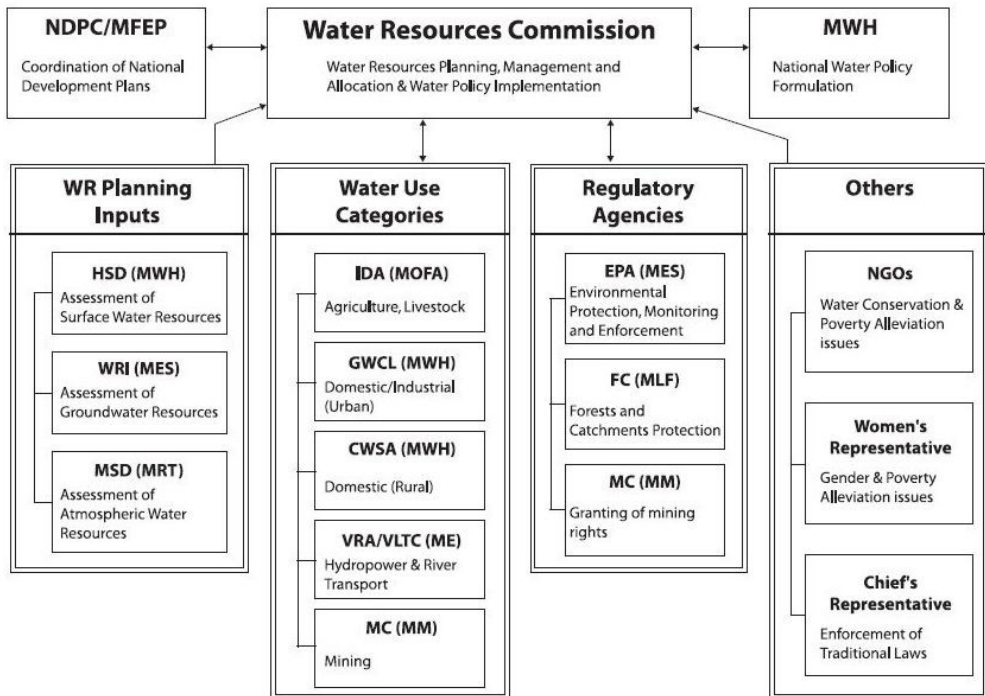


Figure 2.4: Institutional Structure for Water Resources Management in Ghana at the National Level (Source: Opoku-Ankomah et al., 2006).

The key strategy at the national level is to secure good relationships among all stakeholders and to work in a participatory manner, involving all local communities at the basin level (Opoku-Ankomah et al., 2006).

This institutional structure for water resources management in Ghana tries to bring on board all stakeholders in the water sector. However the organizational structure looks complex for effective implementation of the National Water Policy at the National, basin and sub-basin level. Presently, effective monitoring of water related activities is lacking at all levels, implementation of water-use regulations is also lacking as well as effective co-ordination of water-related activities.

Political Administration: The public administration of Ghana consists of ministries, departments and agencies. Public administration in Ghana is decentralized and consists of regions which are governed by regional coordinating councils and the districts which are governed by district, municipal or metropolitan assemblies, depending on their size. The sub-districts are made up of urban, zonal, town or area councils. The unit committee is the lowest level of governance. The decentralization process in Ghana devolved development planning and decision-making to the Metropolitan, Municipal and District Assemblies through the Local Government Act 462 (Birner et al., 2005).

River Basin level Management and Decentralization: The most appropriate level of water management is at the level where all affected parties are represented. The WRC of Ghana has been mandated to facilitate capacity building and awareness raising initiatives at decentralised Integrated Water Resources Management (IWRM) levels. Since its establishment the WRC has been exploring ways to use, in the most appropriate manner, the decentralized government structure, specifically the Regional Coordinating Committees and District Assemblies. WRC is implementing IWRM in the White Volta sub-basin called the White Volta Pilot Project (WVPP) by facilitating an iterative process to evolve a collaborative decentralized institutional framework. The specific objectives of the WVPP are (Rodgers et al., 2007):

- To identify and motivate stakeholders for collaboration and participation in IWRM;
- To establish the institutional framework for IWRM;
- To develop a Water Action Plan; and
- To monitor and evaluate the IWRM process, with a view toward wider application of the lessons learned in the White Volta setting.

This has led to the establishment of the White Volta sub-basin Management Board of Ghana with the secretariat located in Bolgatanga. The members of the basin board are made up of representatives from: (1) the district assemblies located in the basin, (2) the traditional authorities, (3) Water Resources Commission (the basin co-ordinator is an employee of the WRC), (4) Environmental Protection Agency, (5) Ministry of Food and Agriculture, (6) Lands Commission, (7) Meteorological Services, (8) Research Institute (Glowa-Volta Project) and (9) National Council on Women and Development.

The White Volta sub-basin Management Board co-ordinates water resources related issues within the White Volta sub-basin of Ghana and also acts as representatives of Ghana on transboundary related issues with their counterparts in Burkina Faso.

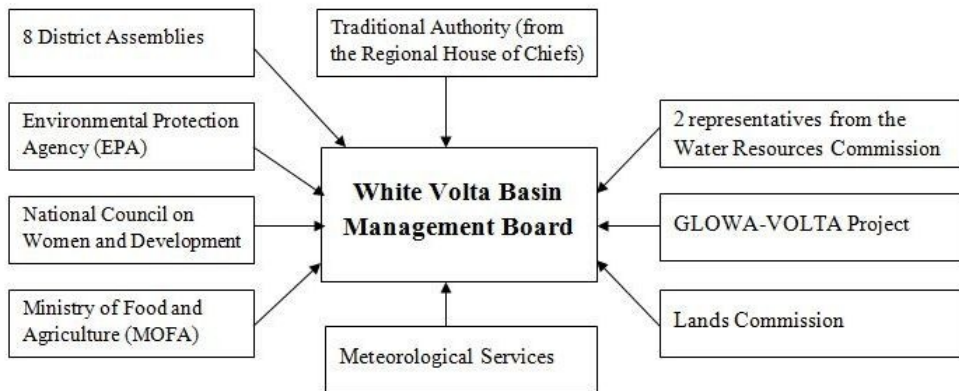


Figure 2.5: Board Members of the White Volta sub-basin Management (Source: after Poolman, 2005).

The secretariat is managed by the WRC Basin Officer in liaison with the WRC headquarters. The basin officer who has overall managerial authority, serves as Basin Board Executive Secretary and co-ordinates stakeholder activities. The basin officer is also responsible for developing and implementing the basin Action Plan and reviewing progress toward project objectives. Among the important responsibilities are registering of water use rights, collecting water fees and creating public awareness of IWRM (Rodgers et al., 2007).

Even though the White Volta sub-basin Management Board has been established for a few years it has made little impact on the Water Resources Management in the sub-basin. For example the National Water Policy which

demands registration of water uses and granting of permit for some specific water uses has not been carried out in the basin because of the following challenges. The the secretariat is under-staffed (has a basin officer and a secretary); the District Assemblies are not fully equipped to be able to do effective monitoring of the numerous water related activities ongoing in the sub-basin. Currently there is no office at the District Assemblies that handles water resources management and water related activities.

2.5.2 Burkina Faso

After Burkina Faso achieved Independence in 1960, the water sector activities were implemented with the view to supplying drinking water for rural areas and developing water for livestock. In 1965, the water sector was integrated into the Ministry of Economy and Planning. From 1967 to 1971, the water sector was transferred to the Ministry of Development and Tourism, and later came under the jurisdiction of the Ministry of Agriculture and Livestock. In 1984 the Ministry of Water was created which was renamed the Water and Environment Ministry (MEE) in 1995 (Opoku-Ankomah et al., 2006).

In 1976, the Rural Development Fund (FDR) was created to strengthen the state's capacity to intervene and combat the impacts of droughts. During the same period the National Office of Dams and Irrigation (ONBI) was created, with the aim of expanding and exploiting the irrigation potential of the country (Dembélé, 1998).

In 1995, the General Directorate of Hydraulics (DGH), within the Ministry of the Environment and Water, was formed to organize water-related activities and interventions in the country, and provide overall coordination to the water sector (Ministère de l'Environnement et de l'Eau 2001, cited in Opoku-Ankomah et al., 2006).

Stakeholder Organisations in Water Resource Management of Burkina Faso

Ministry of Agriculture, Hydraulics and Fishing Resources: In 2002, the Ministry of Agriculture, Hydraulics and Fishing Resources was created to replace the former Water and Environment Ministry. The mandate of this new ministry is implemented through the Directorate of Agricultural Hydraulics (DGHA), the General Directorate for Provision of Potable Water (DGEAP), the General Directorate for Inventory of Hydraulic Resources (DGIRH) and the General Directorate for Fishery Resources (DGRH).

The Directorate of Agricultural Hydraulics (DGHA) directs and organizes work relevant to water use for agriculture, livestock, and energy. The

Directorate for Potable Water Supply (DGEAP) is responsible for potable water supplies to urban and rural areas as well as for industrial uses. The Directorate of the Inventory of Hydraulic Resources (DGIRH) is responsible for collecting, processing and assessing hydrometric data, as well as all data concerning all water-related activities and interventions in Burkina Faso; it also conducts studies to identify areas in need of future water-related interventions. The Directorate of Fishery Resources (DGRH) is in charge of the sustainable exploitation of the country's fish resources and assures the effective management of the fishing industry. It is also entrusted with preserving and protecting aquatic ecosystems (Ministère de l'Agriculture de L'Hydraulique et des Ressources Halieutiques 2004, cited in Opoku-Ankomah et al., 2006).

The National Water and Sanitation Office (ONEA) is a government company with the mission to create and manage infrastructure for drinking water in urban and peri-urban areas. The Water Rural and Facilities and Fund (FEER) collect funds and implements small water resources development projects with the involvement of beneficiaries.

The Sourou Valley Development Authority (AMVS) is mandated to develop the Sourou valley and the high valley of Mouhoun for irrigation. The Bagre Development Agency (MOB) is to develop the Bagre plains for crop irrigation and hydro-power production.

Burkina Faso Electricity Society (SONABEL) is responsible for the production of hydro-power for Burkina Faso.

Water Rights in Burkina Faso

As an element in the democratization process that occurred during the 1990s, most African countries have established a legislative system governing various branches of industry, including water. The Burkina Faso government initiated a national IWRM plan in 1999 called PAGIRE. This process included four components: (a) the development of the national IWRM Action Plan; (b) capacity building to enable Burkina to develop the IWRM plan; (c) pilot intervention of IWRM principles in targeted sub-basin; (d) elaboration of a water management law. So far Burkina has started implementing the IWRM plan. A national Framework Water Law (2001) and some of the required by-laws were enacted during the very process of developing the plan which defined the roles of the sector actors involved in the process. Some key institutions recommended in the IWRM plan such as the National Council for Water, and the Permanent Secretariat of the National IWRM Plan (SPPAGIRE) are in place. The IWRM planning is still

ongoing and the government is yet to fully implement all actions in the plans (Opoku-Ankomah et al., 2006).

Burkina Faso elaborated and implemented a law concerning the Land and Property Reform in 1996 (Rèforme agraire et foncière RAF). The 5th article of the RAF names the State as the owner of water. But, in reality, this statement remains only a simple claim, as a real juridical prerogative would not be accepted without great resistance by the customary water users (Zone, 2002) who claim to have ownership to the resource.

In Burkina, rural water management realities appear quite similar to Ghana. The resource belongs to the entire community, but can be used for personal benefit so long as the collective good is not harmed (Ramatou, 2002 cited in Lautze et al., 2008). In practice, water use is regulated by traditional authorities who govern the resource according to the customary values; that is, water is a spiritual resource which is owned by the community (Zone, 2002).

The customary law of the Mossi (the largest single ethnic group of Burkina Faso, constituting 48 percent of the total population) has community considerations for land and water, i.e. the right of “ownership” of land is a “collective right” to free access, as long as the collective good is not harmed. This law on land is similarly applied to traditional management of water resources, ensuring that water is a “collective right”, of free access and ensured that every community has its “slice” of river, stream and/or lake (Massa and Madiaga, 1995).

According to customary practice the use of water resources is governed by specific prohibitions and taboos that are associated with totems. Prohibitions are considered more important than taboos, as they have a larger sphere of application. The prohibitions represent what is not authorized by the community at the level of the village, thus what everybody forbids. The following prohibitions may apply in villages and can be sanctioned by custom:

- Prohibition to sell water or refuse to let it be drawn from one's own well;
- Prohibition to dirty the surroundings of the well; and
- Prohibition to dig a well without the agreement of the relevant customary leaders.

Land Rights in Burkina Faso

In Burkina Faso, the current legal policies on land and natural resources are determined by two main factors: the present legislation (mainly expressed in

the texts of the *Réform Agraire et Foncière* (RAF) of 1991) and the policy of decentralization (de Zeeuw, 1997).

The Revolutionary regime of Thomas Sankara enacted a very complex legal code, bringing in a “modern” tenure system centred on ownership of cultivated land by those who worked it. In its “revolutionary” logic, the reform rejected any role for the customary authorities, which were regarded as representing “feudalism”. The reform law, which denied all customary rights, was so complex that not even the local officials responsible for its enforcement could understand it. Two successive versions followed (1991 and 1996), which allowed for private property and recognised existing customary rights in undeveloped areas (although providing no legal safeguards to support such claims). The government tolerates customary claims, so long as they do not compromise the state’s own development plans. Traditional chiefs included in the consultation process for re-formulating the RAF have successfully delayed the subsequent legal revisions of the legislation (Delville, 2000).

An overview of local systems shows the wide variety of situations on the ground and the profound transformation that they have undergone. Nevertheless, where customary tenure principles and local regulatory mechanisms still prevail it is possible to point out some common features. These include the fact that rules governing access to land and other natural resources are an integral part of the social structure, that tenure is inseparable from social relationships, and that the use of land confers certain rights (Delville, 2000). These principles are implemented and arbitrated by customary authorities, whose legitimacy usually derives from prior occupancy (they are regarded as the descendants of the community founders) and the magic/religious alliance with the local spirits, or from conquest (Chauveau, 1998 cited in Delville, 2000). These authorities (the land chiefs) then control the territory, exercising their political power to allocate land to other lineage groups and carrying out the rites required for them to clear it for cultivation (Bouju, 1998 cited in Delville, 2000). Families settled in this way have control over the bush areas allocated to them, and these can become family landholdings with transmissible cultivation rights (Delville, 2000).

The distribution of land rights is therefore based on the socio-political system (the political history of the village and region from which the alliances and hierarchical relationships between lineages are derived) and on family relationships (access to land and resources depending on one’s social status within the family), so that social networks govern access rights (Berry,

1993). For example among most communities in the Comoé Province in Burkina Faso land inheritance is still matrilineal, so land stays within the mother's clan over the generations. Sons inherit uplands from the brothers of their mothers, while daughters inherit their mothers' plots in the bas-fonds. Matrilineal inheritance has slowly been changing towards patrilineal inheritance, especially in the uplands (van Koppen, 1998).

Government Policy on Irrigation

The current government policy on irrigation development focuses on two areas:

- Promoting small-scale irrigation at the village level by encouraging the use of treadle pumps for maize and cowpea growing during the dry season;
- Lowland development targeting partial water control. Families or cooperatives are encouraged to develop these lowlands. Hence, in the rainy season, they grow rice on the minor bank, and sorghum or maize on upper sides of the lowlands.

Hydro-Political Water Governance in Burkina Faso

In 2002, Burkina Faso's water institutions underwent another restructuring, targeting the implementation of the Integrated Water Resources Management (IWRM) Programme. An action plan for the Integrated Water Resources Management Programme was adopted in 2003. The IWRM involves the State, the local communities and the users (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques 2003). The objectives of the ongoing action plan for IWRM are to:

- Redefine the role of the State in water resources management;
- Establish the National Council on Water as a national organ, designed for the concerted management of water resources and associating the State, local communities, the private sector and the civil society in its various components;
- Define new management approaches on the basis of the river basin as the appropriate arena for planning and managing water resources;
- Develop and strengthen human resources in the field of water.

An inter-sectoral executive coordination was created at the national, regional, provincial and local levels, to motivate and seek opinions on water development projects at all levels (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques 2003).

The institutional framework has structured water management at the National, Basin, Regional and local level. The structure shows a lot of stakeholders who are involved in the water management which makes the structure complex for effective co-ordination and implementation of water policies. The institutional framework is in its formative stage and therefore not in full implementation. This implies that currently there is lack of effective monitoring and coordination of water related activities also in Burkina Faso.

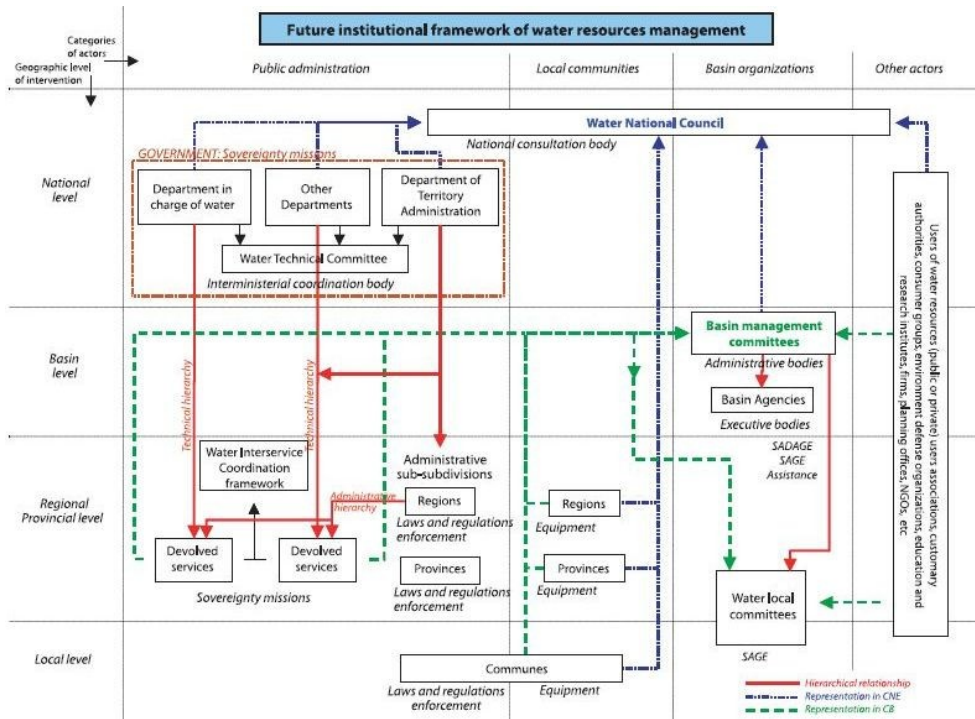


Figure 2.6: Institutional Framework of Water Resources Management for Burkina Faso (Source: Opoku-Ankomah et al., 2006).

2.5.3 Transboundary Water Management

Cooperation on the Volta’s waters (beyond issues related to power supply from Akosombo in particular) was largely initiated and driven by international donors, especially the World Bank, to satisfy lending conditions. Thus, the first existing agreement on water use on the Volta was between Ghana and Burkina Faso in 1996, and arose out of a ‘no objection’ request from Burkina Faso to Ghana for a water supply scheme on the Ziga

Dam on the White Volta in Burkina Faso. It is worth noting that the ‘no objection’ was required by financiers of the project and not out of the realization by Burkina Faso of a need to coordinate the use of the shared water resources (Ministry of Works and Housing 1998).

Further interest in a transboundary water management structure on the Volta gained momentum in 1998, when the reduced water levels at the Akosombo dam led to an energy crisis in Ghana. Prior to that, there was destructive flooding of parts of upper Ghana in 1994. Such events were attributed to preventable events in Burkina Faso, calling for an urgent need to deepen existing cooperation and ultimately to establish formal transboundary agreements on the development and management of the Volta (Ministry of Works and Housing 1998).

A Water Governance Project (2004–2006) sponsored by World Conservation Union (IUCN), in collaboration with Global Water Partnership (GWP), was designed to improve water governance in the White Volta sub-basin, with a focus on Ghana and Burkina Faso. Currently there is no joint management of the White Volta sub-basin between the riparian countries.

2.5.4 Description of Study Sites

For the present study detailed field work was conducted in three transboundary neighbouring catchments located in the White Volta sub-basin. These are the Anayari, Atankwidi and Yarigatanga catchments. The Anayari catchment covers 446km², the Atankwidi 275km² and the Yarigatanga 375km². The study area covers about 1% of the White Volta sub-basin. Forty percent of the Anayari is located in Ghana and the rest in Burkina Faso; 55% of Atankwidi in Ghana and the rest in Burkina Faso; and 80% of the Yarigatanga in Ghana with the rest in Burkina Faso. The study sites have an average annual rainfall of 1100mm/a.

In the Ghana section the three catchments are located in the Upper East Region, specifically in the Bongo, Bolgatanga and Kasena Nankana Districts. In Burkina Faso the three catchments are located in the Nahouri Province.

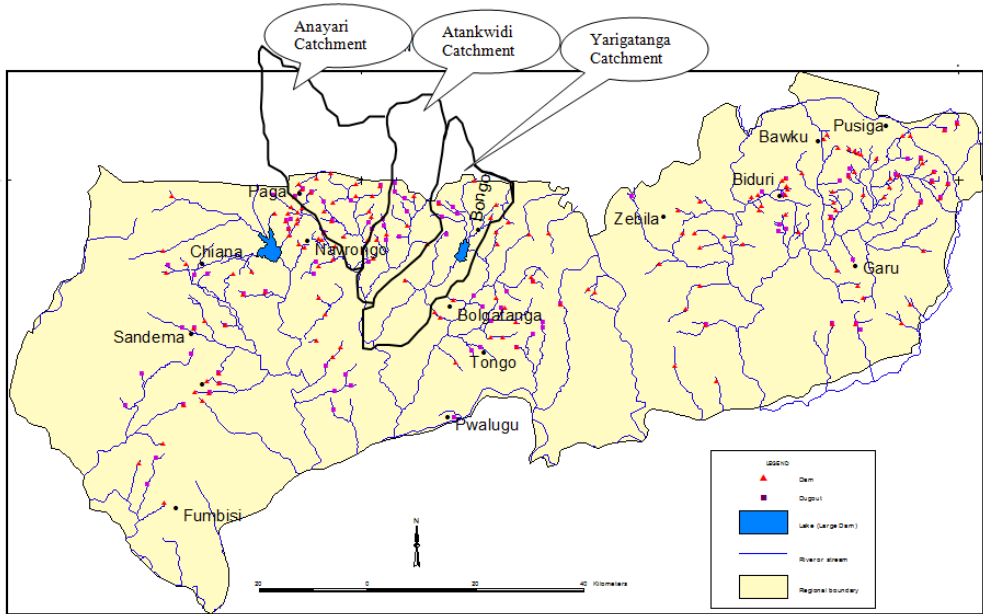


Figure 2.7: Location of the study sites (Anayari, Atankwidi and Yarigatanga catchments) (Source: adapted from GLOWA Volta Project).

There are several water uses identified in the three catchments. These are domestic, fishing, irrigation and urban water supply. The irrigation activities in these catchments depend on the following for their water source: small reservoirs, dugouts, shallow groundwater, riverine water and large reservoirs. These irrigation activities will be discussed in subsequent chapters. The Yarigatanga catchment has a large reservoir irrigation scheme called the Vea Irrigation scheme, which also serves drinking water supply to the Bolgatanga Municipality. All three catchments have small reservoirs, located in both Ghana and Burkina Faso.

The Atankwidi and Yarigatanga catchments have installed streamflow gauges since 2004 while the Yarigatanga has had a rain gauge located close to the Vea Dam since 1961.

Because of the transboundary nature of these three catchments and the presence of the various types of irrigation technologies, the three catchments were selected for detailed field studies. It is assumed that the findings in these three catchments will be representative for other parts of the White Volta sub-basin (van de Giesen et al., 2001; Birner et al., 2005; Sally, 1997).

2.6 CONCLUSION

From the above description of the study area it can be concluded that the Volta basin has a complex formal structure that largely exists on paper only. This ranges from the transboundary level to the National and sub-basin level. Meanwhile there are institutional gaps for water resources management in the Oti, Black and Lower Volta sub-basins. Even though water resources management in the White Volta sub-basin is advanced compared to the other sub-basins there still remains institutional challenges which are yet to be addressed in the White Volta sub-basin. Also some interesting trends exist which pose challenges to water management. The trends include the dichotomy between state institutions and customary practices, the lack of adequate trained professionals in the water sector to make the institutions work, and the integration of the numerous stakeholders in the water sector at various levels.

The current water governance structures in the study area are unable to provide effective management as the rate of water resources development in the study area increases. More professionals need to be trained for the effective implementation of Integrated Water Resources Management in the basin.

Chapter 3

REVIEW OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

3.1 INTRODUCTION

The extreme variability in rainfall, long dry seasons and recurrent droughts, floods, and dry spells pose a key challenge to food production. The sole dependence of farming on rainfall has been a major cause of low food productivity, food shortages, undernourishment and famine in sub-Saharan Africa. The world's hotspots for hunger and poverty are concentrated in the arid, semiarid and dry subhumid regions of the world which depend solely on rainfall for crop production.

Irrigated agriculture has been a major solution used in addressing water challenge affecting food production in areas of unreliable rainfall patterns. Irrigation has historically had a large positive impact on poverty reduction and livelihoods, in both urban and rural areas, producing relatively cheap food and providing employment opportunities for the landless poor (Hussain, 2005). Through increased productivity, irrigation produces secondary benefits for the economy at all levels, including increased productivity of rural labour, promotion of local agro-enterprises, and stimulation of the agricultural sector as a whole (Faurès et al., 2007).

Due to the far reaching benefits of irrigated farming, several investments in sub-Saharan Africa have been directed towards irrigation development. These investments have been driven by government policies (colonial and post-colonial), multinational donor agencies, private investors, markets, technology and innovations such as, drip, motorized pumps and treadle pumps. It has therefore resulted in several types of irrigation systems in sub-Saharan Africa over time.

This chapter reviews the scientific and professional literature on irrigation development in sub-Saharan Africa by looking at the trends, the types of irrigation, the challenges facing irrigation development and analyses factors that have contributed to successful irrigation development in sub-Saharan Africa.

The main aim of this chapter is to gain an improved understanding of "under what conditions irrigation development is successful in Africa", based on existing literature and research reports. The objective is to identify the

successful ways of achieving sustainable development of irrigation which has been a major challenge for achieving the green revolution in sub-Saharan Africa (Faurès et al., 2007).

This chapter depends largely on the review of publications being research reports, books, journal papers and public documents, such as country reports, on irrigation development in sub-Saharan Africa in particular.

Firstly, literature review is performed on the trend of irrigation development in sub-Saharan Africa. This is followed by a description of the types of irrigation development experienced in sub-Saharan Africa by categorizing them under the type of funding. This is followed by a discussion on the challenges affecting irrigation development in sub-Saharan Africa as reported in the literature. The final section develops successful conditions for sustainable irrigation development based on an analysis of the trends, types and challenges presented earlier.

3.2 TREND OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

Following the end of the Second World War, and the period of decolonization, there was a boom in irrigation development which coincided with strongly motivated nation building, particularly in Asia. Irrigated area increased at about 2.6 percent per annum from a modest 95 million hectares (Mha) in the early 1940s to between 250 and 280 Mha in the early 1990s (Siebert et al., 2002; Seckler et al., 2000b). In this era, a key developmental agenda for many countries was the construction of large and small dams and river diversions to abstract and store water for agriculture.

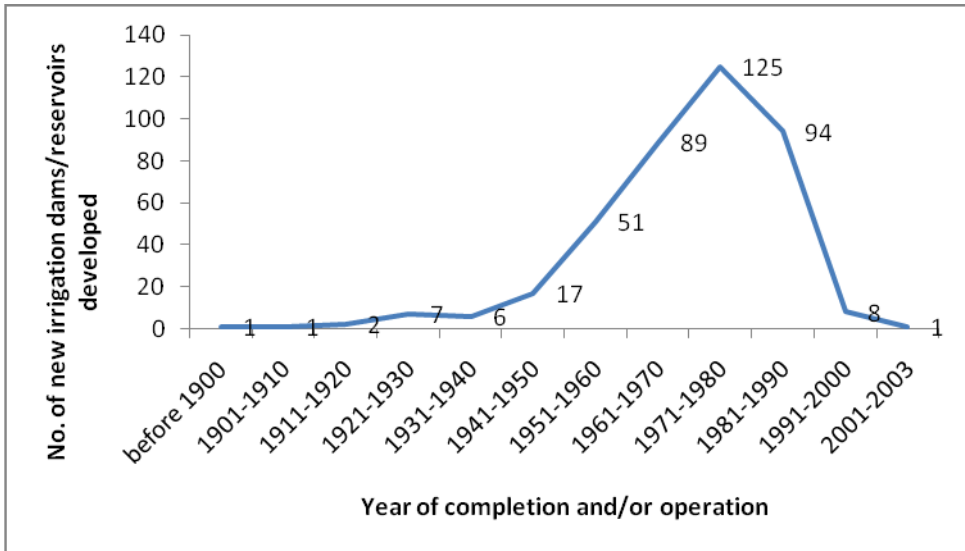


Figure 3.1: Trend of large-reservoir irrigation development in sub-Saharan Africa (Source: Aquastat, available at: <http://www.fao.org/nr/water/aquastat/main/index.stm>).

The last 50 years have seen massive investments in large-scale public surface irrigation infrastructure as part of a global effort to rapidly increase staple food production, ensure food sufficiency, and avoid devastating famine. Investment in irrigation accelerated rapidly in the 1960s and 1970s, with area expansion in developing countries at 2.2% a year reaching 155 Mha in 1982 (Carruthers et al., 1997). As pointed out by Rosegrant and Svendsen (1993) and Kikuchi et al. (2002), unprecedented high food prices during the two food crises in the 1970s induced huge irrigation investments in developing countries (see Figure 3.1). However, the annual growth rate of irrigation development, particularly in large-scale public schemes, has decreased since the late 1970s due to several factors (Faurès et al., 2007). The reasons for decline in large-scale irrigation development include underperformance (Chambers, 1988) which has reduced donor interest (Merrey, 1997), concerns over negative social and environmental impacts, more competition for water from other sectors, and declining cereal prices which have slowed growth in input use and investment in infrastructure with consequent effects on yield (Rosegrant and Svendsen 1993; Carruthers et al., 1997). In view of the above mentioned factors, more rehabilitation projects of large-scale irrigation schemes were implemented by governments and international donors since the late 1970s (Innocencio et al., 2007).

Eventually, the advent of affordable drilling and pumping technologies in India and Pakistan in the mid-1980s, which led to rapid development of shallow tubewells and conjunctive use of surface and groundwater (Shah, 1993; Palmer and Mandal, 1987), also impacted on irrigation development in sub-Saharan Africa. Simultaneous with the decline in public and international donor funding for large-scale irrigation, the 1990s saw a substantial rise in private development of groundwater irrigation based on the availability of cheap drilling and pumping technologies in sub-Saharan Africa. This irrigation development has spread in rural, urban and peri-urban areas in response to higher demand from growing cities for fresh fruits and vegetables (FAO, 2005).

Various studies conducted on the scale of development of irrigation in Sub-Saharan Africa give different figures of irrigated areas. According to the FAO (1995a) the sub-region of sub-Saharan Africa has an irrigation potential of about 42Mha with only about 5.6Mha actually irrigated in 1995. More recent data from FAO shows that in 2003 the actual irrigated area in sub-Saharan Africa had increased to 6.6Mha, an increase of 1Mha in 8 years (FAO, 2005).

3.3 TYPES OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

The dynamic nature of global and government development policies, the variety in irrigation project designs and implementation as well as the wide range of investors in irrigation development all over the world have resulted in two main driving forces behind irrigation developmen, namely government-led and non-government-led (Jones, 1995; Abenerthy et al., 2000; Shah, 1993). The sources of investment also result in two additional categories of irrigation being the scale of the irrigation and the management system employed. The scale of irrigation development could be large, medium, small or micro. A lot of literature have described irrigation development along such scales (Faurès et al., 2007; Albinson and Perry, 2002; Awulachew et al., 2005). In terms of management the literature distinguishes collective management, company (public/private) management, intermediate arrangement (eg. outgrower schemes for plantations) and individual management (Aw and Diemer, 2005; Meinzen-Dick, 1996 and Penning de Vries et al., 2005). It is important to note that usually the specific management arrangements are determined by those who make the investments.

Based on the objectives of achieving long-term success of irrigation development the types of irrigation development in sub-Saharan Africa will

be categorised and discussed under the sources of investment being government-led, non-government-led or a combined effort between private and government (eg. irrigation systems initiated privately and later receiving government support). This approach is chosen because the investor usually dictates the choices and decisions that are made to ensure the success of the irrigation scheme or system.

The descriptions also cover the extent of development of such irrigation types and their socio-economic impact in sub-Saharan Africa citing examples where possible. In addition the description will also capture technology, crop production, financial/technical support, market related issues and development trend (successes and failures). The various management types that exist under these systems are also discussed in some detail.

3.3.1 Government-Led Irrigation Development

Sub-Saharan Africa has benefitted from the development of government-led irrigation schemes which begun during the colonial era. After the colonial era subsequent governments and international agencies continued to develop irrigation schemes. As a result most countries in sub-Saharan Africa have developed a number of government-led irrigation schemes, ranging from a few hectares to tens of thousands of hectares. Thus government-led irrigation has produced irrigation schemes at all scales of magnitude being large, medium and small. Some of the well-known government-led large-irrigation schemes are: the Bakel Project of Senegal, the Bakolori Irrigation Project of Nigeria, the Gezira scheme of Sudan, the Bura West scheme of Kenya and the Office du Niger project of Mali. Government-led medium-scale irrigation schemes are those that range from 100ha to about 5000ha such as the Vea and Tono schemes in Ghana and many more. Small-scale government led-irrigation schemes range from a few hectares to several tens of hectares. Examples of small-scale irrigation systems are the small reservoirs developed in the Northern parts of Ghana and parts of Burkina Faso. However, various organizations and countries have developed their own scale categorisation for irrigation projects. For example in Ethiopia irrigation projects are identified as large-scale irrigation if the command area is greater than 3,000 ha, medium-scale if it falls in the range of 200 to 3,000 ha, and small-scale if it covers less than 200 ha (Awulachew et al., 2005).

Another group of government-led irrigation schemes are plantation schemes which are usually developed jointly by governments and multinational companies or development partners with the government having a shareholding. Such plantation irrigation schemes are used for the cultivation

of rice, fruits, sugarcane, bio-fuels and others. For example in Namibia about 300,000ha of land has been secured by a multi-national company, LL Biofuels Namibia for the planting of jatropha for biodiesel production (Biodiesel Magazine, 2010). Such investments made by multi-national companies need strong government backing and also need to be championed together with the government to succeed.

Government-led irrigation systems mostly use river diversion, river-dam-reservoir, tank, river-lift or lake, groundwater-lift or drainage/flood control for supplying irrigation water. Most large-scale and medium-scale irrigation schemes are developed from large dams which comprise dams greater than 15 meters (m) in height from base to crest, or storage capacity exceeding 3 million cubic meters for heights between 5 and 15 m (ICID, 2000). These large dams developed by governments are sometimes multi-purpose, also supplying water to cities, improving navigation, generating hydroelectric power and/or providing flood control.

The cost of developing government-led large and medium scale irrigation schemes vary widely. Jones (1995), reviewing the experience of the World Bank in irrigation development for a few decades, estimated that the average unit cost for 191 irrigation government-led projects was US\$4,800 per ha in 1991. The average for the whole of Africa was US\$13,000 per ha while that for sub-Saharan Africa was US\$18,300 per ha when indirect costs for social infrastructure, including roads, houses, electric grids, and public service facilities, are included. According to the FAO (2003), irrigation investment costs are generally much higher in sub-Saharan Africa compared to a world average of 5,600 \$/ha. On the other hand, there are sporadic studies showing relatively cheaper irrigation projects in sub-Saharan Africa with average unit costs comparable to Asia (SADCC, 1992; IFAD, 2000; World Bank-AFTS2, 2004). See section 3.4.1 for reasons explaining the high cost in sub-Saharan Africa.

These government-led irrigation schemes have had their various successes and failures which have contributed to the general trend in the development of irrigation schemes in sub-Saharan Africa (Chambers, 1988). The development of government-led irrigation schemes experienced a rise in the 1960s but has consistently dropped since the 1980s due to several factors. Some of these factors include rising construction cost, decline in food prices, an increasing recognition of environmental and social costs of development and failures in the performance of most existing irrigation schemes.

The development of government-led irrigation schemes is considered important as they are associated with useful infrastructure development,

creation of job opportunities, and contributing to agricultural growth and the macro economy (Awulachew, et al., 2005). The beneficiaries are the local farmers who are engaged to cultivate on the developed lands and are expected to pay for the water use and other services rendered to them on the scheme. As a result there are different management styles associated with government-led irrigation schemes. These are the company/agency managed, farmer-managed or the community managed schemes. Some of these management styles are instituted during construction while others have emerged after some years of operation. Most management institutions of government-led irrigation schemes of large or medium scale are public institutions with subvention from the government while the small-scale systems are mostly managed by the communities through Water User Associations.

In a bid to achieve improved productivity, limit external interventions, encourage farmers to take responsibility and also to follow global trends, the management of some government-led irrigation schemes have been transferred to the farmers. While some of these transfers have yielded positive results others have not. The reasons for the failures encountered are due to the fact that the original schemes were not designed for farmer management (Kamara, et al., 2001), wrong farmer-perception on the hand-over of irrigation schemes and financial/implementation challenges (Nkhoma and Mulwafu, 2004).

In many systems management tasks are shared between the public officials and the farmers. A typical example is the Office du Niger irrigation scheme which initially was managed by a powerful government agency and had monopoly over land, civil works, resources, allocation, farm inputs, farmer organizations, food processing and credit. A series of reforms that started in 1982 and backed by farmers, international donors and changing political will, triggered mainly by low productivity, has eventually resulted in the sharing of management responsibilities by the Office du Niger and Farmer Based Organisations (FBOs) (Aw and Diemer, 2005).

In most public managed government-led irrigation schemes, it is an added responsibility of the management to help farmers market their produce or to secure markets for the produce, but this remains a challenge yet to be resolved by some schemes. The inability to secure markets for produce has led to the decline in the productivity of many schemes. There are many marketing challenges for perishable commodities such as vegetables which if not sold in time lead to losses for farmers. Due to the importation of food in sub-Saharan Africa, local products such as rice have marketing challenges. In

the case of the community managed systems, the farmers mostly have to secure the market for their products.

3.3.2 Non-Government led Irrigation Systems

There are various investment sources for irrigation development on-going in sub-Saharan Africa which are independent of government support and interventions. These are purely private sources which may be from individuals, groups, companies or communities. This has led to irrigation schemes and systems developed by commercial farmers, outgrower farmers, community/farmer groups, individual small-holder farmers and, non-governmental organisations (NGOs).

Commercial Farmers

Commercial farmers are private individuals who develop irrigation schemes to produce and market produce on a commercial scale. They employ management and field staff and provide all the financial support to achieve success. Commercial farms often have good links to and knowledge of markets, local or international, to which they sell their products. They observe strict production rules in order to meet the quality standards demanded by these markets. Typical examples of such non-government led irrigation schemes are found in South Africa, Zimbabwe and Kenya.

The commercial farms use modern irrigation technologies such as drip irrigation. They cultivate several crops ranging from flowers, rice, vegetables and fruits in commercial quantities. They have reliable markets they supply products to such as the European markets. For example, commercial farmers in Kenya supply their horticultural products to European markets. Their products are supposed to meet standards referred to as the “European Retailers Working Group on Good Agricultural Practices” (EUREP-GAP), which include European Union regulations for all foods sold in member states (Mati and De Vries, 2005).

Outgrower Farmers

Outgrower farmers are small-scale farmers who grow crops for commercial farmers who have established market linkages. Their irrigation practice is facilitated by well-organised partnerships between them and the large-scale commercial farmers. Such partnerships involve developing memorandums of understanding (MoUs) between the commercial farmers and the outgrowers either as individuals or groups of small-scale outgrowers. The MoUs cover all aspects of crop production, quality control, record keeping and marketing rights. The large-scale commercial farmer is responsible for facilitating the

implementation of the requirements by providing training, extension services, supervision, seeds, fertilizer, pesticides, post processing and guaranteed market. The smallholders on their part grow the exact amount of crop as recommended, follow through with recommended agronomic practices, and sell the produce solely to the contracted farm (Mati and De Vries, 2005).

The technology used by outgrowers may not be as sophisticated as that of the large-scale commercial farmers. They mostly depend on mechanised and mechanical water abstracting systems for irrigation. This type of irrigation exists in locations with large-scale commercial irrigation schemes such as South Africa, Zimbabwe, Kenya, Tanzania and the likes. A typical example of such arrangements is Mukuria-Kyambogo Irrigation Scheme in Kenya (Mati and Penning de Vries, 2005).

Community/Farmer Groups

There are also many instances across sub-Saharan Africa where irrigation systems are initiated by communities. These happen as a result of sharing a common source such as water or of a combined effort to develop a water resource and/or also water transport systems such as reservoirs, canals, furrows and wells. When such investments are made, the investment becomes a communal property which is managed by the community. Rules are set which members have to comply with. The individual farm plots may be owned either by individuals or by the community. In most of these communal efforts the farmers are compelled to join the water user association or farmer-based organisation which resolves all issues surrounding the use of the facility (Mul et al., 2010). They are also able to access credit for their members by virtue of their co-operation. The group leaders may also help members find market for their products. New membership applications have to be passed through the leaders of the group and agreed by the members. Members are expected to pay a fee on a regular basis for the maintenance of the facilities, expansion and management. These fees are decided by the members and failure to pay may lead to loss of membership.

Individual Small-holder Farmers

Several small-scale irrigation systems across sub-Saharan Africa have been initiated by local individuals without any form of government support or interventions. The small-holder farmers are self made entrepreneurs who develop irrigation systems using affordable irrigation technologies. They abstract water by means of technologies such as treadle pumps, bucket and rope, motorized pumps, mechanised pumps and by gravity. Their sources of

water include streams, shallow wells, storage tanks, reservoirs and dugouts. Their farm sizes range from less than a hectare to about 10 hectares with the majority being less than a hectare. These farms are managed by their owners who sometimes join a farmer union or farmer based organisation to address a common agenda such as markets and credits.

Small-scale holders have a record of having a significant degree of success across sub-Saharan Africa compared to large-scale irrigation schemes implemented by governments. For example, in the dry areas of Nigeria, small farmers use traditional techniques to abstract water from perennial surface water and shallow groundwater for irrigation (Carter, 1981).

These small-scale irrigators are behind the springing up of urban and peri-urban irrigation dotted around the urban centres of sub-Saharan Africa growing vegetables to feed the urban population. Urban and peri-urban irrigation farm sizes depend on land and labour available and range between 0.02 and 0.3 ha (typically 0.05-0.1) (Drechsel et al., 2006). According to the FAO (2005) there are 20 million people in West Africa engaged in different forms of urban agriculture including irrigation and in many cities 60-100 percent of the consumed perishable vegetables are produced within the city. Specialization in high-value crops enables farmers to earn a significant income and provide the city with a reliable supply of perishable crops. Particularly during the dry season, when the supply goes down and prices might easily soar (Gerstl et al., 2002; Mbaye and Moustier, 2000), irrigated urban vegetable production is financially attractive (Drechsel et al., 2006).

Non-Governmental Organisations (NGOs)

Another type of irrigation development is initiated by non-governmental organisations especially as poverty reduction strategies for communities. These schemes are usually small-scale and are replicated in several communities across sub-Saharan Africa. Typical examples of such NGOs are the Red-Cross, ADRA and World Vision. They are involved in the design and construction of the irrigation facilities as well as the training of farmers in managing and maintaining the irrigation facilities. The irrigation infrastructure developed by these NGOs includes small reservoirs, dugouts, shallow wells and tubewells. After the provision of infrastructure some NGOs also provide farmers with credits and other forms of financial assistance to start irrigated farming.

NGOs are also involved in the promotion of irrigation technologies such as treadle pumps and drip irrigation for small-scale farming in sub-Saharan

Africa. They either do this on their own or in conjunction with existing irrigation facilities.

The irrigation systems provided by NGOs are mostly managed by the communities through the water user associations that the NGOs help to establish. The WUAs often own the irrigation infrastructure and are responsible for operation and maintenance of the facilities to ensure success and sustainability.

The crop types cultivated and the marketing of products are mostly handled and decided by the beneficiaries of the facilities. In some cases the NGOs link the farmers to the markets and allow the farmers to deal directly with the market or facilitate negotiations between farmers and the markets.

3.3.3 Non-Government Initiated but later supported/partnered by Government

There are other types of irrigation systems which were initiated by private individuals or groups but later received government support or intervention. These have characteristics and success stories different from the types discussed in previous sections. There are examples of private/community initiated irrigation systems in Kenya which were subject to government interventions and led to irrigation expansion. The Ng'uuru Gakirwe water project was expanded by the local users to also provide irrigation. This expansion was financed through a government loan to the farmers which they paid as annual water charges. Irrigation is by sprinkler and each farmer is expected to irrigate up to 1 hectare. The scheme accommodates 430 farmers and has potential coverage area of 6000ha (Mati and De Vries, 2005).

Field surveys conducted in Burkina Faso (Ofosu et al., 2010), identified groups of shallow well farmers being assisted by government to re-construct their shallow wells, line the wells and being promised motorized pumps for lifting water. Such interventions can boost the ability of farmers to produce more.

There are instances where local individuals have rejected or resisted government intervention. A typical example is the Jamaane village scheme in Senegal. It is a small-scale irrigation system established by local people from their own resources. But local people had to respond to attempts by the Senegalese Government to become involved together with USAID when the farmers applied for a US\$60,000 loan from USAID for the purchase of equipment. The farmers rejected the government involvement because they

feared losing control over their products once the government would become a partner (Adams, 1977, cited in Barnett, 1984).

Non-government-led irrigation systems which later receive government intervention are mostly managed by the users. In most of these cases the users are organised farmer-groups who manage their system through elected leadership. The leadership collaborate with the government agency responsible for the intervention on behalf of the group.

3.3.4 Joint Ventures

Joint ventures are partnership arrangements between smallholder irrigation associations and private companies. In joint ventures the two contracting parties have different interests that may complement each other. The private companies are in search of suitable land, water and labour resources, and the local irrigators are looking for assistance in putting their derelict irrigation infrastructure to work (van der Zaag, 2010). These are recent irrigation contract arrangements which are not common across sub-Saharan Africa. Examples of such joint ventures can be identified in Mozambique.

For example, in the Chokwe Irrigation Scheme, the irrigators of one lateral canal (known as “distribuidor 11”), have created an association, AREDONZE (Associação de Regantes do Distributor 11), which entered into a joint venture with MIA (Moçfer Industrias Alimentares), a private company with strong links to the state. MIA engages in seed production, agricultural input provision and processing and marketing of agricultural produce (mainly rice in Chokwe). AREDONZE commands around 1000 ha of irrigated land, which, when fully irrigated, comprises about 15-20% of the annually irrigated area in Chokwe. The association consists of about 350 small to medium rice farmers. The association is entitled to water via HICEP, the semi-public organisation that holds and controls the water license for the whole system. But AREDONZE lacked the financial capital to rehabilitate tertiary canals after encountering some devastating floods. Meanwhile MIA was looking for opportunities to set up shop in Chokwe irrigation scheme and opted to engage in a partnership with AREDONZE (Munguambe et al., 2010).

The agreement is complex and not without risks. This partnership has led to some tangible and positive results in terms of technological development, maintenance, input provision and marketing, but there are also some real drawbacks. For example, despite improved rice production in AREDONZE, after two seasons, the majority of the leadership within AREDONZE

expressed dissatisfaction with the MIA deal, and prepared themselves to re-negotiate some of the modalities of the partnership (van der Zaag, 2010).

3.4 CHALLENGES OF IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

The preceding description of irrigation types in sub-Saharan Africa may paint a picture that irrigation development is well on course. However, this is not the situation as irrigation development in sub-Saharan Africa happens to be the slowest in the world (FAO, 2006a). As a result sub-Saharan Africa has the highest potential to accelerate irrigation development in comparison to other continents to help solve projected world food shortages. However, projections by FAO (2003) predict a much slower expansion of irrigation in sub-Saharan Africa over the next 20-30 years (0.6% per year) as compared with 1.6% per year recorded from 1960-1990. These predictions are informed by the numerous challenges facing irrigation development in sub-Saharan Africa. These challenges, discussed in this section, if addressed, can increase the rate of successful irrigation development.

While some irrigation systems in sub-Saharan Africa are described as moderately successful, several are referred to as failed systems, due to various challenges identified in literature (Barnett, 1984; Faurès et al., 2007).

A research conducted on a number of small-scale irrigation systems across sub-Saharan Africa by Barnett (1984) identified six problems affecting small-scale irrigation: (1) the problem of balancing social benefits, national economic strategies and perceived producer benefits; (2) the problem of control (over decision-making, marketing, water use and etc); (3) the problem of hierarchy and technical requirements; (4) the problem of planning production units and process; (5) the problem of water use and adaptation to farmer experiences; and finally (6) the problem of planning for change.

Other studies (Awulachew et al., 2005; Moris and Thom, 1990) have identified the following problems: the high costs of investment and negative rates of return; technical flaws in infrastructural design, seepage, sedimentation, cracks in dams and silting up of reservoirs; high input costs, especially cost of fertilizer; pests and diseases especially for onions and tomatoes; high interest rates on loans; management failures; political difficulties; and finally marketing problems. Awulachew et al. (2005) observed that where these types of failures occurred, they have generated lack of maintenance, broken down scheme machinery due to lack of spare parts, and lack of access to input and output markets.

Table 3.1: Common challenges affecting irrigation development in sub-Saharan Africa

Challenges	Authors		
	Barnett (1984)	Awulachew et al. (2005)	Shah et al. (2002)
High Irrigation development cost	New schemes involve huge investment	high costs of investment, high input cost;	High cost of working capital;
Lack of access to credit	Governments cut down on operation cost by removing credits for farmers	High interest rates on loans	Poor linkages to credit, input and output
Unreliable Markets and lack of access	Artificial market pricing by management of public schemes	Marketing problems	Poor linkages to market
Ineffective Institutions	the problem of control, balancing social, national and producer benefit; hierarchy and technical requirements; adaptation to farmer experiences	negative rates of returns; management failures; political difficulties	Improper management transfers; land tenure issues; institutional vacuum
Choice of technology and maintenance of infrastructure	Problems with adequate and reliable water supply	technical flaws in infrastructural design, cracks, siltation and seepage in reservoirs; lack of maintenance and spare parts of machinery	Expensive and ineffective mechanisation;
Low Productivity	problems with production units and processes	Pests and diseases, high fertilizer cost	Damaged soils, poor farmer capacity

Shah et al. (2002), studying smallholder irrigation systems in sub-Saharan Africa, identified the following challenges: mismanagement, high cost of working capital, poor linkages to credit, input and output markets, institutional vacuum, land tenure issues, improper management transfers, damaged soils, expensive and ineffective mechanisation, poor farmer capacity and lack of farmer entrepreneurship development.

The commonalities between the challenges observed by the various authors are identified in Table 3.1.

3.4.1 High Irrigation Development Cost

Inocencio et al. (2007) compared irrigation development in sub-Saharan Africa with other developing areas, and confirmed that it is more expensive to develop irrigation in sub-Saharan Africa than in other parts of the world. In sampling 314 irrigation schemes implemented in developing countries, the average cost of a new irrigation scheme in sub-Saharan Africa was US\$14,500/ha and US\$6,000/ha elsewhere. Rehabilitation costs amounted to US\$8,200/ha in sub-Saharan Africa against US\$2,300/ha elsewhere. The high cost is related to the lack of economies of scale because sub-Saharan Africa has many relatively small irrigation schemes (Faurès et al., 2007). Inadequate local expertise in planning, designing and construction of irrigation projects and, hence, the involvement of expensive expatriate expertise at all stages of the project cycle at the early stages of nationhood have also been cited as reasons for high cost of irrigation development (Namara et al., 2010). It is further speculated that the best areas for irrigation schemes development in sub-Saharan Africa have been almost exhausted leading to higher construction cost in future irrigation projects (Faurès et al., 2007). This is further compounded by the need to mitigate the social and environmental costs associated with these developments. This has reduced the rate of development of new irrigation schemes across sub-Saharan Africa.

Due to the high costs of Large-scale Irrigation projects, in the anxiety of planners to meet project targets for the national economic benefit, the government sets up its own administration structures for managing the schemes. The administrative structures are mostly authoritarian and they compel the direct producers to comply with enforced artificial pricing of commodities (Barnett, 1984). This has resulted in challenges where social, economic and producer benefits cannot be balanced and eventually result in low productivity due to lack of farmer interest.

3.4.2 Lack of Access to Credit

Starting in the early 1980s countries across the development spectrum had to adopt a series of policy measures aimed at coping with the severe international economic crisis. An increasing number of countries had to go through economic adjustment processes, either because the drying up of capital inflows left no other option, or because this type of adjustment was made a precondition by the private banks and the multilateral agencies before new money would be released (Edwards and van Wijnbergen, 1992). As a result countries like Ghana introduced the Structural Adjustment

Program (SAP). The situation experienced in Ghana is similar to what was experienced across sub-Saharan Africa.

The introduction of the Structural Adjustment Program (SAP) changed the paradigm of irrigated farming in general and that of the poor in particular. There was a drastic drop in government support to inputs and credit. In Ghana the budget share of agriculture dropped from 12% prior to the reform to only 2% in the 1990s. The drop in budget share resulted in huge cuts in formal credit and input supply programmes, and reduction in subsidies for fertilizer, credit, and animal traction equipment (Reardon et al., 1994).

Though the reforms were meant to create incentives to agricultural producers, to the majority of smallholder farmers the negative impact of the removal of input subsidies outweighed the benefits from the market reforms. Before the reforms fertilizer subsidies were in the range of 40 to 80%. However, after the reforms prices of most agricultural chemicals used in cereal production increased in excess of 40% between 1986 and 1992 and the price of fertilizer in particular doubled between 1990 and 1992 in Ghana (Seini, 2002).

The reforms have not only changed the input price regimes but also the credit environment. That is, credit for the purchase of farm inputs for small holder farmers has been drastically affected by the reforms (Yilma et al., 2004). Before the reform in Ghana, the Agricultural Development Bank (ADB) used to provide credit to the agricultural sector with preferential conditions. In addition to the ADB, commercial banks were also obliged to lend not less than 25 percent of their loanable funds to the agriculture sector at reduced interest rates (Nyanteng and Dapaah, 1997). These policies were gradually abolished; subsequently the interest rates charged for agricultural credit have been raised to levels comparable to rates of non-agriculture. Loans to small-scale farmers have virtually evaporated after the liberalization of interest rates. Further, there is no evidence to show that declining institutional credit to agriculture is being replaced by informal credit (Seini, 2002).

In cases of credit constraints and a risky environment, farmers may use off-farm income to invest in agriculture and thus increase the households' farm productivity (Evans and Ngau, 1991; Reardon et al., 1994; Schrieder and Knerr, 2000). Even in cases where some credit markets exist off-farm income may serve as collateral, for example in Benin (Hoffman and Heidhues, 1993).

Under such circumstances, agricultural communities are forced to resort to activities that secure a more stable income stream. These include rural-urban migration or local non-agricultural employment (Yilma et al., 2004). This

has contributed to the slow rate of irrigation expansion in sub-Saharan Africa.

3.4.3 Marketing and Access to Markets

Poor access to markets for both inputs and outputs creates problems for agricultural production on a market-oriented basis, whereby lack of markets for certain crops after harvest leads to huge losses (Awulachew et al., 2005). Apart from crop diseases and occasional water shortages, it is the unreliability of markets that limits the benefits obtainable from irrigated agriculture. Marketing of irrigated vegetables is therefore suffering from a number of flaws (Laube et al., 2008). Factories could process perishable vegetable crops such as tomatoes which would help to save losses and stabilise the market. A typical example of market failure of vegetable production was experienced in the 2006/2007 irrigation season in Northern Ghana. A promise made to farmers to cultivate tomatoes in higher quantities to supply a newly refurbished tomato processing factory resulted in massive production of tomatoes that season. Unfortunately, the failure of the factory to operate that season resulted in massive losses. This unfortunate incident was further worsened when tomato farmers in Northern Ghana met stiff challenge from their counterpart farmers in neighbouring Burkina Faso who competed for the limited market in the urban centres of southern Ghana.

Marketing of irrigated products in sub-Saharan Africa at local, regional and global markets have numerous challenges which affect the irrigation industry. For example in Ghana, national vegetable market channels are controlled by highly organised women trader organisations which exert a large degree of control on commodity prices, which they frequently manipulate to the farmers' disadvantage. Furthermore, local farmers face a high degree of regional competition from other countries of the sub-region (Burkina Faso for tomatoes, Mali and Niger for onions). But the largest problem stems from the competition of European and Asian countries such as Italy, Holland, Spain or China, where the production of vegetables is highly subsidised, and from where large quantities of vegetables and vegetable products (such as tomato paste) are dumped on the Ghanaian market. Artificially low world market prices negatively affect local prices and marketing chances (Laube et al., 2008). Addressing these marketing challenges is key to sustainable and further upscaling of irrigation development in sub-Saharan Africa.

3.4.4 Ineffective Institutions

Irrigation institutions have to be effective to promote and manage irrigation to be productive, efficient and sustainable. Effective institutions are required from the farm level, catchment level to the national level. These institutions are responsible for ensuring irrigation productivity and efficiency, planning of irrigation development, managing of impacts due to irrigation development, formulating and implementing policy directives and funding towards sustainable irrigation development.

The historical bias toward infrastructure investment to the neglect of ensuring effective institutions is one cause of poor irrigation performance (Faurès et al., 2007). Effective institutional arrangements have failed due to insufficient resources, lack of political support, lack of proper involvement of water users, resistance of public agencies and water users and lack of capacity building.

Ineffective institutions have resulted in limited access to water and land for irrigation development (Lahiff, 1999). Insecure tenure is a disincentive to farmers who wish to make long-term investments on their land. For example in Rhodesia, under the Control of Irrigable Area Regulations of 1970, every plot-holder was issued three permits, which had to be renewed every year (Manzungu et al., 1999). Under such conditions irrigators can be replaced in certain circumstances. As a result farmers were not willing to invest in long-term infrastructure on their land-holdings.

Within the past 15-20 years there have been some institutional reforms in many countries in sub-Saharan Africa with a focus on withdrawing government from management. Management responsibilities have therefore been transferred from centralised bureaucratic management to lower levels (FAO, 1997; Johnson et al., 2004). However as Faurès et al. (2007) put it effective institutional arrangements for irrigation still remain a challenge.

Institutional reforms backed by strong political commitment towards productive and sustainable irrigation development are needed in sub-Saharan Africa (Merrey et al., 2007). Sustainable institutional reforms have the following characteristics: they give legal recognition to farmers and farmer groups, clearly recognise sustainable water rights and water service, specify management functions, provide compatible infrastructure with water service, create effective accountability and incentives for management, have viable arrangements for conflict resolution, mobilize adequate resources for irrigation and ensure that farmer investments are proportional to benefits that exceed costs (Samad and Merrey, 2005; Merrey, 1997).

3.4.5 Choice of Technology and Maintenance of Infrastructure

Experience in many parts of Sub Saharan Africa has shown that with adequate community involvement in planning, design and management, small scale irrigation schemes can be more viable and sustainable than conventional large-scale schemes (Merrey et al., 2002). Limited or lack of community consultation precludes the inclusion of indigenous knowledge or local know-how in scheme planning and construction.

Also the non-acceptance of irrigation schemes by farmers has resulted in the cultivation of only small parts of the potential area. This is largely a function of the top-down implementation process often followed. It also suggests some of the interventions have not been appropriate, given the circumstances of the recipient populations. A classical example is the Meki-Ziway Scheme in Oromia, Ethiopia, which failed largely because farmers could not get spare parts for the imported pumps, could not carry out maintenance, and could not afford the electricity fees to run the pumps. It is now generally agreed that irrigation technology should be commensurate with the capacity of the users (Awulachew et al., 2005). The design should not only fit the capacity of the users, but also many other conditions, such as climate, soils, crops to be cultivated, but also the manner in which the irrigation infrastructure is going to be managed – collectively, individually, as a plantation, as a company or by a public agency. The most difficult is to know and anticipate the capacity of the users to manage a future infrastructure. One of the biggest constraining factors is that there are few experts who can fine-tune all these elements in a design that will prove to work in practice.

There are also issues related to the poor state of existing infrastructure which is affecting the productivity of irrigation schemes. These include technical flaws in infrastructural design and construction which result in seepage, sedimentation, cracks in dams, among others. Apart from the design and structural defects in irrigation infrastructure, the most prevalent challenge is poor maintenance. This may result in silting up of canals, broken sections of canals and laterals, and broken down water control systems which affect the productivity of irrigation systems thereby creating losses for farmers and management organisations. Most irrigation schemes developed in sub-Saharan Africa are unable to produce at full capacity because of poor maintenance.

The reason for poor maintenance as listed by Sijbrandij and van der Zaag (1993) are: (1) the cost of irrigation scheme maintenance is mostly a

significant component of the annual budget of irrigation schemes which sometimes are restricted; (2) neglect of duty by maintenance sections of irrigation management organisations; (3) lack of accountability of maintenance department to the water users; (4) lack of channels for expressing water users opinion on canal maintenance problems; (5) the informal participation of farmers in maintenance which is sometimes hampered by inhibiting social issues between farmers; and finally (6) apathy from water users due to the perception that they are not responsible over the facility. Lessons need to be drawn from these challenges to create functional maintenance culture and strategies among management and water users to sustain irrigation projects.

3.4.6 Low Productivity

According to the FAO statistics (FAOSTAT, available at <http://faostat.fao.org/>), productivity growth in Africa lags far behind other regions of the world and is well below the growth required to meet food security and poverty reduction goals set forth in national and regional plans. A few statistics on cereal production illustrate this point:

- In 2000, cereal yields in Sub-Saharan Africa averaged just less than 1.0 metric ton per hectare, while yields in East and Southeast Asia, Latin America, and South Asia averaged 3.4, 2.9, and 2.4 metric tons, respectively.
- Between 1980 and 2000, cereal yields in Africa grew at an average annual rate of only 0.7 percent, whereas yield growth rates in other developing regions ranged from 1.2 to 2.3 percent

Low fertilizer use is one of the major factors explaining lagging agricultural productivity growth in Africa relative to other regions. In 2002, the average intensity of fertilizer use in Sub-Saharan Africa was only 8 kilograms per hectare of cultivated land, much lower than in other developing regions (78kgs in Latin America, 96kgs in East and South-East Asia and 101kgs in South Asia) (Morris et al., 2007). There are numerous challenges facing improving fertilizer application in Africa.

Typically in Ethiopia, organized input supply through government or government-supported channels are often available only for the major rain-fed season. Farm inputs, especially fertilizer, are scarce and relatively expensive during the irrigation season, i.e. the dry season, which leads to sub-optimal application of inputs, low yields and low profitability. In some instances, farmers attempt to substitute mineral fertilizers with farmyard manure, but this is often not available in desired quantities (Awulachew et al., 2005).

Given the generally low levels of fertilizer use in Africa, there can be little doubt that fertilizer use must increase if the region is to meet its agricultural growth targets, poverty reduction goals, and environmental sustainability objectives. For this reason, policies and programmes are needed to encourage fertilizer use in ways that are technically efficient, economically rational, and market-friendly (Morris et al., 2007).

Also some horticultural crops are highly vulnerable to pests and diseases; often these crops are introduced without accompanying programs of pest and disease management, which drastically reduces yields and the profitability of farming (Awulachew et al., 2005).

Finally, in many African countries the management of smallholder irrigation schemes by parastatal agencies have left behind a legacy of a dependent and impoverished group of farmers (Shah et al., 2002). For example in South African irrigation schemes managed by the Agriculture Rural Development Corporation (ARDC), all that the farmers did was to weed, harvest and move irrigation pipes around. They did not invest much working capital nor did they take management and entrepreneurial decisions. Farmers were reduced to collecting wages for weeding and harvesting. Scheme managers have mostly attempted to 'manage' farmers rather than encourage entrepreneurial development (Shah et al., 2002). In such instances farmers are not stimulated to develop their innovation capacity to improve production, evidenced in consistent low productivities. This situation is similar in other African countries. As a result farmers are not able to contribute to the management of irrigation schemes. In the case where management is transferred to irrigators, more challenges are encountered because the farmers have yet to build up the capacity to manage the schemes.

3.5 SUCCESS FACTORS FOR ACHIEVING PRODUCTIVE AND SUSTAINABLE IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

3.5.1 Background

The above listed challenges need to be addressed holistically in order to achieve sustainable upscaling of irrigation development in sub-Saharan Africa. Having reviewed the challenges, the next step is to establish the way forward for successful irrigation development in sub-Saharan Africa. It calls

for the identification of the factors that enable productive and sustainable irrigation development across sub-Saharan Africa.

By definition (Molden et al., 2003), irrigation productivity relates to the net socioeconomic and environmental benefits achieved through the use of water for irrigation. One of the reasons necessary for increasing irrigation productivity is the need to meet rising food demand of a growing, wealthier and increasingly urbanized population. Improved irrigation productivity will contribute to poverty reduction, productive employment and economic growth.

The achievement of productive and sustainable irrigation development hinges on vital requirements or enabling factors. Penning De Vries et al. (2005) suggest five ‘capitals’ as being required for socio-economic development including irrigation:

- Human capital (skills and knowledge, labour, health)
- Natural capital (water, land, genetic resources)
- Social capital (organization, regulations, policies, trust and security, gender equity)
- Financial capital (savings, loans, markets)
- Physical capital (infrastructure, technology, equipment)

Penning De Vries et al. (2005) argue that all the above five types of capitals are required, and that in a given situation the smallest capital has to be strengthened first. This implies that the strength of the successful irrigation development is equal to the weakest factor. However, these capitals are far too broadly defined to be of much conceptual help – so what is required is to define relevant aspects of these capitals much sharper. Another issue is that “capitals” are like stocks, and what seems to drive irrigation development is demand for products – which seem to behave more like fluxes.

3.5.2 Success Factors for Sustainable Irrigation Development

Looking at the challenges discussed above and comparing with suggestions proposed in the literature, the following success factors are identified as being vital for sustainable irrigation development in sub-Saharan Africa: secure access to land and water, appropriate technologies, predictable and stable input/output markets, favourable policies and effective institutions, reliable farmer support environment. A suitable relationship between these five factors is a chain of shackles, the chain being as strong as the weakest shackle (adopted from Penning De Vries et al., 2005 and Vishmudas et al., 2007) (see Figure 3.2).

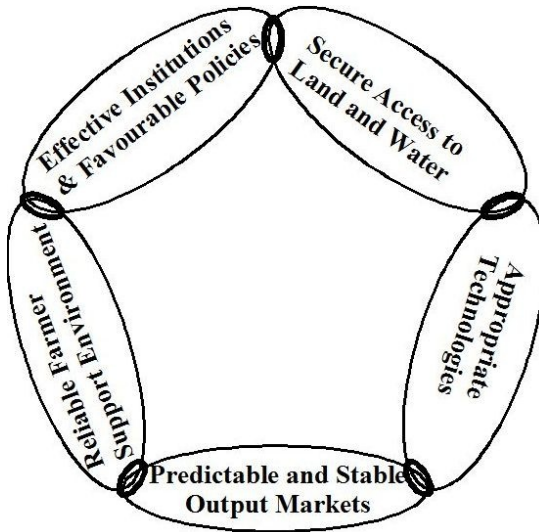


Figure 3.2: Chain of Success Factors for sustainable Irrigation Development (Source: modified from Vishnudas et al., 2007).

Secure Access to Land and Water

Land and water are basic necessities for the development of irrigation. The challenge usually associated with accessing land is the prevailing land tenure system which determines how land is accessed by individuals and organisations for irrigation, and the security over the landholding. These conditions influence the investments that one is willing to make into irrigation development. Often, the lack of clarity among the plot-holders about what their rights precisely are with respect to their plots seems more problematic than the absence of ownership (Shah et al., 2002).

The acquisition of land for irrigation is done in consideration with accessing potential *water* sources for irrigation. The sources of water which can be harvested for irrigation include groundwater and surface water. Institutional arrangements that allow and protect water access would obviously help to promote irrigation development.

Appropriate Technology

Irrigation development involves *technology* for the abstraction, transportation, distribution and application of water. Infrastructural and technological development forms the most expensive aspect of irrigation development which needs *investment* from both government and private

initiatives. There is the need to invest in new irrigation schemes or systems and in new types of irrigation technologies as well as existing ones to improve productivity. The lack of investment constrains irrigation development in sub-Saharan Africa.

The nature of investment should promote innovative and appropriate technologies which empower users to better control agricultural production as well as fit into the local context (socio-economy, geography, soils, crops and sources of water). Different technologies enable and/or constrain certain types of organisation of irrigators (centralised/de-centralised which coalesce with different modalities of investment: individual, collective, corporate or government). New technologies may unlock some entrepreneurial investment so far unexploited.

Reliable and Stable Input/Output Markets

Markets are key in irrigation development, and in particular output markets. Output markets have either been the driving force behind several irrigation developments or the reason for their collapse. Produce markets that are predictable and reliable to the extent that prices paid make irrigation economically viable without any distortions are a pre-requisite for successful irrigation development. Issues of market failure, artificial low pricing by governments and market fluctuations have led to severe losses and has further suppressed irrigation development in sub-Saharan Africa. These unfavourable market conditions are detrimental to successful irrigation development and lessons can be learnt from cases like the Office du Niger irrigation scheme (Aw and Diemer, 2005).

Effective Institutions and Favourable Policies

In order to ensure sustainability, there is the need for institutions to effectively take care of the public interests through leading, ruling and managing of the resources.

Effective irrigation management institutions have the following characteristics: (1) has a defined boundary (e.g. hydrological); (2) provides incentives for stakeholders to invest and participate in the profitability of the system; (3) has adequate infrastructure to deliver services in terms of rules and allocations; (4) has the capacity to adapt to changing circumstances; (5) employs cost recovery mechanisms and is equipped with legal instruments for implementing and enforcing policies and laws; (6) has decentralised, integrated and transparent functions; and finally (7) involves stakeholder

participation by creating a platform that represents all interest groups at all levels (Perry, 1995; Savenije, 2000; Merrey et al., 2007).

Irrigation policies can enable and facilitate irrigation development. Governments have implemented several policies which have had dire consequences on irrigation development instead of improving them in sub-Saharan Africa. These include the removal of subsidies for farming through the structural adjustment program, removal of credit facilities for farmers and improper management transfers.

Policies that target the creation of conditions that stimulate the entrepreneurship abilities of farmers and make them innovative can positively influence the development of irrigation. Also policies that improve credit accessibility of farmers and/or reduce the capital cost of the producer will contribute positively to irrigation development.

Reliable Farmer Support Environment

Irrigation farming is a business venture that thrives in an enabling environment. An accessible and reliable farmer support environment can sustain and improve irrigation productivity. Irrigation farmers depend on some vital support services to achieve success and improved productivity. These supports are best utilised if easily accessible by farmers. The reliability of these support services can boost farmer confidence and may lead them in investing further in irrigated agriculture. Farmers also depend on information on markets, seeds, soil requirements and fertilizer.

The availability of affordable credit facilities gives farmers the opportunity to improve and expand production. For example, with credit farmers can afford to buy fertilizer or invest in more efficient irrigation technologies.

Farmers depend on labour (both skilled and unskilled) for most of their irrigation activities. According to Namara et al., (2011), labor constitutes 31 percent to 64.2 percent of the variable cost of production depending on the type of the crop. Even though there is slight variation from region to region, the four major labor demanding operations are harvesting and threshing, water management, weed and pest control, planting, and land preparation. The labor required varies from 114 to 212 person-days/ha depending on the crop type.

Farmers have sometimes been introduced to certain irrigation technologies without technical support for maintaining them. As a result farmers could not find spare parts and skilled labour to repair their broken down equipment. These have resulted in unsustainable irrigation development.

Finally, farmers are sometimes faced with certain technical challenges such as diseases, pest, low yields and poor water management that require technical advice to address them. Thus the availability of reliable technical advisory services such as extension services or farmer advisory centre is equally needed.

An enabling environment where all these supports are accessible by farmers is important for sustainable and successful irrigation development.

3.5.3 Impact of Success Factors on some Irrigation Schemes/Systems in sub-Saharan Africa

The five success factors identified in the previous section are tested on selected irrigation schemes. These success factors are tested on a scale of weak, intermediate and strong. Irrigation schemes were selected from across sub-Saharan Africa, whereby the availability of detailed information on prevailing conditions was an important criterion. They include the Office du Niger irrigation scheme under two different periods (1932-1982 and 1982-present), the Niger Valley irrigation schemes, the Sakassou Rice irrigation system in Cote d'Ivoire, the Ng'uuru Gakirwe irrigation system in Kenya, the Mukuria-Kyambogo group irrigation scheme in Kenya, the Community Empowerment Irrigation Project in Northwest Somalia and, finally, the Usangu irrigation system in Tanzania.

The results are summarised in Table 3.2, and show (1) that these five factors are relevant; and (2) that the irrigation schemes/systems are as successful as the weakest of the five factors identified. The successful irrigation schemes and systems have been tagged as *bright spots* of irrigation development across sub-Saharan Africa (Penning de Vries et al., 2005).

3.6 CONCLUSIONS

Irrigation development in sub-Saharan Africa begun in the pre-colonial era and have continued through the colonial and post-colonial era. In the last two decades a significant amount of irrigation in sub-Saharan Africa has been developed by private commercial farmers, outgrower farmers, small-holder individuals and communities as well as non-governmental organisations. These sources of investment have mostly dictated the kinds of management system adopted. There appears to be few success stories of government-led irrigation schemes as compared to other irrigation systems across sub-Saharan Africa.

The rate of irrigation development in sub-Saharan Africa is the slowest compared to other regions of the world and can be linked to the following unresolved challenges: high development cost of irrigation, lack of access to credits for farmers, unreliable and unpredictable markets, ineffective institutions, low productivity, and finally inappropriate technologies coupled with poor infrastructural maintenance.

The potential irrigable area of sub-Saharan Africa is 42 million hectares with only 5% developed, making sub-Saharan Africa a potential bread-basket for the future global population. This potential can not be realised until an enabling condition is created. The study has identified five success factors for irrigation development in sub-Saharan Africa and the enabling condition through which it can be achieved. These factors include: (1) secure access to land and water, (2) appropriate technology, (3) predictable and stable input/output markets, (4) reliable farmer support environment, and (5) effective institutions with favourable policies. These factors function as a chain of shackles, the chain being as strong as the weakest shackle. This implies that in a given situation the weakest shackle has to be strengthened.

This theory has been tested on some irrigation systems across sub-Saharan Africa with various degrees of success and has proven to reveal the sources of success and failure. In the reviewed cases the weakest aspects were secure access to land and water, and effective institutions and favourable policies.

Table 3.2: Measure of Success Factors on Some Irrigation Systems in Sub-Saharan Africa.

Irrigation Project	Type	Secure access to Land and Water	Appropriate Technology	Predictable and stable input/output markets	Reliable farmer support environment	Effective Institutions & Favourable Policies	Measure of Success
Office du Niger in Mali (1932-1982) (Source: Aw and Diemer, 2005)	Government-led scheme	Land security absent – (<i>weak</i>)	Government investment – (<i>strong</i>)	poor output market - (<i>weak</i>)	Heavily indebted farmers, lacked incentives to raise yields couldn't hire labour (<i>weak</i>)	Government monopolised management, Artificial market prices for products (<i>weak</i>)	<i>weak</i>
Niger Valley Irrigation Schemes in Niger (Source: Abernethy et al., 2000)	Government-led scheme	Secured by government for farmers - issues of landownership prevailing (<i>intermediate</i>)	Developed by Government and Donors but Farmers pay high fees for services and maintenance (<i>intermediate</i>)	High demand for products from local market (<i>strong</i>)	accessible credits for farmers payable in a year (<i>strong</i>)	Managed by Cooperatives overseeing Irrigator Organizations, Both institutions lack management skills due to illiteracy and Ineffective management transfers, (<i>intermediate</i>)	<i>intermediate</i>
Sakassou Rice	Government-	Land availability	Irrigation system	The Farmer	Farmers are	Managed by Farmer	<i>intermediate</i>

Irrigation Project	Type	Secure access to Land and Water	Appropriate Technology	Predictable and stable input/output markets	Reliable farmer support environment	Effective Institutions & Favourable Policies	Measure of Success
Irrigation System in Côte d'Ivoire (Source: Hundertmark and Abdourahmane, 2003)	led scheme	with accessibility constraints and poor water services during peak periods (<i>intermediate</i>)	developed by government (<i>intermediate</i>)	Cooperative assists farmers with Inputs and marketing (<i>strong</i>)	assisted with inputs payable at the end of the season, abundant labour for farmers (<i>strong</i>)	groups and Water Management Committee with Technical Assistance provided by public agency (<i>strong</i>)	
Office du Niger in Mali (1982 – Present) (Source: Aw and Diemer, 2005)	Government-led scheme reformed by Water User Association	Farmer-friendly land-tenure security (<i>strong</i>)	Government and Donor Investment (<i>strong</i>)	Vibrant Private sector participation in input and output markets; doubling of rice price (<i>strong</i>)	Farmers access credit from private sector, abundant labour (<i>strong</i>)	Farmers have access to credit, no price controls, Farmers unions involved in management (<i>strong</i>)	<i>strong</i>
Ng'uuru Gakirwe irrigation in Kenya (Source: Mati and Penning de Vries, 2005)	Private-led system with government intervention	Land owned by farmers, water is easily accessible by all. Water limitation factor for expansion	Farmers converted a water supply-system into irrigation. Later government	Farmers have their own processing and packaging factory. Products are sold to European Markets (<i>strong</i>)	Farmers get inputs and credits from the processing company owned by farmers,	Farmers have organised union. Special training package is organised for farmers by the European Markets	<i>intermediate</i>

Irrigation Project	Type	Secure access to Land and Water	Appropriate Technology	Predictable and stable input/output markets	Reliable farmer support environment	Effective Institutions & Favourable Policies	Measure of Success
		<i>(intermediate)</i>	loaned farmers to expand system <i>(strong)</i>		abundant labour <i>(strong)</i>	<i>(strong)</i>	
Mukuria-Kyambogo Group Irrigation Scheme in Kenya (Source: Mati and Penning de Vries, 2005)	Outgrower small-scale farmers	Land tenure is individual ownership with title deed, adequate water supply controlled by farmers <i>(strong)</i>	Started with a loan secured by a group of 15 farmers <i>(strong)</i>	Are outgrower farmers for large-scale commercial farmers who provide inputs and markets <i>(strong)</i>	Credit is accessed by the group on behalf of members <i>(strong)</i>	Organised farmer group having effective collaboration with commercial farmers. Small-scale farmers are trained by commercial farmers <i>(strong)</i>	<i>strong</i>
Community Empowerment Irrigation Project in Northwest Somalia (Source: Omar and Yonis, 2005)	Government-Led with Donor (IFAD) Support	Farm plots are owned by the farmers <i>(strong)</i>	Farmers were given loans by the project to develop shallow wells <i>(strong)</i>	Farming communities gain access to market through rehabilitation of feeder roads <i>(strong)</i>	Farmers are given credits in ploughing and in cash and can also access credit through rural financial services instituted by the	Comprehensive program for strengthening local institutions, agricultural extension services for farmers <i>(strong)</i>	<i>strong</i>

Irrigation Project	Type	Secure access to Land and Water	Appropriate Technology	Predictable and stable input/output markets	Reliable farmer support environment	Effective Institutions & Favourable Policies	Measure of Success
Irrigation in Usangu in Tanzania (Source: Lankford and Beale, 2007)	small-scale private individuals irrigation system	Control of land is generally inflexible, governed by money, location prestige and time occupied, unreliable water source (<i>weak</i>)	Private individuals secure loans to investment in technology. (<i>intermediate</i>)	Capital-rich farmers have good access to markets than the poor farmers. (<i>intermediate</i>)	project (<i>strong</i>) Accessible credits from a small credit union, however capital-rich farmers have good access than poor farmers (<i>intermediate</i>)	Weak institutions, resulting in competition for land and water. Unresolved downstream impacts from upstream irrigation (<i>weak</i>)	<i>weak</i>

Chapter 4

IS LARGE-SCALE PUBLIC IRRIGATION THE WAY-FORWARD FOR SUB-SAHARAN AFRICA?

4.1 INTRODUCTION

4.1.1 Background

The last 50 years have seen massive investments in large-scale public irrigation infrastructure as part of a global effort to rapidly increase staple food production, ensure food sufficiency, and avoid devastating famine. Investments in irrigation accelerated rapidly in the 1960s and 1970s, with area expansion in developing countries at 2.2% a year reaching 155 million ha in 1982. Global irrigated area rose from 168 million ha in 1970 to 215 million ha over the same time frame (Carruthers et al., 1997).

Large-scale irrigation has received the greatest share of public agricultural investments in the developing world and most of the public operating subsidies (Jones, 1995). Newly developed large irrigation schemes swallow vast amounts of capital, both at the construction and at the operation phases, and often require costly rehabilitations (sometimes after less than five years of operation) (Diemer, 1988).

While these investments have yielded significant impacts in terms of improving food security and poverty reduction in areas such as South-East Asia and East Asia, the same cannot be said of sub-Saharan Africa (Rosegrant et al., 2001; Hussain 2005). Literature (FAO, 2005) shows that sub-Saharan Africa has the least developed irrigable land in the world (5.5% of the potential).

Several reasons have been sought with regard to the low rate of irrigation development in sub-Saharan Africa, and one of the reasons that keep coming up is that large-scale irrigation schemes in sub-Saharan Africa have underperformed resulting in lack of further investment into large-scale irrigation (Chambers 1988; Merrey, 1997). This has generated debates on whether large-scale irrigation is the best way for irrigation development in sub-Saharan Africa (Wallace, 1979; Williams, 1988).

Diemer (1988) argues that the sum total of large-scale irrigation expenditures often put a big question mark behind the economic viability of the schemes. In most cases revenue has neither fully recouped the investment

costs nor the operations and maintenance costs (Faurès et al., 2007). Newly developed large-scale irrigation has in many instances also set the stage for the emergence of new and often blatant, social and economic inequalities, for destructive environmental processes and for administrative and political neglect of rainfed cultivation (Diemer, 1988). Data from FAO (2005) show that the underutilisation of large-scale irrigation schemes in sub-Saharan Africa is about 18%. This means that on the average about 82% of developed hectares in large-scale irrigation schemes are utilised.

Jones (1995) outlined some of the wasteful but expensive irrigation schemes constructed in Nigeria (South Chad Irrigation Scheme, Lower Anambra Irrigation Scheme and Bakalori Irrigation) which didn't meet expectations. They were developed to produce wheat for import substitution; interestingly it costs more to grow wheat on the irrigation projects than to import it.

Wallace (1979) pointed out that some large-scale irrigation projects have taken away more land under irrigation than they may have put in by blocking supply of water for irrigation of river banks downstream. A small number of farmers have benefitted from access to irrigated land and other means of production at a high cost to the state. According to Williams (1988) farmers are mostly the receivers of unfair policies and decisions made by the management of these schemes which impoverish them rather than enrich them. Farmers have to rely on management to plough their fields and to receive water and other inputs, meanwhile staff of the project tend to meet their own needs and those of powerful outsiders with land in the projects first. These have sometimes led to conflicts between farmers and management.

Also concerns have been raised over negative social impacts such as the displacement of residents in affected communities and lack of compensation for the lands confiscated, for example under the Veia scheme in Ghana (Konings, 1986) and the Kano River project in Nigeria (Wallace, 1979). Calls for increased in-stream flows for environmental purposes, have received increased attention and discouraged lenders from investing in more large-scale irrigation (Faurès et al., 2007). Lenders rather invest in improving what already exists (Inocencio et al., 2007). As a result, the annual growth rate of irrigation development, particularly in large-scale public schemes, has decreased since the late 1980s (FAO, 2005; Inocencio et al., 2007).

The fact remains that in sub-Saharan Africa the best option to enhance food security is investment in both rainfed and irrigated agriculture. Faurès et al. (2007) advises that the conditions that led to public investment in irrigation

in the second half of the 20th century have changed radically, and today's circumstances demand substantial shifts in irrigation strategies. The ultimate question then is "should policies still consider investing in large-scale irrigation developments or should it support other types of irrigation development."

Governments will continue to be the biggest investors in irrigation development; however they need to be advised using empirical evidence and comparative analysis. While there are cases of failed irrigation schemes which discourage investment, there may also be cases of successful irrigation development from which positive lessons can be drawn to influence future investments and policies. It is therefore important to contribute to the ongoing debate by assessing the performance of large-scale irrigation schemes across sub-Saharan Africa from which lessons can be drawn to help inform decision making.

This chapter provides an overview of large-scale irrigation development and their impact in sub-Saharan Africa. It subsequently narrows down to assess the performance of two large-scale irrigation schemes in the White Volta sub-basin in Ghana (Vea and Tono) managed by a public institution. The results will contribute to the ongoing debate and may help policy makers to make better informed decisions with respect to investments in order to promote sustainable irrigation development.

4.1.2 Objective

There seems to be an unending debate on which direction irrigation development in Sub-Saharan Africa should take (Wallace, 1979; Williams, 1988; Faurès et al., 2007). Many issues have been raised about the gross inefficiencies and lack of proper management associated with large-scale public irrigation schemes, exemplified by low productivity levels in sub-Saharan Africa. This has led to the emergence of alternative irrigation types such as small-scale irrigation development to improve irrigation productivity.

This chapter seeks to contribute to the debate on the types of irrigation technologies suitable for up-scaling in sub-Saharan Africa by investigating the performance of two large-scale irrigation schemes located in the Upper East Region of Ghana within the White Volta sub-basin. The performance indicators used include crop productivity, water productivity and financial sustainability of the scheme. Also the challenges facing the schemes are investigated with a final analysis on their overall sustainability.

Both schemes are located in a region where small-scale irrigation technologies have rapidly spread over the past two decades. The latter will be analysed in

subsequent chapters. A comparative analysis of large and small scale technologies will help draw meaningful conclusions on the way forward for upscaling irrigation development in sub-Saharan Africa.

4.2 LARGE-SCALE IRRIGATION DEVELOPMENT IN SUB-SAHARAN AFRICA

The semi-arid and savannah regions of sub-Saharan Africa have little choice but to practise irrigated agriculture to support their dependent population. Basically, these consist of the Sahel countries of West Africa, the drier portions of northeast Africa and the broader lands of the Kalahari Desert in Southern Africa. The Sahel is a zone demarcated roughly by the rainfall isohyets of 100mm/a in the north and between 500 and 600mm/a in the south with less than 100days for growing crops under rainfed conditions. In the savannah zone the mean annual rainfall is between 880 and 1200mm/a, with between 120 and 240 days for growing crops (FAO, 1986; Rosegrant and Perez, 1997). The success of irrigated agriculture is seen as a key ingredient for the long-run development of Africa's semi-arid lands. African leaders in these regions saw that further attention to irrigation development was unavoidable (Moris and Thom, 1990).

Irrigation has however, remained limited in most sub-Saharan countries; with a few large commercial schemes developed during and after the colonial period and a relatively modest small-scale irrigation sub-sector (FAO, 2005). Among the colonial large scale irrigation projects are the Office du Niger project of Mali, the Gezira scheme of Sudan, Loumbila scheme of Burkina Faso and Jebel Aulia (Jabal Awliya) scheme of Sudan.

Sub-Saharan Africa has benefitted from the development of large-scale irrigation schemes during the post-colonial era with projects developed by governments and international agencies. These include: the Bakel Project of Senegal, the Bakolori Irrigation Project of Nigeria, the Bura West scheme of Kenya, the Lery scheme of Burkina Faso and Manyuchi II scheme of Zimbabwe.

Semry I and II irrigation schemes in Cameroon are considered as some of the few success stories of large-scale irrigation schemes in sub-Saharan Africa. Semry I and II have had estimated rates of return above 20 percent/a under highly centralized management regimes. Management of water, agronomic decisions, and cost recovery were handled by project management rather than farmers and high financial returns were maintained for the farmers, ensuring their continued participation and support. Brown and Nooter

(1992) name efficient management, relatively low-cost infrastructure, low operating costs, good technical design, and availability of agronomically suitable crops and cropping systems as conditions for success of Semry I and II.

Interestingly, Office du Niger irrigation scheme which was once considered as one of the failures of large irrigation schemes is now praised as a success. When Mali's Office du Niger (ON) irrigation scheme embarked on a reform in the 1980s, all stakeholders agreed on the need for reforms, but no one was certain what the results might be. Now, two decades later, the impact as reported by Aw and Diemer (2005) is extraordinary. Between 1982 and 2002, rice yields have quadrupled, total production has increased sixfold, incomes have increased dramatically while supporting a four-times larger population, agriculture has diversified, cropping intensities have increased and food security has improved. Maintenance of irrigation infrastructure is fully paid by farmers, who have organized themselves to be fully involved in the management of the scheme. A buoyant private sector has emerged, making a sustainable living out of milling, trading and transporting rice; providing farmers with credit; manufacturing farm equipment and selling farm inputs. The ON has become an attractive investment opportunity for investors who want to expand irrigation to enhance and accelerate the important contribution irrigated agriculture is making to the national economy of Mali (Aw and Diemer, 2005).

The Bura system in Kenya, built between 1977 and 1984, is a classic example of a failed large-scale project. At the initial appraisal stage, irrigation was planned for 6,000 hectares, at an estimated cost of US\$98 million. However, additional appraisals identified soil problems, including salinity, high sodium content and low subsoil permeability that resulted in a reduction of the area to be irrigated to 3,900 hectares. At the same time, costs escalated to US\$128 million, which meant that the unit cost increased to US\$32,000 per ha (Lele and Subramanian 1990; Adams 1990; Moris and Thom 1990). Currently about 1,000ha are irrigated and a third of the settler farmers have returned to their rural areas (National Irrigation Board, Kenya, 2007).

Investigations conducted by Inocencio et al., (2007) on the development trend of large irrigation schemes in sub-Saharan Africa revealed that since the 1970s donor agencies have invested more into the rehabilitation of existing large irrigation schemes than the development of new ones. With Africa lagging behind other continents in irrigation development, there is the need to maximise the productivities of existing large scale irrigation schemes and consider the most appropriate options for future irrigation development.

4.2.1 Socio-Economic Impact of Large-Scale Irrigation in sub-Saharan Africa

Large-scale irrigation, if managed efficiently, can generate a stable flow of income through increased intensity of cropping, improved yields and more stable yields across seasons and years, which may also augment employment opportunities, in-migration and real wage rates.

Sub-Saharan Africa has agricultural-based economies with about 80% of the inhabitants depending on agriculture. Agriculture represents about 40% of Gross Domestic Product (GDP) of sub-Saharan African countries. Irrigation not only raises farmer income but also feeds into the economy of the countries concerned. For example, the Office du Niger irrigation scheme has created an agro-based industry which forms the backbone of the Mali economy.

Poverty reduction in many parts of India has been attributed to the availability of irrigation (Ray et al., 1988). According to statistics from the World Bank (2000, 2001) there are huge regional differences in the proportion of cropland that is irrigated and these coincide with successes or failures in poverty reduction. Regions that have the greatest proportion of cultivated irrigated area (namely East Asia and Pacific and North Africa and Middle East) have experienced the greatest poverty reduction. In sub-Saharan Africa less than 5% of cropland is irrigated and the region has remained stricken in poverty. Statistics show that poverty in Sub-Saharan Africa only reduced from 47.7% to 46.3% from 1990 to 1998 with a corresponding increase in irrigated area of a mere 0.5% (World Bank, 2000; 2001).

Large-scale irrigation has also helped to reduce adverse consequences of drought by storing water for both livestock and the surrounding communities. Around the large reservoirs of many such schemes buoyant fishing economies developed, created additional employment for many poor people, as well as additional supplies of valuable proteins.

Large-scale irrigation development, however, has also created negative social impacts. Some inhabitants were resettled during the development of large-reservoir irrigation schemes without adequate compensation. In the resettlement process their livelihoods were severely affected leaving them in worse conditions. An example is the development of the Veia irrigation scheme in Ghana. During the development of this scheme, the inhabitants of the project area who used to farm there were resettled along the periphery of the scheme, but were not compensated for loss of infrastructure, land and

deprivation of livelihoods (Konings, 1986). Records show that in some large irrigation schemes, families residing on the schemes had the lowest food production for home production (Niemeijer et al., 1985; Diemer, 1988).

4.2.2 Environmental Impact of Large-Scale Irrigation in sub-Saharan Africa

The development of large reservoirs and irrigation schemes has come at the environment's expense, degrading ecosystems and reducing water supplies to wetlands. Large-scale irrigation is also associated with higher prevalence of malaria, schistosomiasis and other waterborne diseases (Faurès et al., 2007). The incidence of malaria has increased due to the development of large-reservoirs for irrigation which serve as breeding ground for mosquitoes (Keiser et al., 2005).

The environmental impact of irrigation development arises from the withdrawal, storage and diversion of water from natural aquatic ecosystems and the resultant changes to the natural pattern and timing of hydrological flows (Rosenberg et al., 2000). Rivers have in many instances become disconnected from their floodplains and from downstream estuaries and wetlands resulting, in some instances, in total and irreversible wetland loss (Faurès et al., 2007; MEA, 2005).

Wetland water quality has deteriorated in areas under high-intensity irrigation (MEA, 2005). Nutrient loading primarily from fertilizers (nitrogen and phosphorous) applied to irrigated areas is one of the drivers of ecosystem change, resulting in eutrophication, hypoxia and algal blooms (Faurès et al., 2007).

4.2.3 Challenges facing Large-Scale Irrigation in Africa

It is important to understand the challenges that large-scale irrigation schemes face. These challenges are described as problems that should be considered during the design, development and operation of the large irrigation schemes. The most prevalent sources of failure are design and technical flaws, management failures, and political difficulties. Together, these failures have led to far higher than expected costs and lower than expected benefits (Moris and Thom, 1990).

One of the important reasons given to the low performance of sub-Saharan Africa's formal irrigation schemes is that irrigation projects designed by outsiders frequently assume that people will show the interest and motivation one would expect from farmers, when in reality these conditions

are not found. In many instances, the initial design work was faulty or incomplete, requiring mid-term corrections and rebuilding of schemes, leading to drastic cost inflation (Moris and Thom, 1990). A review of World Bank irrigation investments estimated that development cost averages US\$18,300 per hectare when indirect costs for social infrastructure, including roads, houses, electric grids, and public service facilities, are included (Jones, 1995).

Management problems have contributed to the failure of many large-scale schemes. For example, the Office du Niger irrigation scheme in Mali which started operations in 1934 performed very poorly and produced low returns. This parastatal corporation was financially independent due to revenues from farmers' fees, but utilized only 20 percent of fee revenue on purchases of farm inputs, with the remainder being put back into central operations. By 1983, there was one staff member for every 1.5 farmers (Brown and Nooter, 1992). This pattern of excessive centralization of management has often been repeated in African irrigation schemes. The inability of ministry and agency headquarters to respond in a timely and efficient manner to field-level problems leads to poor performance and returns. Excessive centralization took control from the hands of farmers and perimeter directors without providing a viable substitute (Rosegrant and Perez, 1997).

The following are the challenges affecting large scale irrigation schemes in sub-Saharan Africa as reported in the literature:

- Inherently difficult agroclimatic and agronomic conditions, some of which have not been anticipated during design and implementation stages (Moris and Thom, 1990);
- Lack of appropriate crop varieties and low use of complementary inputs, particularly fertilizer (Reardon et al., 1993);
- Labour scarcity, which leads to high labour costs and labour bottlenecks at peak seasons;
- Insecure land tenure and water rights, which reduces incentives to invest in and maintain irrigation facilities and land quality (Rosegrant and Perez, 1997);
- Problems in coordination of technical and socioeconomic aspects of irrigation and irrigated farming, combined with lack of experience of African farmers and irrigation managers with these management problems, including scheduling and timing of water releases, arrangements for common services such as field preparation or transport, provision of inputs, and crop marketing (Moris and Thom, 1990);

- Poor operation and maintenance of irrigation system (Inocencio et al., 2007);
- Overvalued exchange rates acting as a disincentive to agricultural production (Jones, 1995).

The general expectation is that irrigation development generates sufficient returns to justify investment. The problems experienced in many large scale irrigation schemes in sub-Saharan Africa have raised the question whether large scale irrigation schemes represent an appropriate policy solution in the African context. This question will be answered at the end of the chapter.

The next section of the chapter will make an inventory of large-scale irrigation schemes in the White Volta sub-basin (Burkina Faso and Ghana); with the subsequent section discussing the performance of two large irrigation schemes found in the White Volta sub-basin (Vea and Tono).

4.2.4 Large-Scale Irrigation Development in the White Volta sub-basin

Burkina Faso and Ghana, which have the largest shares in the White Volta sub-basin, have developed large reservoirs for the purposes of irrigation, hydro-power, water supply and livestock. An inventory of the large irrigation schemes developed in both countries is given in the following section.

The White Volta sub-basin of Burkina Faso

The potential irrigable area of Burkina Faso in the White Volta Basin is 142,000ha (FAO, 1997). The development of large-scale irrigation schemes intensified after the 1970 droughts. Water supply for Large-scale irrigation schemes in Burkina Faso are from either large reservoirs or rivers. Some of the large reservoirs are used for hydro-power and irrigation at the same time. Table 4.1 is a compilation of some large-scale irrigation schemes in Burkina Faso located within the White Volta sub-basin.

Table 4.1: Some large-scale irrigation schemes in the White Volta sub-basin of Burkina Faso.

Irrigation Scheme	Year of completion	Purpose	Potential Irrigable Area (ha)	Developed Irrigable Area (ha)
Bagre	1992	Hydro-power and Irrigation	30,000	2,140
Sourou	1985	Irrigation	30,000	2,000
Loumbila	1970	Irrigation and water supply	1000	60
Savili	1978	Irrigation and livestock	700	42
Tensobenenga	1960	Irrigation and water supply	200	100

(source: FAO, 2005; Molden, 1998; Van den Bossche and Bernacsek, 1990)

The White Volta sub-basin of Ghana

The potential irrigable area in the White Volta sub-basin of Ghana is 314,200 ha. The total actual irrigated area in the Volta Basin of Ghana is about 6,500ha (Wiafe, 1997). There are three large reservoir irrigation schemes developed: the Veia irrigation scheme developed in 1975 with an irrigable area of 850ha, the Tono irrigation scheme opened in 1985 with an irrigable area of 2,207ha and the Bontanga irrigation scheme opened in 1986 with an irrigable area of 450ha.

4.3 CASE STUDY ON THE VEA AND TONO IRRIGATION SCHEMES

The Veia irrigation scheme is the only large irrigation scheme within the study area. But the Veia and Tono schemes both in the Upper East Region of Ghana are managed by one public institution (Irrigation Company of Upper Region). They have been operating for more than twenty years. Investigating and analysing the experiences gained may contribute to our understanding of sustainable irrigation development in Africa.

4.3.1 Methodology and Data Collection

The study employed the following: (a) a literature review on the two projects, review of project documents, consultancy reports, operational reports for two years, production figures from 1985-2007 and corporate plans

of the management; (b) interviews with project managers of Vea and Tono, the management of the Irrigation Company of Upper Region (ICOUR), and technical officers. Also two farm leaders each were interviewed from Vea and Tono; in addition five farmers were interviewed from Vea and six farmers from Tono; (c) field observations of irrigation practices were conducted during both the rainy and dry seasons of 2006-2008 at both Vea and Tono. The state of the infrastructure, and other facilities such as rice mills and offices was also observed.

4.3.2 Description of Vea and Tono Irrigation Schemes

Development of the Vea and Tono

The Vea and Tono schemes were developed by the government of Ghana through the assistance of international donor agencies. The two irrigation schemes include large reservoirs constructed on the Nakambe River of the White Volta River. The Vea and Tono irrigation schemes have total command areas of 850ha and 2,490ha respectively (Table 4.2).

Table 4.2: Features of the Vea and Tono Irrigation Schemes.

		Vea	Tono
The Development	Started	1965	1975
	Fully completed	1980	1985
The Areas	Gross Project Area	1197 ha	3860 ha
	Irrigation Area Developed	850 ha	2490 ha
	Average Irrigation Area Cultivated	Dry season – 315ha Wet season – 500ha	Dry season – 1200ha Wet season – 1035ha
The Reservoir	Catchment area	136 km ²	650 km ²
	Max surface area	405 ha	1860 ha
	Maximum storage	17 x 10 ⁶ m ³	93 x 10 ⁶ m ³
	Dead Storage	1 x 10 ⁶ m ³	10 x 10 ⁶ m ³
	Live Storage	16 x 10 ⁶ m ³	83 x 10 ⁶ m ³
	Crest Length	1585 m	3471 m
	Max Depth	16 m	25m
The Canals	Length of main canals	21 km	42 km
	Number of canals	62	91
The Farmers	Registered	2000	4000
	Women	15-20%	10-15%
	Village committees	8	8
Annual Water Use	Irrigation Requirements	7.15 x 10 ⁶ m ³ /a	39.78 x 10 ⁶ m ³ /a
	Urban Water Supply	3.1 x 10 ⁶ m ³ /a	none

The purpose of developing these irrigation schemes by the government of Ghana was:

- ✓ To improve food security by increasing productivity
- ✓ To increase crop yields through improved agronomical practices
- ✓ To reduce poverty in the rural areas, and
- ✓ To reduce rural-urban migration by providing employment opportunities for the youth

The constructions of the Veia and Tono schemes started in 1965 and 1975, and were completed in 1980 and 1985 respectively. According to the FAO (2005) the cost of developing the Tono Irrigation scheme was US\$40,000-50,000/ha, this included the cost of three townships that were built, a club house, a swimming pool, a tarred road network, streetlights and the cost of extending power from the nearest town to the project site.



Figure 4.1: Location of Veia and Tono Irrigation Schemes in the Volta basin.

Prior to the construction of both irrigation schemes, parts of the developed areas (i.e. reservoir and irrigable areas) were occupied by inhabitants who lived as communities. During the construction these inhabitants were resettled outside and along the project area. These inhabitants are currently the main farmers (about 90% of the total) in both schemes. The indigenous farmers are from the village committees around the projects. Both Veia and

Tono have 8 village committees each. Each farmer is allocated a plot of land ranging from 0.2-0.6ha. Other users of the irrigation scheme include contract commercial farmers, farmer groups, private institutions and government institutions. The Vea and Tono schemes have approximately 2000 and 4000 farmers respectively, comprising indigenous small-scale farmers and contract commercial farmers.

The large reservoirs are used not only for irrigation but also to support aquaculture and livestock farming in the area. A number of fishponds have been developed for the local people while they also fish from the main reservoir. Livestock also depend on the freshwater in the reservoir and canals during the dry season. The Vea reservoir is also used for urban water supply and supplies water to the Bolga Municipality which has priority over irrigation water use.

Management of the schemes

Both Vea and Tono irrigation schemes are managed by ICOUR. ICOUR is an autonomous company wholly owned by Government of Ghana, with the Irrigation Development Authority as its representative, and directly financed by the Ministry of Finance. Its organogram is shown in Figure 4.2.

Apart from the management team there are other committees and groups which play vital roles in the management of the scheme. These committees are described as follows.

ICOURE Board Members

- Regional Minister (chairman)
- Representative of Minister of Food and Agriculture (MOFA)
- Representative of Minister of Finance
- Representative of Ghana Irrigation Development Authority (GIDA)
- Representative of Bank (used to be Social Security Bank, but has changed to Agricultural Development Bank)
- Two farmer representatives (1 from Vea and 1 from Tono)
- Managing Director of ICOUR
- Deputy Managing Director of ICOUR (co-opted member)
- Finance Officer of ICOUR (Board Secretary)

Consultative Committee Members (There are separate committees for Vea and Tono)

- District Chief Executives (DCEs) of Kassena Nankana District and Bulsa District for Tono Consultative Committee and DCEs of Bolga and Bongo for Vea Consultative Committee

- Traditional authorities of Kassena Nankana and Bulsa traditional areas for Tono and that of Bolga and Bongo for Vea.
- Two Farmer Representatives from the project
- District Directors of MOFA for Kassena Nankana and Bulsa Districts for Tono and District Directors of MOFA for Bolga and Bongo Districts for Vea

Consultative Committee meetings are held twice a year before the start of each season, thus every May and October. They meet to discuss problems of previous season, look at incoming projects, discuss service charges and also develop policy decisions to be forwarded to the ICOUR board.

Land Allocation Committee: It is headed by the District Chief Executive and meets every 5 years to reassess the land in the project area. Land allocation is done based on the ranking of village performances each season for the 5-year period and the performance of contract farmers. Cropping area is usually increased for the best performing village committees by taking land from non-performing contract framers and as well as non-performing village committees. Interviews showed that this company policy has not been implemented within the past decade.

Village Committees: Each village committee has an executive of 5 members. They meet to elect representatives for committees such as the Consultative Committee and the Board. They also assist agricultural extension officers in allocating land as well as with the collection of water levies every season. Under the village committees there are lateral leaders appointed by farmers along each lateral who collect the water levies of farmers along that lateral. The lateral leaders pay the water levies at the project office and are given receipts which they show to their Village Committees for land allocation. The village committees have the responsibility of ensuring 80% payment by their members before they receive water.

Farmer Based Organisations (FBOs): These are legally registered organizations with the Department of Co-operatives which operate by a constitution and register its members at a fee of US\$15. They are able to establish links with financial institutions, markets and other voluntary organisations.

Currently there are 54 FBOs at Tono but only 15 of them have been certified by the National Department of Co-operatives. The FBOs at Tono are all under the Tono Irrigation Farmers Co-operative Union (TIFCU). The ICOUR management has recently organised farmers along laterals for

smooth payment of water levies, instead of using village committees. In Vea there are currently 52 farmer groups with membership ranging from 15 to 35 in each group; 14 of these groups are registered with the Department of Co-operatives as FBOs.

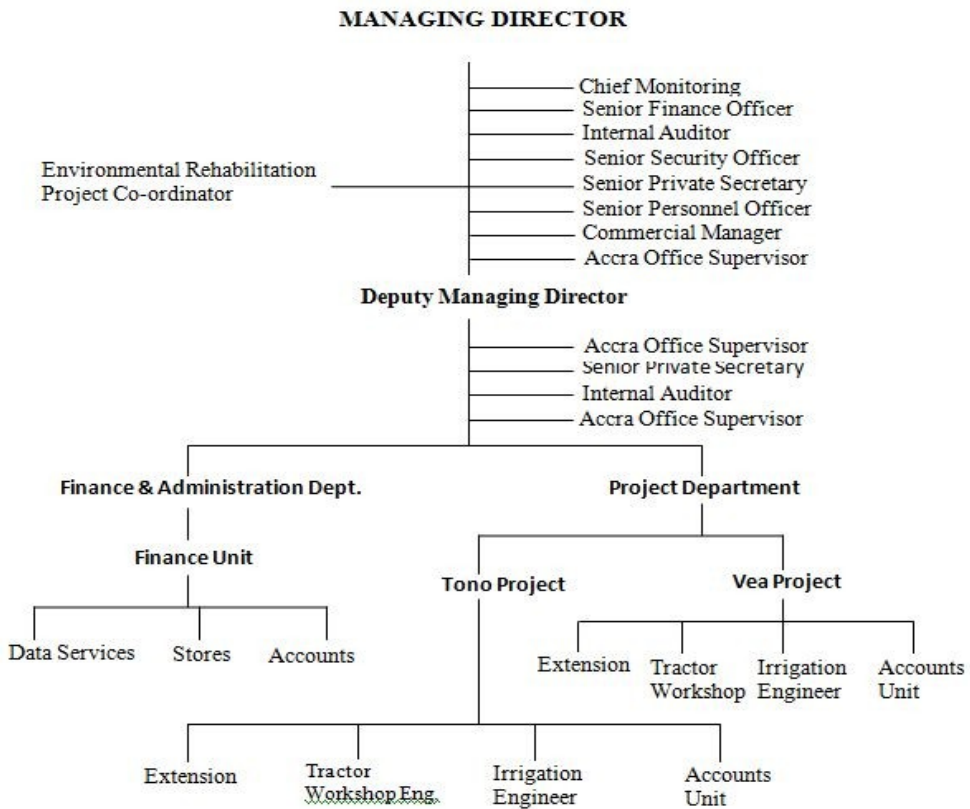


Figure 4.2: Organisational Structure of ICOUR Management.

According to the management, credit is available for farm inputs such as fertilizers, feeds and fingerlings. Farm inputs are made available by ICOUR to rice farmers in the Tono Scheme who must sell their products to ICOUR. This gives ICOUR guarantee for the payment of their services. Farmers who cultivate vegetables buy their own farm inputs and sell their products to markets of their choice.

Irrigation Practices at Vea and Tono Schemes

This section describes the irrigation practices of both Vea and Tono. The description is combined for both schemes because the practices and management are similar.

Bio-physical features

A significant feature of the Vea and Tono irrigation schemes is that the projects have been developed on both sides of the river valley. The cropping areas are divided 50:50 between upland and lowland areas. Uplands are sloping areas of light coarse textured free draining soils and the plots are designed for furrow irrigation. Crops grown in upland plots include tomatoes, onions, millet, pepper, groundnuts, sorghum and maize.

Lowlands are the more level areas of heavier textured soils adjacent to the old river course. These lowlands are used for rice production and irrigation method is by basin flooding.

During the dry season, farmers depend on irrigation to cultivate paddy rice, onions, tomatoes, soybean and pepper. In the wet season the farmers depend on rain water and supplementary irrigation (only in Tono) for their rice, groundnut, millet/sorghum, cowpea and maize.

Water management

Water supply to the irrigation scheme is controlled by management. There are two main seasons, the dry season irrigation (November to April) which has full-scale irrigation and the rainy season (May to October) which has supplementary irrigation.

Crops cultivated in the irrigation schemes include rice (two crops/year), vegetables (tomatoes, onions), soybeans, millet, sorghum, maize, cowpeas and groundnuts. Farmers have to contribute to the costs of services and maintenance by payment of a development levy (wet season) and an irrigation water levy (dry season). The wet season development levy is charged per farm area irrespective of crop type (US\$28/ha), but the dry season irrigation water levy depends on the crop irrigated (Tomato=US\$56/ha, Rice=US\$42/ha and Leafy vegetables=US\$28/ha).

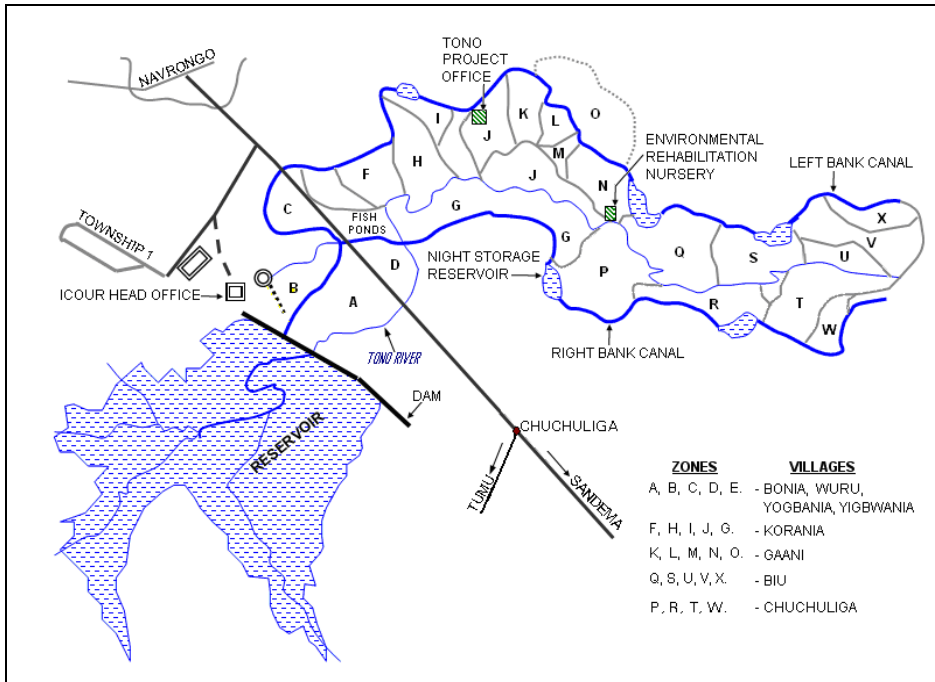


Figure 4.3: Layout of Tono Irrigation Scheme.

Due to ageing components the water control systems are weak. This makes it very difficult to prevent farmers from having access to water when they refuse to pay water levies. On average only 60% of farmers in Vea pay water levies. Meanwhile the project targets 80% payment before releasing water to farmers. Payment is usually regular with upland farmers but very poor with lowland farmers. The reason is that lowland farmers join the upland farmers later in the season and are able to benefit from the water being used by the upland farmers. This makes it difficult to enforce payment since they already have access to water. For example in the 2006/2007 dry season 136ha of land were cultivated in Vea but levies for only 62ha were paid, leaving 55% unpaid.

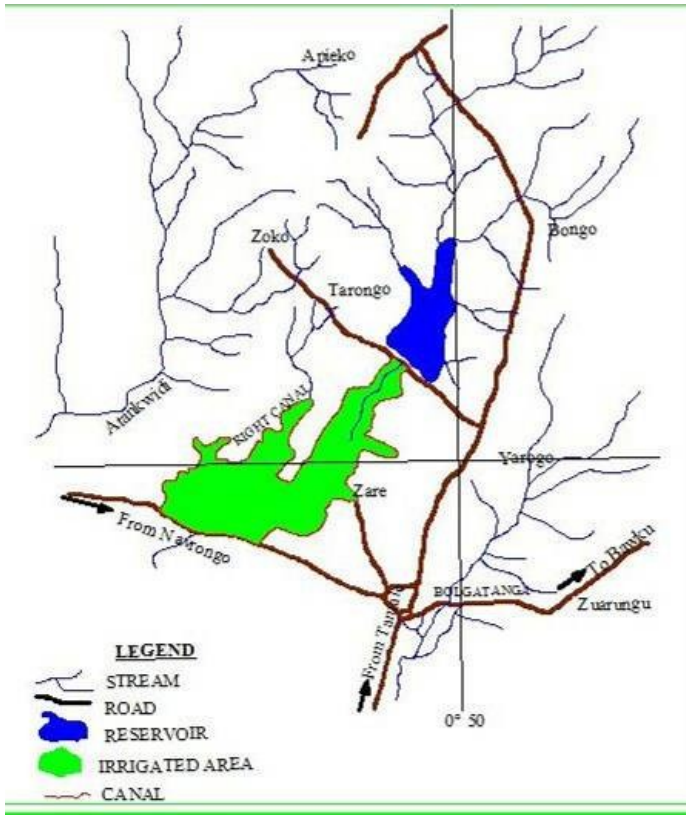


Figure 4.4: Layout of Veia Irrigation Scheme.

The current condition of the canals has compelled farmers in areas cut-off from canal water supply to use motorized pumps to abstract water from other canals directly to their farms (see Figure 4.5a) or into empty canals leading to their farms whichever is appropriate. Also some farmers cultivate in areas which are not designed to receive water from canals. These plots are located close to the stream which acts as the main drain for the irrigation scheme. Farmers therefore pump water from the stream carrying excess water and return flows or from nearby canals to irrigate such farms.

Generally, farmers direct the water from the laterals to their farms by gravity via furrows onto their fields. Farmers growing vegetables irrigate their crops by directing the water through the trenches created in between the beds. A farmer closes the entrances of all trenches with sand before releasing water to the farm. When the full length of a trench is filled with water the irrigator seals the opening of the trench with sand and then

removes the sand sealing the entrance of the next trench. He repeats this cycle until the farm is completely irrigated. After watering the farm the farmer either directs the water to the next farmer or closes the spout on the lateral from where he/she directed the water.



Figure 4.5: a) Pumping water from main canal in Vea b) Main canal transporting water by gravity to the fields in Vea

Rice growers use what is called basin flooding to water their crops. Rice farmers subdivide their plots into smaller units of about 20m² and they transplant the rice into them. What basin flooding means here is that, the plots are completely inundated with water to varying depths of water above the ground level (5 - 10cm).

During the period of research the Tono irrigation scheme was undergoing rehabilitation (which started in March 2008 and was completed by the end of 2010). The rehabilitation entailed reshaping of the main access road and dam wall to control erosion, replacement of concrete lining of the main and lateral canals, construction of washing bays, culverts, water control gates, and clearing of main drains. The rehabilitation is being done at a cost of \$7.9 million and it is sponsored by the Government of Ghana? The government of Ghana is planning to also rehabilitate the Vea scheme.

Irrigation Land Management

The irrigable land in Vea and Tono are divided into three sub-categories. The major part is for local small-scale farmers, another part for contract/commercial farmers and the third part for ICOUR demonstration sites. Land for local farmers are managed with the village committees and that for contract/commercial farmers are handled directly by ICOUR.

The two large reservoir irrigation schemes have problems with land tenure which have played major roles in the management of irrigation in these schemes. Since the first fields were developed for irrigated agriculture at Vea

from 1969 onwards, there has been a continuing struggle over land between the farmers displaced by the dam and the irrigation works and absentee/commercial farmers. There were numerous incidents of open conflict on land until ICOUR took over in 1981 and established the Land Allocation committees for each scheme who set up priorities and rules (see Table 4.3) for land allocation (Tate and Lyle, 1982).

It should be noted that farmers were not consulted nor given the option of dissenting from the rules established. The above mentioned rules for land allocation are being followed in Tono but not in Vea. In Vea the land is formally owned by ICOUR but in practice controlled by the farmers. The current situation takes its roots from land management lapses which took place at the commencement of the irrigation scheme.

Table 4.3: Priorities and Rules for Land Allocation at Vea and Tono.

Priorities for Land Allocation	Rules for Land Allocation
1. Those people who have lost their homesteads and farmland in the construction of the project	Age limit males over 18 years
2. Those who lost only farmlands in the project area	Women not considered except where circumstances make them household heads
3. Organisations or commercial farmers	ICOUR decides the area to be allocated to individual farmer
4. People who reside in areas around the project	Land to be allocated on individual basis but in the case of Vea it will be on household basis due to pressure on land
	Each farmer (tenant) will be required to sign a tenancy agreement with ICOUR

The land allocation committee for Tono has not met for almost a decade as hinted by some committee members. The reason given was that there have not been any serious land issues to resolve. The last land allocation meeting held at Vea could not be determined by the manager who was fresh at post. Other long-serving staff could also not recollect the last meeting held.

The 1932 Land Rights Ordinance vested the management, control and administration of northern lands in the Governor in trust for the people. What is clear is that the Ordinance made it lawful for the Governor to appropriate land for development purposes, subject to payment of compensation for dwellings and economic trees. The provisions were

subsequently reconfirmed by Ghana after independence. It is under these legal terms that the government acquired the land at Tono and Vea schemes from the farmers hitherto cultivating those areas. The latter were paid compensation for their dwellings and economic trees but not for the land itself (Tate and Lyle, 1982). In Tono chiefs and opinion leaders were in agreement to give their land for the project. Also before the project there were only few patches of land under cultivation within the Tono area, unlike in Vea which was experiencing active farming within the project area. The immediate effect of the government acquiring the land at Vea and Tono was to dispossess farmers of a substantial proportion of their farming land.

The initial allocation of Vea irrigation land dispossessed original users of the project land. This resulted in a series of struggles and conflicts over land between the original users and the management of the scheme. After ICOUR took over the management of Vea, land was re-allocated in Vea partially in accordance with the priorities set by the Land Allocation Committee. The land given to the dispossessed farmers was given to compound/family heads who signed tenancy agreements with ICOUR instead of household heads. The family/compound head then shared the allocation to the households within the extended family. This allowed some degree of permanency on the land in Vea since the land given to the family head became hereditary. In addition, farmers in Vea insisted that during the rainy season they would cultivate their lands without supplementary irrigation. This has continued to a stage where the farmers have assumed some permanency on their lands making it difficult for the management to assess and redistribute land in Vea every 5-years as the policy states. As a result, it is these "landlords" who rent out the land for irrigation during the dry season and collect the water levies from their tenants and pay to ICOUR on their behalf. According to the management, there have been several instances of farmers paying the levies to the "landlords" but these "landlords" refusing to pay ICOUR. In Vea local farmers' plots are supposed to range from 0.2-0.6ha, but one farmer (who had taken over his father's land in the scheme) was controlling 10ha. When asked whose name was with ICOUR as the registered farmer he claimed it was his father's name. Because he could not cultivate all the 10hectares, he leased out land to interested farmers during the dry season by charging them some money for the land. He also collected the water levy and paid on behalf of the farmers on his plot.

Due to the land tenure challenges at Vea, contract farmers have been reluctant to farm at Vea irrigation scheme. The water levy collection rate at Vea is low and this has had dire consequences on the efficient management of the scheme. Usually new projects or proposals received by ICOUR are

implemented at both Vea and Tono, but on almost all occasions the Vea scheme has underperformed.

However, the lessons of Vea guided ICOUR management not to repeat the same mistakes at Tono. In practice at Tono, the village committees sign a tenancy agreement with the management over some land holdings for 5 years. Each village committee farmer is allocated a 0.2-0.6ha plot, but contract farmers can have up to 5ha of a plot. Based on their performance at the end of the period the tenancy agreement is reviewed. The extension unit of ICOUR assists the village committees to do the allocation to farmers seasonally. The lateral leaders collect the water levies of farmers along their laterals and pay to ICOUR. After this the extension service conducts a crop survey to confirm farmer names and holdings as submitted by lateral heads.

4.4 DATA ANALYSIS

4.4.1 Productivity of the schemes

Adopting the productivity definition by Molden et al. (2003), irrigation productivity relates to the net socioeconomic and environmental benefits achieved through the use of water for irrigation. One of the reasons necessary for assessing the irrigation productivity is the need to meet rising food demands from a growing, wealthier and increasingly urbanized population in the context of water scarcity. The productivity of both schemes is assessed under two categories being crop productivity and water productivity. Data used for the productivity analysis are recorded figures obtained from the management organisation.

Crop Productivity

The crop productivity of both schemes is analysed based on the cultivated areas against developed areas, crop yield against the potential yield over the years and the trend of production achieved so far. Both schemes have two main seasons of production with the main irrigation occurring in the dry season and supplementary irrigation in the wet season (only in Tono).

Crops so far cultivated in the Vea irrigation scheme in the dry season are rice, tomato, soybean, cowpea, onion and pepper; and in the wet season rice, groundnut, soybean, maize cowpea and sorghum/millet. In the Tono scheme crops grown in the dry season include rice, tomatoes, onions, pepper, soybean, cowpea, paprika and groundnut; and in the wet season rice, soybean, cowpea, groundnut, maize, sorghum, millet and cotton (Table 4.4).

Table 4.4: Cropped areas in the Veia and Tono Irrigation Schemes from 1986-2007.

Crops	Veia Irrigation Scheme Average of cultivated areas (ha)			Tono Irrigation Scheme Average of cultivated areas (ha)		
	Wet Season	Dry Season	Annual Total	Wet Season	Dry Season	Annual Total
Rice	159	153	312	594	768	1,362
Tomatoes	0	179	179	0	349	349
Onion	0	8	8	0	24	24
Soybean	15	4	19	217	40	257
Cowpea	2	3	5	14	4	18
Pepper	0	10	10	0	13	13
Sorghum/millet	211	0	211	76	0	76
Groundnut	115	0	115	134	0	134
Maize	27	0	27	58	0	58
Total	529	357	886	1,093	1,198	2,291
Percentage of Potential	62	42	52	44	48	46

Table 4.4 shows that 62% and 42% of the Veia scheme are cultivated in the wet and dry seasons, respectively; producing an annual average of 52%. In the Tono scheme 44% and 48% are cultivated in the wet and dry season respectively resulting in annual average of 46%.

Figure 4.6 reveals that land use in both schemes is just about 50% of the potential implying that both schemes are underperforming. Factors influencing these percentages include the following: (a) farmers are unwilling to pay for the water levy, (b) the bad state of the canals prevent large portions of the developed area from being irrigated, (c) farmers complain they need financial assistance to purchase fertilizer for their dry season irrigation but are unable to have it, and (d) Increased production of tomatoes in the White Volta sub-basin (both Ghana and Burkina Faso) has raised competition for market thereby resulting in losses for some tomato farmers.

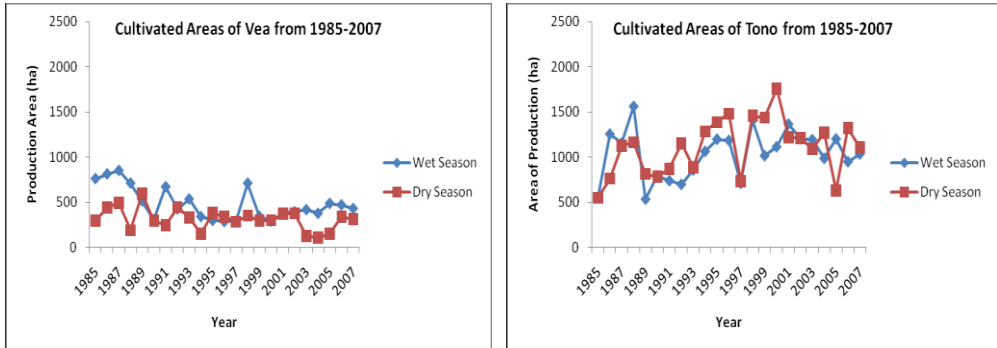


Figure 4.6 a: Cultivated areas of Veve Scheme b) Cultivated areas of Tono Scheme

A further explanation for the underperformance of the Veve scheme could be deduced from the effect of the land-tenure problems. It is observed in the land production figures of Veve in Table 4.4 that more farmers are willing to cultivate in the wet season when no water levy is charged than the dry season which does require payment of the water levy.

In the Tono scheme 50% of the developed land is unutilised and the historical trend shows no sign of improvement. Reasons given by the management are: (a) an area of 490ha has not been irrigated since construction due to technical problems in the design; (b) during full irrigation farmers at the tail end of the scheme cannot get water thus those fields are usually unused; and (c) the canals and laterals were in a bad state for a long time but are now undergoing rehabilitation.

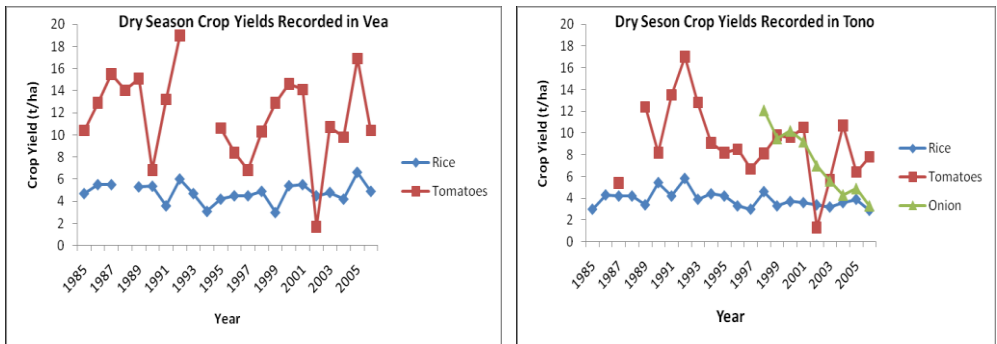


Figure 4.7: Dry season crop yields; a) Veve scheme b) Tono scheme

The average yields obtained for the three major dry season crops (rice, tomatoes and onions) are respectively 4.8t/ha and 11.5t/ha for the Veve scheme and 3.9t/ha, 9.0t/ha and 7.3t/ha for the Tono scheme (Figure 4.7).

The yield of onion has declined from 12.1t/ha in 1999 to 3.3t/ha in 2007 for Tono, while rice yield has been consistent around 4.7t/ha in both schemes. Tomato yields have declined from 15.5t/ha in 1988 to 10t/ha in 2007 in Tono and from 12.4t/ha in 1990 to 7.8t/ha in 2007 at Ve a. This decline may be due to loss of crop soil nutrient at both schemes and inadequate application of fertilizer.

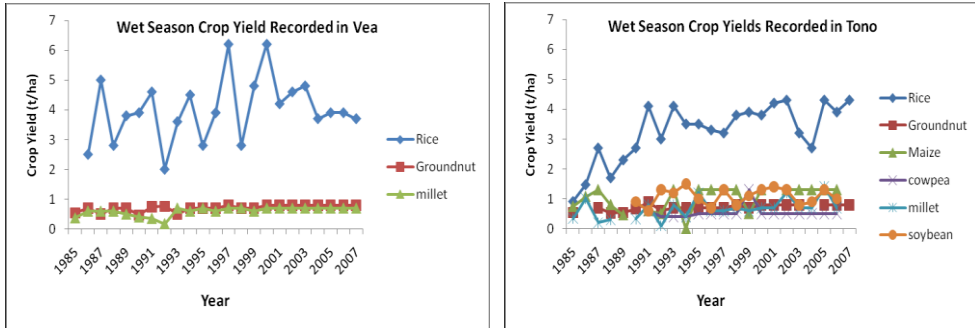


Figure 4.8: Wet season crop yield; a) Vea scheme b) Tono scheme

The wet season yields recorded in the Vea scheme show a constant yield of 0.7t/ha in groundnut and millet and a fluctuating rice yield ranging between 2.5 and 6.2t/ha during the period 1985-2007. Figure 4.8a reveals that there has been no improvement in yield with respect to wet season farming at Vea for a period of two decades. Wet season farming in Tono from 1985-2007 was no different from Vea. Apart from rice which experienced a significant yield increase from 0.91t/ha in 1985 to 4.3t/ha in 2007, all other crops had constant yields; with maize recording 1.3t/ha, groundnut 0.8t/ha, cowpea 0.5t/ha, millet 0.7t/ha and soybean 1.1t/ha (see Figure 4.8b).

Table 4.5: Comparison between recorded crop yields at Vea and Tono irrigation schemes and the potential yields (FAO) for semi-arid and arid regions.

Crop	Average crop yields (t/ha)		Good yields of high-producing varieties adapted for semi-arid and arid regions by FAO (1979) (t/ha)	Percentage of FAO good yield achieved (lower limit) (%)	
	Vea	Tono		Vea	Tono
Wet Season			Good yield		
Rice	4.0	3.3	6-8	75	55
Groundnut	0.71	0.72	3-4	24	24
Maize	1.23	1.01	6-8	21	17
Cowpea	0.48	0.54	2.5 – 3.8	20	22
Soybean	0.85	1.1	2.5-3.5	34	44
Millet/Sorghum	0.6	0.67	3.5-5	18	19
Dry Season					
Rice	4.8	3.9	6-8	80	65
Tomatoes	11.5	9.1	45-65	26	21
Pepper	0.5	0.3	15-20	4	2
Onion	6.1	7.3	35-45	18	21

Source: ICOUR.

Table 4.5 compares the average crops’ yields and their potential yields for both dry and wet season production and shows that rice is the only crop which has performed well in terms of yield. The yields achieved for all other crops are less than 50% of potential.

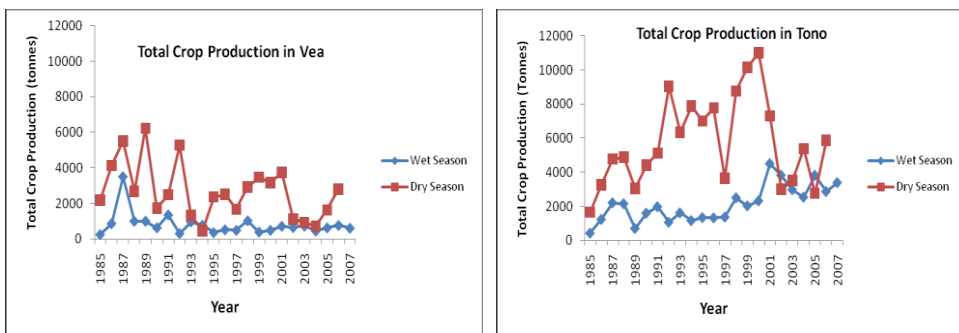


Figure 4.9: Total crop production; a) Vea scheme b) Tono scheme

Figure 4.9 shows that the total crop production at Vea and Tono in the dry season increased from the initial years in 1985 to 1999 but took a downward trend from the year 2000 to 2007. The trend of crop production experienced in both schemes is a product of the land production and crop yields shown in Figures 4.6, 4.7 and 4.8. Figure 4.9 also shows that dry season food production is generally higher than wet season food production contrary to the fact that the cropped areas in the wet season are either higher or almost equal to that of the dry season. This is due to the cultivation of tomatoes in the dry season which has higher yields compared to the cereal crops cultivated in the rainy season.

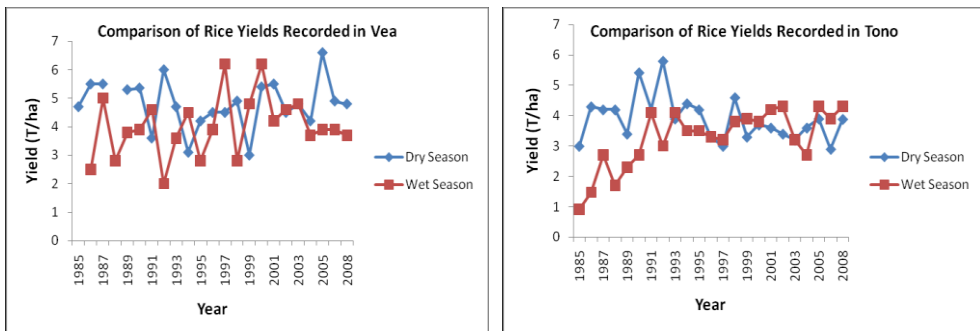


Figure 4.10: Rice yields recorded in both seasons a) Vea scheme; b) Tono scheme

The impact of soil nutrients and water supply on the crop yields can be deduced from the yields between the two seasons using rice production which is a common crop in both seasons. Figure 4.10a shows a lower average rice yield in the wet season of Vea compared to the dry season. The reason can be due to lower fertilizer application in the wet season and/or inadequate water supply due to lack of supplementary irrigation. Figure 4.10b shows almost equal yields for rice from 1997 in both wet and dry seasons, suggesting that the supplementary irrigation at Tono in the wet season influences the yield while fertilizer application may be equal in both seasons.

Water Use Efficiency and Productivity

Both schemes use traditional irrigation technologies, being basin flooding and furrow irrigation which relies on gravity to deliver water to crops. With furrow irrigation, water is diverted from a lateral/canal, or other water transport system, to flow down a furrow between rows of crops. With flood irrigation, water is similarly diverted but in a sheet of water over a slightly graded section of land between widely placed levies.

A measure of the water use efficiency can be defined as the overall irrigation efficiency of the irrigation scheme. The overall irrigation efficiency is the ratio between net irrigation requirement and the water released from the headwork (ICOUR, 2009).

$$\text{Overall Irrigation Efficiency} = \frac{\text{Net Irrigation Requirement}}{\text{Water Released from the headworks}}$$

(Equation 4.1)

Records obtained from ICOUR on water use, irrigated crops and their corresponding areas were used together with crop water requirements to compute the irrigation efficiencies. The net irrigation water requirement was computed using CROPWAT (see Appendix A for CROPWAT input data).

The water released from the headworks is supposedly based on the irrigated area but in actual fact this has not always been the case. This is because the irrigation system has several malfunctioning water control systems which make it impossible to effectively control the release of water for irrigation.

In Veia the irrigation efficiency was based on dry season irrigation. Also in Tono where both dry and wet season irrigation are practiced the irrigation efficiency was based on dry season irrigation. The reason was that, during the rainy season, rainfall is the major source of water.

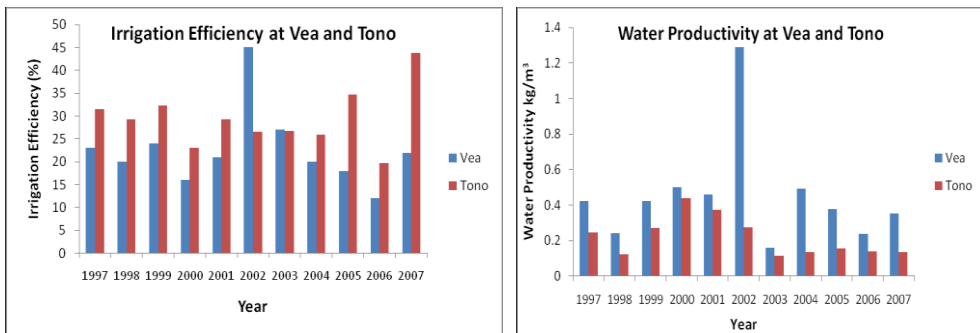


Figure 4.11: a) Irrigation efficiency for dry season irrigation; b) Water productivity for dry season irrigation

Figure 4.11a shows low irrigation efficiencies at both schemes: Veia has an average of 24% irrigation efficiency and Tono 30%. The ongoing rehabilitation of the canals and laterals at Tono is expected to improve its irrigation efficiency significantly.

Agricultural production is achieved through the combination of inputs (land, water, capital, nutrients, energy and labour) to produce agricultural outputs. An analysis of the productivity of a single input factor enables assessment of opportunities for maximizing returns from the use of this factor. Since the provision of water is the main responsibility of the irrigation scheme for agricultural production, the water productivity of the irrigation scheme is worth knowing.

Table 4.6: Range of Global water productivity values for selected crops.

Crop	Rice	Maize	Groundnut	Tomatoes	Onions	Cowpea
Water Productivity (kg/m ³)	0.15-1.6	0.3-2.0	0.1-0.4	5-20	3-10	0.3-0.8

Source: Molden et al., 2007, Renault and Wallender, 2000

Data used for the analysis of the water productivity included records of food production and irrigation water use during the dry season. Water productivity is a partial-factor productivity that measures how the systems convert water into food (Molden et al., 2003). Its generic equation is:

$$\text{Water productivity (kg/m}^3\text{)} = \frac{\text{Output Derived from Water use}}{\text{Gross Water Input}} \quad (\text{Equation 4.2})$$

Figure 4.11b shows that Vea has higher water productivity than Tono which contradicts the irrigation efficiency. The reason is that in Vea the cultivated area of tomatoes is higher than rice and the opposite occurs in Tono. The yield of tomato is higher than that of rice. Meanwhile, rice consumes more water than tomatoes. Therefore the relatively high production of tomatoes in Vea results in higher crop yield at Vea which translates into high productivity as compared to Tono.

The highest irrigation efficiency experienced in 2002 was due to a measure by the management of Vea to reduce the amount of waste water getting to the downstream end of the irrigation field so as to compel the farmers using the wastewater to pay water levies as well even though they were farming outside the project area. This also resulted in high water productivity that year. From this account it implies that, despite the weak structures, the amount of wastage in irrigation can be reduced by management, namely if management allows downstream users outside the scheme to benefit from the return flows. The excess water used by users outside the scheme is included

in the computation of the water productivity since it was released from the reservoir; however the food production of the downstream users outside the scheme is not factored in the computations. This is because the excess water from the Vea scheme is considered as having completed its productive use in Vea. Therefore whatever the excess water is used for including irrigation, downstream of the Vea scheme is not counted as a productivity of the Vea scheme.

Comparing the water productivity of the schemes with attainable levels of water productivity (Table 4.6) shows that productivity levels at both schemes are generally low.

4.4.2 Financial Sustainability of the Irrigation Schemes

Sustainable development was defined in the Brundtland report ‘Our Common Future’ WCED (1987) as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.” For an irrigation scheme to be sustainable the financial sustainability is equally as important as all other factors of sustainability. As put by Savenije and van der Zaag (2000) “only if the financial costs are recovered can an activity remain sustainable.” For an irrigation scheme to be sustainable, it should be able to generate enough funds to cover its operational cost. This section analyses the financial sustainability of Vea and Tono irrigation schemes based on the principles quoted above.

Budget and Revenue of ICOUR

The 2008 corporate plan of ICOUR, shows that irrigation depends heavily on government support. Eighty-one percent of the funds needed to support the annual budget of ICOUR is from the government with 19% being internally generated funds (IGF). This implies that both Vea and Tono irrigation schemes are not self sustaining financially and thus the government continues to subsidise the operations and maintenance costs of the schemes after 35 and 25 years of operation, respectively. The annual budget of both schemes is US\$1,185,000 with the government contributing about US\$965,000 annually. If the government does not provide all the needed funds for the budget, several aspects of the irrigation scheme will suffer leading to further inefficiencies and reduced productivity of the scheme.

The internally generated funds of ICOUR are generated from the following: water levy, land preparation, silos sales, equipment hire, contracts and guest

house. The percentage contributions of the sources of funds are shown in Figure 4.12. The chart shows that ICOUR's largest revenue source is from contracts (hiring of land to contract farmers). The payment of contracts is apparently more reliable than revenue from water levies.

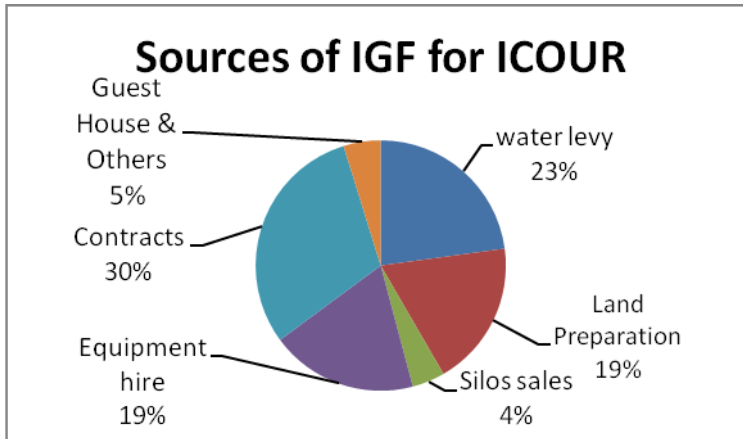


Figure 4.12: Annual contribution from the sources of Internally Generated Funds of ICOUR.

Records obtained for the 2005/06 farming season showed that the management at Tono collected 57% of the target irrigation water levy while it achieved 48% of targeted funds from ICOUR projects. In the 2006/07 farming season, Vea management collected 70% of its target revenue. There was no target for other services, but an insignificant amount of less than US\$100 was collected from mechanical services. This shows that ICOUR achieves low revenue collection rates. The management has blamed the low water levy collection on the poor state of the water distribution and water control infrastructure. Management is optimistic that after successful rehabilitation, which is ongoing, the situation will improve.

In the operational report for both irrigation schemes of 2009, ICOUR stated that it could raise 40% of its projected internally generated funds and that it only received 60% of the funds requested from the Government of Ghana. The inability of ICOUR to achieve its budget estimates implied that several targets could not be met.

Farmer Support Services

Some of the responsibilities of the management are to provide tractor hiring services, technical advisory services, sell farm inputs to project farmers, and assist in the organisation of credit and marketing for small-scale services.

Assessing the delivery of these services by the management is an important measure of the performance and sustainability of the irrigation schemes. Records could only be obtained from Tono irrigation scheme which happens to perform far better than Vea in terms of management and productivity. Most tractors in the Vea scheme are broken down.

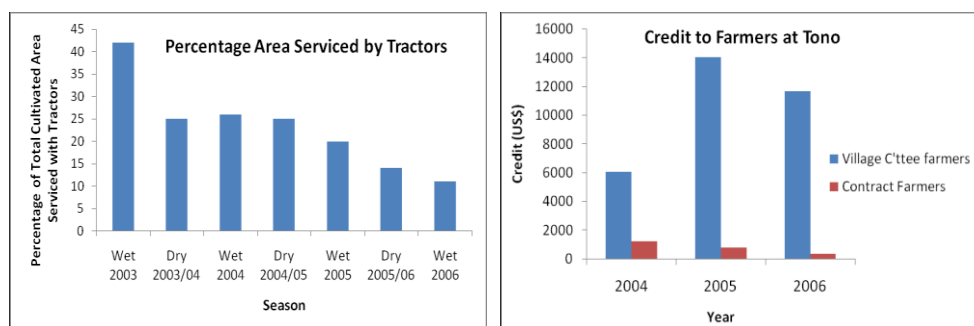


Figure 4.13: a) Tractor support services provided at Tono; Figure b) Credit support services provided at Tono

Figure 4.13a shows that there has been a consistent decline in the percentage area cultivated by tractor services at Tono since 2003. Reasons for this decline are due to lack of tractor maintenance, poor revenue collection and/or inadequate credit facilities to enable farmers to hire tractor services.

Table 4.7: Credits provided for rice farmers in Tono scheme and re-payment records.

Season	Credits (US\$)		Re-payment (%)	
	Village Committee Farmers	Contract Farmers	Village Committee Farmers	Contract Farmers
Dry 2004/05	10,110	746	93	98
Wet 2005	4,623	543	90	95
Dry 2005/06	5,743	432	92	97
Wet 2006	6,508	401	88	98
Dry 2006/07	13,180	354	95	100
Wet 2007	6,664	---	32	---
Dry 2007/08	5,639	---	70	---
Average	7,495	495	80	98

Figure 13b shows that most credit is provided to village committee farmers and a consistent decline in credit provided to contract farmers. However,

credit was distributed to some 2000 village committee rice farmers in Tono. In 2005 each farmer received an average of US\$7.0 credit which happens to be the highest on record. This amount is woefully inadequate for meaningful irrigation production. A check conducted on the re-payment rate by beneficiaries of credit showed an average of 80% for village committee farmers and 98% for contract farmers (Table 4.7). According to ICOUR the 2007 wet and 2007/08 dry season recovery rates were adversely affected by the 2007 floods that occurred in the region. These high re-payment rates are encouraging and thus should ensure the continuation of loan credits; however they cannot explain the declining credit for contract farmers.

Maintenance of facilities

The irrigation scheme comprises a lot of facilities being embankments, canals, laterals, control gates, roads, buildings, machinery and plant which all need routine maintenance to keep them in good condition for continuous and efficient operation. Some other maintenance activities include the protection of the lakeshore from erosion by means of tree planting, promotion of weed growth on the downstream face of the dam as an erosion check and shrub cutting on the upstream and downstream face of the reservoir.

Maintenance records obtained from ICOUR showed that routine maintenance is planned for but the execution is below expectation. Consistent lack of maintenance of facilities has resulted in the poor state of facilities after 25 and 35 years, respectively, of operation of the irrigation schemes. Observations at both irrigation schemes show broken canal sections and laterals, faulty control gates, broken machines, uncultivable areas due to broken laterals, silted canals, poor roads and few working farm equipment.

4.5 DISCUSSION OF RESULTS

4.5.1 Challenges

Discussions held with ICOUR management as well as the results obtained from the analysis above reveal certain challenges facing ICOUR.

According to the management, ICOUR does not have a free hand to operate as a private entity thus cannot generate commercial funds. The farmers were pre-determined (i.e. the local farmers who were dispossessed and allocated land in the project) according to the original objectives of the scheme. ICOUR's mandate is to manage the irrigation scheme for the benefit of the surrounding local farming communities and interested commercial farmers.

Staff are paid by the government and the government remains the major financier of both schemes. The schemes are currently not financially self-sustaining.

Also, initially when the irrigation schemes were commissioned, there were no water levies charged to the beneficiary farmers until after some years. Since the introduction of the levies, not all farmers have embraced the decision, especially the first generation irrigators who still find it difficult to pay water levies.

The issue on land management is a major challenge affecting the sustainability of the Vea scheme. The control over land in Vea by farmers coupled with the poor state of water control structures is affecting the management's ability to collect water levies. Thus the management is unable to meet the budget which is intended for operations and maintenance. The ICOUR management does not seem to have a clear strategy to resolve the controversy over the control of land in Vea.

Both schemes have experienced fluctuations in number of farmer cultivating over the years. This has affected overall production levels. Reasons for the fluctuations include the effect of pest and diseases which affect tomato cultivation and results in low productivity and the inability of the scheme to secure markets for some of their products, such as tomatoes and rice. When farmers lose on income it affects their participation the following year. ICOUR has been unable to find solutions for the challenges from diseases affecting tomatoes, nor securing reliable markets for tomatoes. ICOUR has been able to develop rice mills at Tono and with the assistance of an NGO, also at Vea. This gives ICOUR the ability to provide farm inputs for rice farmers who sell their rice to ICOUR for smooth repayment of financial assistance.

Both schemes are unable to achieve good yield for crops other than rice. This has affected the overall productivity (crop and water) of these schemes. Thus ICOUR has not been able to meet the expected target of production throughout its history. In addition to the above listed challenges there are several other factors which have affected the overall productivity of both schemes and these include:

- ❖ Lack of market for some of the produce and market information for farmers;
- ❖ Increase in the cost of farm inputs;
- ❖ Elimination of agricultural subsidies under the PAMSCAD program in the early 1990s;

- ❖ Lack of adequate credit facilities for farmers;
- ❖ The inability of farmers to play a leading role in the scheme management;
- ❖ Unwillingness of farmers to cultivate on the same plot due to the loss of soil nutrients as a result of continuous cultivation. Farmers allow land to fallow to regain fertility.

4.5.2 Lessons from Veia and Tono Irrigation Schemes for Future Irrigation Development

The analyses conducted on both schemes so far have revealed that both irrigation schemes are under-performing in terms of productivity, with the Tono scheme being better than Veia. Both schemes are financially unsustainable and need pragmatic interventions to be salvaged. The huge investment into both schemes has not yielded the expected productivity for the economic benefit of the country. What is the implication for future irrigation development in Ghana and sub-Saharan Africa in general?

The challenges affecting the Veia Irrigation Scheme began with unresolved social impacts during construction which eventually incapacitated the management in instituting effective and agreeable land-tenure arrangements with affected local farmers. Tracing back the source of these problems, it can be deduced that consultations and negotiations that took place between the developers of the irrigation schemes and would-be-affected persons was not enough or agreements were breached by the developing party. The interests of the affected local people who would become eventual beneficiaries of the irrigation schemes were ignored, and this has resulted in them having managed to control the Veia scheme. The lesson here is that future irrigation developments have to ensure effective stakeholder participation and respect of all negotiated agreements.

Another lesson is the low land, crop and water productivity of both schemes. Only about 50% of developed irrigable lands is cultivated, and with the exception of rice other crops obtain low yields. The low productivities can be linked to (a) faulty irrigation system design (especially in Tono); (b) broken irrigation canals which have made some lands non-irrigable; (c) lack of farmer motivation due to lack of credit and unreliable market for perishable commodities; (d) unresolved land-tenure issues; (e) poor crop yield and (f) ineffective institutional arrangements and functions.

About 500ha of Tono irrigation scheme (i.e. 20% of total) have not been irrigated since commencement of the irrigation scheme due to faulty design. The lack of routine maintenance of infrastructure has also resulted in

reducing the total productive land of both schemes. Reasons for poor maintenance of infrastructure have been linked to lack of finance. This is because initially beneficiary farmers did not pay for services rendered to them until after some time when government could not sustain the huge financial burden of operation and maintenance. Initial decisions not to charge for services resulted in lack of routine maintenance of infrastructure since government support could only pay for salaries of staff and little for maintenance works. The situation has aggravated beyond the capabilities of the management and requires significant support to revamp both irrigation schemes.

The lack of credit and reliable markets for farmers is a serious disincentive to every farmer who wants to improve production. Taking the prevailing financial state of the beneficiary farmers into consideration, the irrigation schemes can only benefit from the maximum potential of the farmers if farmers are resourced with credits or farm inputs at affordable cost and also assured of reliable markets for their products at good marginal values. Only then can farmers expand production and invest in their irrigation activities. These conditions have been achieved for rice farmers but not for vegetable farmers. Employing similar strategies applied to the rice production to vegetable farming will improve overall productivity for both schemes.

Finally, the institutional lapses shown by the management of the Vea and Tono schemes in addressing land-tenure issues, collecting water levies, water management, project revenue, and farmer participation, all have contributed to the poor performance of both schemes. Even though there are plans to improve farmer participation in management, this may not be enough to resolve all the institutional challenges affecting the schemes. The current trend of irrigation management reforms which has yielded some positive results for some irrigation schemes may be considered in addressing the institutional challenges confronting both schemes (Aw and Diemer, 2005; Johnson, 1997).

In summary it has been proven from the case study on Vea and Tono irrigation schemes that developing a large-scale public irrigation scheme demands that detailed studies and stakeholder participation be conducted to forestall possible negative consequences. Secondly, developing an irrigation scheme is not as easy as achieving the desired productivity and maintaining sustainability. As described by Plusquellec (2002) the performance of irrigation projects is determined by a combination of physical, institutional and policy factors. The success of the irrigation scheme is as strong as the weakest success factor. Thus attention must be given to strengthening weak

factors and maintaining equilibrium of success factors to ensure productivity and sustainability (Awulachew et al., 2005).

The inability of large-scale public irrigation schemes to strengthen and maintain the enabling factors for productivity and sustainability may be the reason why farmers individually or in small-groups have resolved to develop small-scale irrigation systems which allows them to effectively control resources such as land and water and also to cultivate manageable farm plots. It is not surprising that despite the unused irrigable lands in both schemes, farmers within the region who could benefit from these unused irrigable lands in the large-scale irrigation schemes have decided to develop their own small-scale irrigation technologies which have been spreading rapidly during the past two decades.

4.6 CONCLUSIONS

Irrigation will continue to remain an important ingredient in solving the numerous challenges affecting food production and socio-economic improvement of sub-Saharan Africa. Large-scale irrigation schemes cannot be left out of the palette of technologies that can be employed in promoting irrigation development in sub-Saharan Africa. Having analysed two large-scale irrigation schemes in the White Volta sub-basin, it is evident that the productivity and sustainability leave much to be desired.

Since governments have invested so much into such schemes, it is important that they perform beneficially rather than allowing them to be a financial drain on the weak economies they are located in; 80% of their annual budget is still funded by government. Less than half of the developed lands are cultivated, with the management unable to collect about 40% of water levies from farmers annually. The irrigation efficiency is very low (about 30%) showing inefficient use of water.

The problems of the schemes (a) originate from unresolved social impacts of the irrigation development leading to long-standing land-tenure issues; (b) ineffective institutions; (c) lack of credit and reliable market for farmers; and (d) lapses in irrigation system design.

Small-scale non-government led irrigation development which gives farmers control over resources and decisions do not suffer from these problems. This explains why such innovations have rapidly spread in Northern Ghana during the last two decades. This is the subject of the next chapters.

Chapter 5

DESCRIPTION OF IRRIGATION TECHNOLOGIES IN THE WHITE VOLTA SUB-BASIN

5.1 INTRODUCTION

The conditions that led to large public investment in irrigation in the second half of the 20th century have changed radically, and today's circumstances demand substantial shifts in irrigation strategies (Faurès et al., 2007). The advent of affordable drilling and pumping technologies in India and Pakistan in the mid-1980s led to rapid development of shallow tubewells and conjunctive use of surface water and groundwater (Shah, 1993; Palmer and Mandall, 1987). Similarly the 1990s saw a substantial rise in private irrigated peri-urban agriculture in sub-Saharan Africa in response to higher demand from growing cities for fresh fruits and vegetables (FAO, 2005).

In recent times the prospects of vegetable production has triggered the initiation and upscaling of several irrigation technologies in the White Volta sub-basin. Meanwhile, available literature on irrigation activities in the White Volta sub-basin and the Volta in general fails to provide a detailed description of these various irrigation technologies that can form a basis for a comparative analysis (see also Namara et al., 2010). Such analysis would be useful to inform agricultural and water policies. This chapter seeks to address the following questions which put together give a comprehensive description and history on each irrigation technology: Which irrigation technologies are practised in the White Volta sub-basin? What is the history of these irrigation technologies or how did they emerge? How have these irrigation technologies expanded over time through policies, technology and socio-economic development? Furthermore, it is important to know what makes up these irrigation technologies in terms of water abstraction, transportation and application; the management system employed and the biophysical features associated with these irrigation technologies and how they are affected by land ownership. Also the participation of female farmers will be highlighted.

Information used to describe these irrigation technologies have been gathered from extensive field survey conducted in the sub-basin with about 200 irrigation farmers selected across the study area and from different irrigation technologies for two consecutive irrigation seasons (2006/2007 and 2007/2008 irrigation seasons) and also from field observations, interviews and

interactions held with farmers, farmer groups, NGOs, researchers, Ministry of Agriculture, Traditional Authorities and markets associated with irrigation inputs and products.

5.2 STRUCTURE OF CHAPTER

This chapter first defines the terms “irrigation scheme” and “irrigation technology” followed by a description of the prevailing irrigation technologies in the study area. The description of irrigation technologies includes the following: historical background and development trend, infrastructure and technology, biophysical characteristics and management.

5.3 DEFINITION OF IRRIGATION SCHEMES AND TECHNOLOGIES

The concept of “irrigation scheme” conveys the idea of large-scale and comprehensive development, as these used to be developed by colonial and post-colonial governments; the latter mostly assisted by international development banks such as the World Bank and IFAD, and managed by government agencies (Kay, 2001). Examples of irrigation schemes were discussed in the previous chapter, such as the Vea and Tono Irrigation Schemes of the Upper East Region of Ghana and the Office du Niger irrigation scheme of Mali.

In the 1980s attention turned to the informal sector, and to small-scale or smallholder irrigation, which is described as the ‘bottom-up’ or ‘grass-roots’ approach to development, where in most cases farmers were responsible for (part of) the investments themselves. Experience in sub-Saharan Africa has shown that successful smallholders generally use simple technologies and have secure water supplies over which they have full control. This is irrigation practised by individual farmers or smallholders, usually farming on a small scale (a few hectares) under their own responsibility; usually at low-cost with little or no government support and using technologies they understand and can manage easily themselves (Kay, 2001).

What is currently happening in the White Volta sub-basin is exactly the type of irrigation development which is not centrally planned and developed. It is initiated by local people who combine land, water and technology in original ways to irrigate. This development can best be described by considering the various irrigation technologies that are emerging.

Technology can significantly reduce the drudgery of lifting and applying water and can help solve water management problems faced by small-scale

farmers enabling them to apply the right amount of water to their crops at the right place at the right time. The technology must be appropriate for the situation if irrigation is to have a chance of success (Kay, 2001).

Generally, an irrigation technology supplies water at rates and at times needed to meet crop irrigation requirements and schedules. An irrigation technology diverts water from a source, conveys it to cropped areas of the farm and distributes it over the area being irrigated (James, 1993). There are different irrigation water sources (surface reservoirs, groundwater, overhead tanks, streams/rivers) with several ways of diverting (gravity, motorized pump, manual pump or rope and bucket), conveying (water hose, bucket or gravity through open channels or pipelines) and applying water (sprinkler, trickle, basin flooding, furrow, bucket or water hose) on the farms. It is the specific combination of these that account for the different irrigation systems or technologies.

In this study irrigation technologies are differentiated by the source of water (reservoir, well or tank), water abstraction mechanism (by mechanised pump, manual pump, bucket and rope or gravity using valve) and the method of water application (gravity fed by furrow, bucket, sprinkler and drip) on the field. The sources of water identified for irrigation in the White Volta sub-basin are used to denote the different irrigation technologies described in this study.

These irrigation technologies are: small reservoirs, dugouts, permanent shallow wells riverine water, temporal shallow wells and riverine alluvial dugouts. A description of the characteristics of these irrigation technologies covers their historical background, development trend, infrastructure, water abstraction, transportation and application methods, bio-physical features and the management practices employed by the users.

The order of the technologies is based on the inception of these technologies in the study area. The first of these is the small reservoirs, followed by the dugouts, permanent shallow wells, riverine pump, temporal shallow wells and riverine alluvial dugouts.

5.3.1 Small Reservoir Irrigation Technology

Historical Background and Development Trend

According to the International Commission on Large Dams (ICOLD), small reservoirs are impoundments with dam walls up to 15m in height or storage capacities of less than 3 million m³ of water (ICID, 2000). Small reservoirs

are an important tool to bridge gaps in surface water availability at village level in semi-arid rural areas around the world. In West Africa, thousands of such reservoirs can be found. Small reservoirs are a widely common infrastructure in the White Volta sub-basin for the provision of water mainly for irrigation (<100ha), for livestock watering, fishing/aquaculture, construction and domestic use (van de Giesen, 2006).

Dam development in Burkina Faso began in 1920. With the severe drought years in the seventies, development of reservoirs increased. Most irrigation development in Burkina Faso takes the form of village-level schemes with imperfect hydraulic control. In 1991, 1,100 village dams (small reservoirs) had been built, mainly for cattle and drinking water purposes (Sally, 1997). Presently, many dams are built or converted to function also as dams for irrigation purposes. By the year 2000 Burkina Faso had between 1,000 and 2,000 dams (ICOLD members-Burkina Faso, 2001).

In the Ghana part of the White Volta sub-basin, the government started the construction of small reservoirs in 1951. These reservoirs were mainly used for the supply of water for livestock, domestic and irrigation purposes. Apart from the government a few NGOs are also developing small reservoirs as poverty reduction strategies for communities in Northern Ghana. Currently there are 156 small reservoirs in the Upper East Region of Ghana (IFAD, 2005).

In the 1960s and 1970s various development cooperation organisations were involved in funding projects whereby dams were constructed in order to help rural communities in supplying sufficient water to meet their demand. However, not all systems remained functional, which engineers often based on a lack of experience or interest of farmers to maintain the irrigation infrastructure.

During the 1980s, however, it was realised that the problems with small reservoir irrigation schemes were not due to incompetent farmers per se, but were caused by the fact that the knowledge of the farmers had not been used and that local economic, social and cultural contexts had not been taken into account in designing the systems. As a result, organisations such as the World Bank, FAO and IWMI from the 1990s started to invest in rehabilitation of the existing systems and in improving the planning, operation and maintenance of the systems. A typical example is the rehabilitation of 64 small reservoirs by the International Fund for Agricultural Development (IFAD) under the Upper East Land Conservation and Rehabilitation Project Phase I (LACOSREP) in the Upper East Region

of Ghana from 1990 to 1997 and another 36 under the Phase II of the same project (IFAD, 1990, 2005).

A study conducted by Birner et al. (2005) found that, out of 16 communities in the Upper East Region that had small reservoirs either constructed or rehabilitated in recent years, only 7 communities cultivated the full area designed for irrigated agriculture, 4 cultivated part of the area, and 5 did not irrigate any land at all. The reason for this low performance was lack of water which was associated with poor dam construction, lack of maintenance, or due to wrong hydrological and climatic estimations.

The construction of a single small reservoir without irrigation development in the late 1990's cost approximately US\$130,000 (Birner et al., 2005). Between 2004 and 2007 newly constructed small reservoirs with irrigation development by an NGO in the Upper West Region of Ghana cost between \$422,000/10ha² irrigable area and \$500,000/20ha irrigable area (source: personal communication).

Infrastructure and irrigation technology (water abstraction, transportation and application)

An assessment conducted in the Upper East Region of Ghana in 1995 by GIDA showed that the impoundments of small reservoirs in general are fed with water from catchment areas ranging from 10–544ha; have storage volumes ranging from 0.15x10⁶m³ to 0.47x10⁶m³, full scale storage area of 3.5–28ha, a maximum depth of 2.0–6.5m, embankment length of 100–1,000m and an earth/concrete channel spillway connected to one end of the embankment (Figure 5.1). The inner face of the embankment is typically covered with boulders and in some cases with wire mesh to prevent crocodiles from boring into the embankment. Restricted areas are created in the catchment area by planting trees which are used to prevent farming activities and thereby reduce the rate of siltation into the reservoir.

Generally, small reservoir irrigation schemes have developed irrigable fields downstream of the impoundment, furnished with water abstracting and transporting facilities (see Figure 5.1). Water abstraction from the reservoir to the developed irrigation field is by means of a water outlet point located close to the lowest point in the impoundment comprising a tunnel fitted with a sieve at the end and connected to a distribution point (furnished with

² The units are not in per ha because of the scale factor in costing small reservoirs. The cost of 20ha small reservoir cannot be automatically divided into two to represent the cost of a 10ha small reservoir.

control valves) located behind the embankment. Water from the distribution point is transported to the irrigation fields by gravity via open canals, tunnels or pipes.

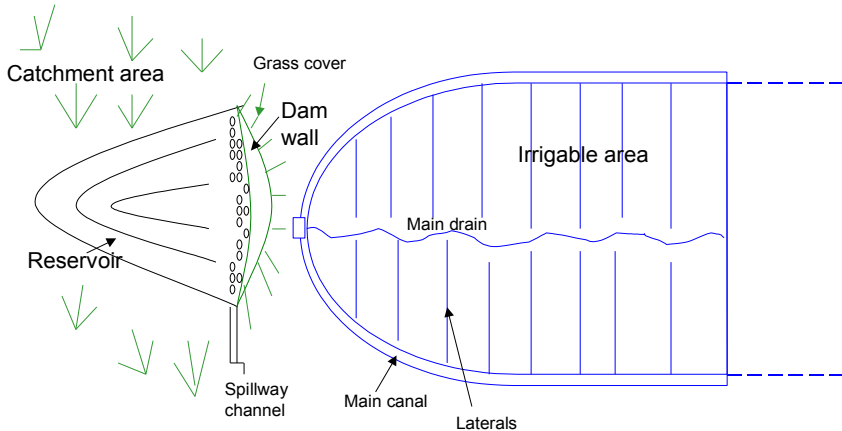


Figure 5.1: Schematic presentation of a small reservoir system (Source: Gyasi, 2005).

In the Upper East Region, almost all small reservoir irrigation schemes observed had irrigation fields developed downstream of the impoundment. However, at some of these reservoirs (e.g. Dorongo dam) two main methods of water abstraction and transportation were being employed. Apart from the normal water abstraction method by means of intake structures in the impoundment and transportation by gravity via canals to the officially developed irrigable areas, some irrigators also abstract water directly from the reservoir by means of motorised pumps and transport the water with hoses to their farm plots located outside the officially developed irrigable area (see Figure 5.2a). At Dorongo dam these farm plots are larger (0.5-1.0ha) than farm plots in the developed portions (0.05-0.45ha). Irrigators using this method explained that the plots in the developed portions were too small for them. Meanwhile the majority of these farmers cultivated in the developed portions of the small reservoir and at the same time used motorized pumps to irrigate outside the developed areas. Therefore the total irrigated area was 1.5 times the developed irrigable area. The farmers did not experience any problem with water scarcity; there is the potential that irrigation will be expanded due to the fact that water is available in the reservoir at the end of the season.

In Burkina Faso a number of small reservoir irrigation schemes had no developed irrigation fields downstream of the reservoir as described for Ghana. This means that there are no water outlets from the canals for water

abstraction. In such cases the farmers cultivated around the upstream sections of the reservoir. They employed various means of water abstraction and transportation to irrigate their crops. The water abstraction and transportation methods identified were by means of motorised pumps connected with water hoses and by means of rope and bucket. Some also developed shallow wells along the periphery of the small reservoirs as the waters receded and used rope and buckets to abstract and carry the water to their plots. Government officials confirmed that there were plans to develop the downstream ends of the small reservoirs for irrigation.

The traditional furrow irrigation which relies on gravity to deliver water to crops is the main irrigation technology applied except for the irrigators using rope and bucket. With furrow irrigation, water is diverted from a canal, or other water transport system, to flow by gravity down a furrow between rows of crops (see Figure 5.2b). This method requires a substantial volume of water over a short period of time. Farmers irrigate their crops by directing the water through the furrows in between the crops. An irrigator closes the inlets to all furrows with sand before releasing water to the plot. The inlets to the furrow are opened for water to enter by gravity. When the full length of a trench is filled with water the irrigator seals the opening of the furrow with sand and then moves to the next furrow and repeats the same action. This cycle is repeated until the farm is completely watered. After watering the farm the irrigator either directs the water to the next farmer or closes the spout on the lateral from where he/she directed the water.



Figure 5.2: a) pumps used in abstracting water from small reservoirs b) furrows used in irrigating fields of small reservoir irrigation schemes.

Bio-physical features

According to a study of 28 small reservoirs conducted by MOFA/LACOSREP in 2003, an average of 170 persons practised gardening on land irrigated by one small reservoir. The average size of land irrigated by a small dam was 8.5 ha, which results in an average cultivated area per gardener of only 0.05ha, for producing vegetables, mainly onions, tomatoes, pepper and leafy vegetables (Birner et al., 2005). Where motorized pumps are used for water abstraction, plot sizes are much larger, ranging from 0.1ha to 1ha.

Due to the absence of fresh vegetation during the dry season, livestock owners release their animals to search for food. This is a major source of worry for dry season irrigation farmers because the livestock are attracted to their crops. Most farmers have suffered heavily from the destruction of crops by livestock. Farmers have employed various means of protecting their crops from livestock. Small reservoir farmers come together to fence their farms with local material. Some small reservoirs had their irrigable areas fenced by NGO's while others had the construction of the fence incorporated in the total development of the small reservoir.

Management

A small reservoir irrigation scheme belongs to a community and thus is managed by that community. The management system of small reservoir irrigation schemes employed within the sub-basin is communal with the farmers being the managers of the system. A Water User Association (WUA) is usually formed during the development of the small reservoir irrigation scheme by the development agency and is trained to carry out the management activities of the irrigation scheme. The water user association elects executives to carry out management decisions. The management practices being carried out by executives of a WUA on small reservoir irrigation schemes typically include:

- Organise, register and share plots for farmers who express interest in using the small reservoir;
- Decide on water levies and collect water levies for the maintenance of canals and other infrastructure;
- Manage the use of water by controlling the release of water to the farm plots;
- Organise farmers for communal activities within the irrigation system;

- Liaise between the farmers and the Agricultural Extension Officers/MOFA and GIDA on issues concerning irrigation;
- Resolve conflicts among farmers and also conflicts between farmers and outsiders on issues regarding irrigation;
- Organise farm inputs for farmers and market for their products; and
- Implement the constitution of the organisation.

The level of organisation and implementation of the constitution of the water user associations differs for each small reservoir. Many small reservoirs have government employed Agricultural Extension Officers assigned to them.

More than 30% of the farmers involved in small reservoir irrigation are female.

Land Related Issues

Both literature (Birner et al., 2005) and field interviews conducted show that in the Upper East Region of Ghana, during the rehabilitation and construction of small reservoirs under the Upper East Land Conservation and Rehabilitation Project (LACOSREP), MOFA pursued the following approach to resolve land issues. The landowners with land in the future irrigable area sign an agreement to hand their land rights for the dry season over to the WUA. The WUA is then supposed to distribute the land amongst its members. While the WUA does not collect direct land use fees, it does collect fees for the use of irrigation water, often linked to the size of plot a gardener cultivates. At the end of the dry season, the original landowners take over again to proceed with rainfed agriculture. The agreement is signed not only by the landowners but also by traditional authorities, assembly members and persons that are referred to by government agencies as “local opinion leaders.” No compensation is paid to the original landowners.

Landowners upstream of the reservoir and in the location of the reservoir who lose their land contact the *tendana*, who finds land for them to develop and farm. In case their property such as building is destroyed, the community organizes labour to help the landowner construct a new house on a new land allocated to him by the *tendana*.

This institutional set-up has not been implemented for all small reservoirs. In some cases the original landowners still hold on to bigger portions of the land in the dry season implying that the land does not belong to the community. In others the land is distributed by the landowners and they receive some kind of fee (cash or kind) from the gardeners. In a small

number of dams the land was permanently handed over to the WUA, and WUA members farm it in the dry as well as wet season.

5.3.2 Dugout Irrigation Technology

Historical Background and Development

Dugouts are fundamentally excavations positioned within the flood plains of rivers and streams (Ofori et. al., 2006). Dugouts are usually positioned in depressions close to streams or rivers and may not necessarily have spillways nor are their banks constructed with boulders. Dugouts are constructed by scooping the sand in the flood plain/depression using bulldozers and excavators to create the embankments. The embankments of dugouts are not engineered or designed like the embankments of small reservoirs. Dugouts are constructed to receive surface water runoff through diversion channels from the streams during the rainy season and store the water for livestock farming, aquaculture, irrigation and domestic water use during the dry season.

The main distinguishing feature between dugouts and small reservoirs is that while small reservoirs are constructed in the stream channel, dugouts are constructed in the flood plains of the stream and are fed by surface water in the flood plains. A second distinguishing feature is that dugouts are much smaller. catchment areas ranging from 4–165ha; have storage volumes ranging from $0.4 \times 10^4 \text{m}^3$ to $0.58 \times 10^5 \text{m}^3$, full scale storage area of 0.04–3.2ha, a maximum depth of 0.7–3.0m, embankment length of 38–320m

The development of dugouts has been concurrent with the development of small reservoirs both in the Upper East Region and Burkina Faso. Data compiled by the GIDA in 1994 showed that there were about 73 dugouts in the Upper East Region. By 2003 there were over 850 dugouts in the Northern and Upper East Regions of Ghana (Ofori et al., 2006).

Most dugouts in the sub-basin have been developed by either government or development agencies aimed at improving the supply of water for domestic and agricultural purposes to communities.

Some farmers however have developed their own dugouts purposely for tomato irrigation in the dry season (Figure 5.3). At least two farmers seen irrigating with dugouts narrated how they developed these dugouts with their own financial resources. These farmers happened to be landowners whose farmlands were located close to streams from which they could divert water into their dugouts.

Infrastructure and Irrigation Technology (Water abstraction, transportation and application)

Dugouts can be constructed in any texture of soil but dugouts constructed in clay are watertight. Dugouts have features similar to small reservoirs, such as embankments, reservoirs and sometimes spillways. The spillways of dugouts can be constructed with concrete walls or earth walls as a simple overflow weir or can be constructed with culverts.

Dugouts have different shapes and sizes. An assessment of the data on dugouts in the Upper East Region shows that the length of the embankment ranges from 30m to 314m, the maximum depth ranges from 1m to 6m, the full scale level reservoir area ranges from 0.2ha to 28ha and the reservoir volume ranges from $4 \times 10^3 \text{m}^3$ and $64 \times 10^3 \text{m}^3$. Dugouts identified in the sub-basin have no water transport structures such as canals or pipes connected to irrigation fields.

Water abstraction from dugouts to irrigation fields is mostly done by motorized pumps and the use of buckets or watering cans. Private dugout owners use motorized pumps to abstract water and transport the water by means of water hoses. At a public dugout, farmers can be seen to be using different abstraction methods such as buckets, watering cans and motorized pumps.



Figure 5.3: a) Example of private dugout; b) Abstracting Water with motorized pump from a private dugout.

Bio-physical features

Irrigated plots of private dugouts are mostly fenced with local materials such as thorns or dry stalks to prevent livestock from destroying the crops. Also in public dugouts where the irrigated fields are not very large, the farmers

manage to fence the irrigated area from livestock, otherwise they do communal policing to protect their crops.

The size of farm plots irrigated with water from dugouts depends on the amount of water stored in the dugout and thus differs from season to season. In some cases the embankments of the dugouts fail due to flooding resulting in less water stored for irrigation thereby reducing the potential irrigable area. Private dugout owners have permanent shallow wells on their farms or resort to riverine alluvial dugouts (see section 5.3.6) which they use to supplement water supply to their fields in situations when there is shortage of water in the dugout. The main crop cultivated with dugouts is tomatoes followed by onions and sometimes okra.

Management

Private dugouts are maintained and used by their owners; no one else is allowed to use the water in critical periods such as the dry season, nor fish from the dugout. Dugouts belonging to communities are managed by the people who use it for various activities. Even though there are many uses, (e.g. fishing, domestic, construction, livestock and irrigation) those who usually take the leading role in the management of such dugouts are the irrigation farmers. In the absence of irrigation farming the fishermen take over the leading role. The irrigation farmers try to maintain the embankments from collapse so as to store enough water for the dry season. In such cases the irrigation farmers organise themselves and contribute towards the maintenance and also elect leaders who handle the management.

Land around a community dugout usually has clearly defined ownership rights and as such interested persons need to contact the landowners before they can be allowed to farm around the dugout. Due to the existing relationships and land tenure system in the communities, these arrangements are normally easily made. The percentage participation of women in this irrigation technology is comparable to that of small reservoirs, except for private dugout schemes.

5.3.3 Permanent Shallow Well Irrigation Technology

Historical Background and Development

The permanent shallow well irrigation technology is one of the oldest irrigation technologies practised in the sub-basin. Some of the wells found in the study area were over 40 years old. In some cases the current users did

not know when the wells were constructed. The initial purpose for the construction of permanent shallow wells in many instances was for the provision of domestic water, but with time people started using them for backyard irrigation during the dry season which later became part of its main uses. This development was identified in both Ghana and Burkina Faso.

This technology is made up of a permanently constructed well. The well is either lined with concrete, sandcrete or stones to stabilise the walls or is unlined. Wells having lined walls have the walls raised above the ground level to prevent runoff and silt from entering the wells. This technology is practised by landowners who live in areas with a high groundwater table but not necessarily near a stream. They usually fence their farms from the invasion of livestock and also to protect livestock from falling into the well. A major advantage with this source of water is that farmers can start their dry season irrigation early and also that they use the water source for supplementary irrigation during dry spells in the rainy season.

Infrastructure and Irrigation Technology (Water abstraction, transportation and application)

Permanent shallow wells are constructed and lined to last long and are used for irrigation and domestic purposes. However some of these wells are unlined but are still maintained in order for them to last long. Owners of such wells have plans to line the wells but complain about lack of funds. Apart from the digging cost which is usually around \$40/well of 8m depth, farmers spend an extra \$110 in lining the well. Generally, one well can irrigate a garden of about 0.02ha.

The water-lifting mechanism used here is mostly the rope and bucket method (Figure 5.4). Similar to the temporal shallow well technologies (see section 5.3.5), farmers irrigate their crops based on the number of buckets/bed/crop. Bucket sizes used for watering usually range between 8L and 14L in volume.



Figure 5.4: Farmer using rope and bucket to irrigate from a permanent shallow well.

Information gathered from an interview with the Ministry of Agriculture in the Upper East Region on the use of Treadle Pumps revealed that, it has been promoted before in Nankolong, a community in the Kassena-Nankana District, but the technology was later rejected by the irrigators. Reasons given by the irrigators were that the Treadle Pump was time and energy wasting compared to their rope and bucket method. Similar comments were passed by farmers in Burkina Faso who claimed they were introduced to Treadle Pumps but later rejected them because it weakened them more than the rope and bucket.

Almost all permanent shallow well irrigation farms identified in the study area are fenced with either dry stalks, wire mesh or clay walls. Fences constructed with dry stalks and clay walls are unable to stand permanently and thus are rebuilt every year.

Bio-physical features

Permanent shallow well irrigation farms are located in areas with a relatively high ground water table, most of them being close to streams and also close to residential areas. The permanent shallow wells are close to residential areas because of their dual purpose of serving domestic and irrigation needs. The fence surrounding the farms makes them easily identifiable from other structures.

Farmers who use the permanent shallow well technology for irrigation are used to cultivating a wide variety of crops. In Burkina Faso, even though tomato is the main crop, a lot of farmers also produce onions, cabbage, lettuce, pepper and potatoes. Burkina Faso permanent shallow well irrigators start irrigation very early and continue into the rainy season (October to June) such that they are able to cultivate two or three crops in succession. A

common practice observed in Burkina Faso is that after farmers harvest their tomatoes, they immediately plant potatoes which they irrigate until the beginning of the rainy season.

In Ghana permanent shallow well irrigators cultivate once (e.g. tomatoes, okra and pepper at a time) in the dry season and in few cases a maximum of two crops in succession.

The ownership of permanent shallow wells in Ghana is identified with men who own the irrigated plots. The role of women in this technology is to support their husbands in watering, harvesting and selling of the products. The reason why women don't own these irrigation technologies is because ownership of a permanent shallow well is directly linked with land ownership, and the land tenure system disallows women from owning land in the area. The positive development observed is that some men develop permanent shallow wells on separate plots for their wives to use for irrigation. In Burkina Faso, women are seen cultivating the permanent shallow well irrigation schemes but they belong to organised irrigator groups.

Management

In Burkina Faso, almost all permanent shallow well irrigators observed within the study area were in organised farmer groups. In some cases (both in Ghana and Burkina Faso) some farmers had their own fenced permanent shallow well farms but belonged to a farmer group comprising permanent shallow well farmers in the vicinity. These groups have elected executives who lead the day to day activities of the group. In another case in Burkina Faso a permanent shallow well farmer group had a fenced 8 acres of land which they had developed for irrigation. In that group, the wells belonged to the farmer group and the group executives were responsible for sharing plots and managing the system.

The formation of irrigator groups is being pushed by the government of Burkina Faso which aims to improve irrigation farming in the country by assisting organised irrigator groups. In one instance, the government supported the improvement of permanent shallow wells (deepening and lining the wells to make them last). There were plans to also furnish the beneficiary farmer organisation with a motorized pump. Also in Burkina when the government improves a permanent shallow well irrigation scheme, a series of training courses are organised for the farmers on farm management and government officials help them to secure credit. Such farmer groups are recognised by the Ministry of Agriculture and have extension officers assigned to them.

A permanent shallow well farmer group in Ghana called Niyuuri Farmers Group, was formed in 2004 with 18 members and currently has 28 members. The group was formed to assist each other through communal labour and also to seek financial and technical assistance as an organised group. The group is led by an elected executive and guided by a set of by-laws.

It is common to find some of the permanent shallow well irrigation plots isolated in the sub-basin. The owners of these irrigation plots do not belong to any group and as such manage their plots individually. Permanent shallow well farmers in Ghana have no link with the Ministry of Agriculture and as such no extension officer is assigned to them.

5.3.4 Riverine Water Irrigation Scheme

Historical Background and Development

One of the most reliable water sources which farmers find relatively easy and cheap to access is flowing water in perennial rivers. Over the years farmers have been farming along the banks of the White Volta. This technology has been practised in the sub-basin since 1992 around Pwalugu in the Upper East Region and has expanded over the years. Also due to the regulating effect of dams, small rivers like the Nakambe have become perennial streams in the lower reaches in Burkina Faso, even improving supplies to towns in northern Ghana (ICOLD members-Burkina Faso, 2001). This has contributed to the upscaling of this irrigation technology. Meanwhile, since the eradication of river blindness, the use of land along the river banks of the White Volta sub-basin for irrigated farming has increased considerably (Birner et al., 2005).

Other farmers also locate their farms downstream of large irrigation schemes such as Veia and Tono and use the return flows and excess water from these schemes (see Figure 5.5).

Riverine irrigation technologies are practised by commercial irrigators. Due to the availability of water especially along the perennial rivers, farmers are not restricted by water availability and thus have the ability to cultivate large plots of crops (0.5ha to 6ha)³ compared to the plot sizes in large and small reservoir irrigation schemes. However, competition for water intensifies

³ This range of farm size is typical of irrigation farms along the perennial streams like the White Volta at Pwalugu, while downstream of large irrigation schemes the range is 0.2-1.0ha.

when the streamflow is low and may be insufficient especially towards the end of the dry season.



Figure 5.5: a) Diesel pump abstracting water from river b) method of transporting and applying water under riverine irrigation technology.

In 2005, the MOFA Regional Directorate conducted a successful field trial of growing maize as a third crop per year by pumping water from the White Volta for irrigation. The average yield was 3.7 ton/ha, compared to a national average of 2.5 ton/ha and a regional average of less than 1.2 ton/ha. Irrigation is certainly a major factor for this yield difference. MOFA planned in 2005 to plant one vegetable crop and one maize crop during the dry season, and one cereal crop during the rainy season (Birner et al., 2005). Farmers irrigating downstream of the Veia Irrigation Scheme were seen following this initiative by MOFA in the 2007/2008 dry season.

Irrigators who use pumps for extracting water from the White Volta and other streams plant crops directly on the river banks. This has caused major problems of erosion, as well as pollution from chemicals applied on farms, and goes against existing regulations by MOFA that forbids the cultivation of lands located within 100m from the river course. In practice what this would imply is that the water is pumped out of the White Volta over this distance (100m), and then by gravity the farm plots are irrigated, taking advantage of the sloping lands. MOFA also instituted a rule that the 100m strip should be planted with economic trees such as cashew and mango to provide an income; and where the reserved 100m strip is not yet deforested, the forest should be protected. There have been difficulties in enforcing these regulations, however. The White Volta sub-basin Board has tried to improve enforcement by involving traditional authorities and the District Assemblies, and providing awareness campaigns (Birner et. al., 2005). However, enforcement of the instituted measures is still lacking.

MOFA has estimated that this technology could potentially irrigate an additional 10,000ha in the Upper East Region (Birner et al., 2005). The limitation of this technology is that the option exists only along the perennial White Volta River, which crosses four of the eight Districts in the Upper East. As a result of upscaling, land rents along this river are becoming expensive.

Infrastructure and Irrigation Technology (Water abstraction, transportation and application)

There is no physical water infrastructural development under this technology. Farmers rather invest heavily in water abstraction and water transportation equipment. The majority of the farmers use diesel pumps to abstract water from the river (see Figure 5.5a) while others use petrol pumps. Most use aluminium or pvc pipes (100- 150mm in diameter) to convey water to their fields, with a few using water hoses (Figure 5.5b). Water application is by means of furrow irrigation (identical to the small reservoir irrigation technology, see section 5.3.1).

Bio-physical features

Riverine irrigation systems are mainly used to cultivate tomatoes followed by onions and in some cases pepper. The farm sizes range from 0.4ha to 6ha especially with tomato farms. Most irrigators employ labour. There are permanent labourers who live on the farm throughout the irrigation season. Riverine Irrigation systems are not fenced due to the sizes of the farms and labourers keep livestock from the fields.

Irrigation farmers located downstream of irrigation schemes are sometimes negatively impacted when the streams dry up before the irrigation authorities release water from the reservoir. When situations like this arise the riverine water irrigators compete for the remaining water in the stream and in the worst case resort to riverine alluvial dugouts to water their crops until they receive water from the upstream releases. This phenomenon mostly dictates the size of the plot that the farmer can cultivate in the season.

The irrigation farmers in riverine irrigation schemes are mainly men; women are employed as labourers for the transplanting and harvesting of tomatoes.

Management

Farmers located downstream of large reservoir irrigation schemes are not organised and thus manage their farms individually. However in some places

farmers along the perennial river have formed farmer associations. The members of the association encourage new farmers who farm along the Pwalugu River, to join so that they can benefit from economic and social systems, such as market negotiations and championing of their concerns with one voice to MOFA and other related institutions.

Land under these technologies are privately owned. Therefore irrigation farmers contact landowners to negotiate the leasing of their land. In few cases the landowners irrigate the land themselves.

5.3.5 Temporal Shallow Well Irrigation Scheme

Historical Background and Development

The use of temporal shallow wells is one of the new irrigation technologies that have emerged in the sub-basin within the past two decades (Figure 5.6a & b). It is common in the Upper East Region, specifically in the Atankwidi and Anayari sub-catchments where groundwater levels range between 3-8m throughout the dry season. This kind of technology was not identified in the Burkina section of the study area. As has also been described by Namara et al., (2010), temporal shallow wells tend to be used in cases where the irrigation farmer rents the land from the landowner for just the dry season. This may explain why the wells are temporal. As a condition for obtaining the land for irrigation the next season, the irrigation farmer agrees with the landowner to refill all the wells at the end of the season with sand for reasons of preventing farm animals and people from falling into them and also to save their farming area from being reduced by the wells. Interviews conducted in the area showed that this technology started a few years before the riverine alluvial dugouts. This technology started in the Atankwidi catchment in the early 1990s while the riverine alluvial dugouts started in 1996. The relatively low capital investment (\$30/well) accounts for the high rate of upscaling of this technology in the sub-basin in recent times. The field count conducted on the riverine alluvial dugouts, was done concurrently with the temporal shallow wells. A total of approximately 3,000 were counted within a 30km stretch along the Atankwidi River, with about 40% of them being used by women farmers.

Infrastructure and Irrigation Technology (Water abstraction, transportation and application)

The main infrastructure associated with this technology is the temporal shallow well. The diameter of these wells is between 0.6-1m and irrigation

farmers dig about six of these wells per farm area of 0.1ha which are optimally spaced (distances between wells is usually 6-10m) to create the shortest travelling distance in watering their crops. Irrigators either use family members or hire labour to dig these wells. A total of four labourers are capable of digging one well of 4m depth in two days, which on average costs \$20/well. Later into the season as the groundwater level drops, the farmer digs deeper for more water and may end up with a depth of 8m by the end of the season.



Figure 5.6: a) Shallow well with hip pump b) Rope and Bucket Watering used in Temporal Shallow well farms.

The common water lifting method used for this source of water is the rope and bucket. Treadle pumps and hip pumps have been introduced by NGOs and researchers in the Atankwidi area but less than 1% of all temporal shallow well irrigators in Atankwidi use them. The cost of treadle pumps on the Ghanaian market in the sub-basin ranges from \$80 to \$110, and they were not popular among the irrigation farmers surveyed in Ghana and Burkina Faso.

Farmers using rope and bucket, water their farms more regularly than other technologies. They irrigate their crops almost every morning, while some do the irrigation both morning and evening. They have specific number of buckets per bed which they apply to their farms. The number of buckets per bed is increased when the fruits flower and is later reduced when the fruits are riped.

Bio-physical features

Temporal shallow well irrigation technology is associated with relatively small farm sizes ranging from 0.01ha to 0.1ha. Tomato is the main crop cultivated under this technology. Temporal shallow well farms are located along river channels which are heavily occupied with irrigators such that

almost all farm plots are contiguous. Neighbouring irrigators therefore complement each other in preventing livestock from destroying each other's crops.

In order to access groundwater with less efforts almost all temporal shallow well farms are located in areas with high groundwater tables, mostly close to a stream. The soil condition in these areas is characterised by loamy clays with rich alluvial deposits and rich in nutrients for vegetable cultivation. In the rainy season such areas are usually flooded and are used for cultivating rice. The irrigation sites are characterised by heaps of soil which are the result of digging the wells, and which will be used to refill the wells at the end of the season.

Management

The management of temporal shallow well irrigation schemes is similar to that of the riverine alluvial dugouts. Some temporal shallow well farmers are members of irrigation groups formed by the riverine alluvial dugouts farmers. Some of these temporal shallow well farmers are able to “graduate” from temporal shallow well technology to riverine alluvial dugout technology after some years (from the farmers' perspective, the alluvial dugout technology is more productive). However, the majority of the temporal shallow well farmers are individuals who manage their farming activities on their own. The participation of women in this technology is between 10% and 15%. The men are mostly found supporting the women with the labour intensive activities such as digging.

5.3.6 Riverine Alluvial Dugout Irrigation Technology

Historical Background and Development

The prospects of dry season irrigation farming in the sub-basin coupled with the lack of adequate surface water resource is the driving force behind the development of alluvial dugouts. The main difference between Riverine Alluvial Dugouts and the Dugouts mentioned previously is that, while dugouts are located in the flood plains of the river or stream and fed by surface water source, riverine alluvial dugouts are located in the river channel and fed by underground water. Riverine Alluvial dugouts are practised mainly in non-perennial streams in the sub-basin. Also whereas dugouts are developed using earth moving equipment such as bulldozers, riverine alluvial dugouts are developed manually.



Figure 5.7: a) Initial stages of Riverine Alluvial Dugouts b) Latter stages of Riverine Alluvial Dugouts.

From interviews conducted, this irrigation technology has been practised since 1995 in the Atankwidi sub-catchment of the White Volta. The farmers who introduced this technology were a group of four brothers who conceived this idea during the construction of the Bolgatanga-Navrongo main road. During the dry season of 1995, one young man by name Joel Aferigoh (a native of the area who used to practise irrigation in Kumasi) returned from Kumasi to Anateem, a village in the Atankwidi sub-catchment and observed that some embankments created by the ongoing construction of the Bolga-Navrongo Road had created some water storage in the Atankwidi river which was unusual during dry season. Being a landowner along the river, he decided to cultivate tomatoes along the river using rope and bucket to irrigate his plot. After a successful harvest and high income that year, his three brothers joined him in the dry season of 1996. This time they decided to change from using rope and bucket to a motorized pump. Later on in the season as the water dried up they decided to scoop the sand in the river to have access to groundwater. This became a yearly practice. The scooping results in irregularly shaped depressions in river channels called dugouts which can also be classified as temporal shallow wells of irregular shapes, sizes and depths. A field count made during the 2007/2008 dry season within a stretch of about 30km along the Atankwidi River showed that there were about 705 farmers using the riverine alluvial dugout technology on both sides of the river. Thus the entrepreneurship skills acquired from Kuamsi helped Joel to exploit the water resource, and ended up creating a technology which did not exist in the area.

Infrastructure and Irrigation Technology (Water abstraction, transportation and application)

Riverine alluvial dugout irrigation schemes have non-permanent irregularly shaped depressions of various sizes and depths (3–5m) located in the river channel (see Figure 5.7a & b). These alluvial dugouts are spaced at least 5m apart and dotted along the river channel. All these dugouts are temporal structures which last only in the dry season. They are filled up with silt during the rainy season such that by the onset of the next dry season all dugouts are covered. Farmers re-invest in the digging of these dugouts every irrigation season. The digging of alluvial dugouts is a continuous process throughout the irrigation season. Farmers employ labour for the digging which is usually done weekly. A farmer can have as many as five alluvial dugouts depending on the size and location of his/her farm.



Figure 5.8: a) Water abstraction method b) Water application method for Riverine alluvial dugouts technology.

Water abstraction is by means of motorised pumps (petrol pumps) and water hose. The cost of a new pump is about \$400. Not all the farmers can afford such investments and therefore decide to hire it for the season at a cost ranging from \$55 to \$100. Also due to the cost of a water hose (\$2/m) farmers either borrow hoses or practise what they term water transfer by pumping from one dugout to the next until they reach their farm plot. This practice increases pumping cost.

Farmers direct water within their plots to the crops by means of furrows (see Figure 5.8b). The mode of water application is similar to that of the large reservoir technology where trenches are used to control the irrigation of crops. The farmer waters the crops by using a shovel to direct the water into the trenches.

Bio-physical features

On average a farm size of about 0.2ha will use about three different dugouts with each having an average surface area of about 6.5m² and end up with a depth between 3m and 5m by the end of the irrigation season. The farm plots are located along the river channel and range from 0.01ha to 0.7ha in size. In this technology the irrigators do not observe the directive by MOFA 'not to farm within 100m strip form the river course'. Since land is scarce in such areas boundaries between farm plots are usually thin lines (about 30cm wide) which are in the form of trenches or ridges. Due to the closeness of the plots and the vast extent of riverine alluvial dugouts, farmers are unable to fence their farms to protect them from grazing livestock. Farmers therefore build temporal housing structures on their farms where they stay throughout the season to drive away livestock from destroying their crops.

By virtue of the closeness of the farm plots to the stream channel, the groundwater level in the area is relatively high and the soil in the area is sandy loam with rich alluvial deposits. The soil condition is therefore good for vegetable cultivation. In the rainy season such areas are usually flooded and are used for cultivating rice. Tomato is the main crop grown under riverine alluvial dugouts with a few farmers cultivating pepper and okra in addition to tomatoes.

Along the river channel two main irrigation technologies are identified: temporal shallow wells and riverine alluvial dugouts. These technologies are mixed up along the river channel with the shallow wells being located a little further away from the river channel than the alluvial dugouts. Farmers live in harmony and no conflict or struggle for water between them was observed.

This technology is mainly practised by men. Out of the 705 farmers counted along the river channel only 5 were women. Farmers interviewed mentioned the fact that this is a highly labour intensive technology as the main reason why so few women are involved.

Management

Two management practices are identified with riverine alluvial dugouts: organised irrigation groups and individual irrigators. An interview with members of an irrigation group by name 'Ayambire Bunmo Farmers Association' showed that the group's membership is made up of farmers using two different irrigation technologies (riverine alluvial dugouts and temporal shallow wells) who are neighbours geographically. The association was formed in 1999 with 21 members and currently has 31 members of whom three are women. The group was originally formed to have a common front

to face market women; to access loans from banks and solve problems together. This group has helped father three other groups in an area with about 1,000 farmers, but not all the farmers are members. Even though not all the farmers have joined the groups, the activities of the groups have impacted on other irrigators within the area. They benefit from negotiated market prices by the groups, because they happen to be in the same vicinity where the market price is the same. The irrigator groups are registered with the department of co-operatives and are recognised by MOFA and the banks. The groups have developed their own constitution and elected executives.

The other management system identified is by individual irrigators who are not registered with any farmer group. They have no obligations to others but respect the ethics (e.g water rights and communal policing) that prevail at the farm level. Irrigators have the right to abstract water as much as they can find and also respect boundaries between them and their neighbours. Because the irrigators have social relations by birth and by community relations they are able to manage their farming activities and conflicts by help of their social ties.

Land Management

Land along the river channel is owned by the family heads who hold it in trust for their families as is the custom of the area. Most of the family heads are elderly men who do not have the physical strength to do dry season irrigation farming. Irrigators (mostly young men) who wish to farm along the river channel but do not own land have to contact a landowner and negotiate to get access to land. It is not difficult to rent land from landowners as observed in the area. However as the landowners prefer to rent out large areas, they prefer to give their land to men more than women because men tend to cultivate larger areas than women. This notwithstanding, women are eligible to negotiate for land for the dry season farming.

Apart from paying for renting land for irrigation, the farmer is expected to plough the land for the landlord at the end of the irrigation season as a rental condition. The irrigator offers the landowner a small initial payment (about US\$5 – US\$10) and pays a bigger amount at the end of the season depending on the harvest and the farm. The amount paid to landlords at the end of the season ranges from US\$20 to US\$100.

5.4 EVOLUTION FROM ONE TECHNOLOGY TO ANOTHER

Field interviews and interactions revealed that with the onset of the irrigation technologies discussed above, there has been the evolution from one technology to the other by irrigators. Typical of these is the evolution from temporal shallow wells to riverine alluvial dugouts. Because of the labour intensity and time involved in watering the farm plot with rope and bucket, the irrigators practising temporal shallow well irrigation technology are unable to cultivate large areas. Some of the practitioners of temporal shallow well technology have the ambition to “graduate” to riverine alluvial dugouts using motorized pumps to irrigate, so that they can expand their farms. Some of the temporal shallow well irrigators were trained by the riverine alluvial dugouts irrigators when they worked under them as farm boys. After some years of working as farm boys they began their own farm using temporal shallow wells from which they aim to “upgrade” to riverine alluvial dugout.

Another evolution that was identified is that riverine alluvial dugout irrigators are shifting to riverine water irrigation. Because of the cost involved in digging for water and the insufficiency of water at the end of the season, some riverine alluvial dugout irrigators have started practising riverine water irrigation in addition to their alluvial dugouts. Also some riverine alluvial dugout irrigators have expressed their intentions to expand their farm plots, but due to the insufficiency of water under the alluvial dugouts they are restricted from expanding their farm plots. The consideration they are making now is how to access flowing water in streams during the dry season. They have already started discussing various options (water transfer from one perennial river, upstream dam and improved groundwater abstraction methods) with stakeholders like the Ministry of Agriculture, Researchers and Irrigation Development Authority.

Also farmers using small reservoirs complain of the small farm sizes in the irrigable area. Some of these farmers manage to add on other technologies such as: pumping directly from the reservoir using motorized pumps, developing temporal shallow wells downstream of the irrigable area to add to their farm plots or practising riverine water technology in addition to their farm plots.

In Atankwidi one landowner who previously rented land to irrigators who practised temporal shallow wells and riverine alluvial dugouts on portions of his land was found using permanent shallow wells (8 in number for a farm size of 0.25ha). He was previously irrigating from riverine alluvial dugouts.

When contacted he said the wells were constructed by an NGO which wanted to promote permanent shallow well technology and was using his farm as a pilot case. The NGO provided the motorized pump and fuel which the farmer used. This shows that there is the potential to develop more permanent shallow wells to replace temporal shallow wells if landowners are encouraged and assisted.

5.5 CONCLUSION

A summary of the composition of irrigation technologies in the sub-basin is presented in Table 5.1. The table shows that all irrigation technologies have specific water abstraction methods associated with them, the exception being small reservoir irrigation which can employ three different water abstraction methods (motorized pumps, intake valves and buckets). The abstraction method associated with both riverine water and riverine alluvial dugout irrigation is motorized pumps. The abstraction method associated with both temporal and permanent shallow wells is rope and bucket.

From the material presented in this chapter it may be concluded that irrigation development in the sub-basin was initiated by both governments developing small reservoirs, large reservoirs and dugouts since the early 1950s. However, in the past twenty years the driving force behind irrigation development basin has been predominantly private and by associations of individuals, assisted by some donors. The trend of irrigation development in Burkina Faso and in Ghana is comparable. However the rate of development is more advanced in Burkina Faso compared to the Upper East Region in Ghana. This may be a result of Burkina government's policy of improving the irrigation technologies initiated by private individuals and also equipping the farmer groups to manage the irrigation system.

Most irrigators are unaware of the prevailing water rights in their countries and have no idea of the requirement to register their irrigation water using activity. However, payment for the water abstraction does not apply to most of the irrigators since their farm sizes are less than 1ha. There are no institutional arrangements at the grassroots to enforce the water-use regulations. Some alluvial dugouts irrigators were of the view that if the government should provide them with water, they were willing to pay, which they presumed would be cheaper than the amount they currently spent on digging for water in a season.

These irrigation technologies have spread in the sub-basin because the direct control of water sources, either through groundwater pumping, drainage

reuse or direct pumping from canals and rivers has brought the flexibility in water delivery to irrigators that the large-scale surface distribution systems did not offer. Also a growing market demand for vegetables in the urban areas of southern Ghana and the transfer of knowledge on irrigation technologies and farming have contributed to the upscaling of irrigation technologies in the sub-basin. Meanwhile it has also brought challenges in managing irrigation development in the White Volta sub-basin, because of the uncoordinated irrigation water use and the rising competing uses of water.

Table 5.1: Summary of Description of Irrigation Technologies.

Irrigation Scheme	Irrigation Technology			Crops	Range of Farm Size (ha)	Development & Management
	Water Abstraction Method	Water Transportation	Water Application			
Large Reservoirs	Intake Valves	Canals and Laterals	Furrows/ basin flooding	Tomatoes, Rice, Onions, Pepper, soybeans	0.2-0.6	Government & Public Institution
	Intake valves	Canals and water pumps	Furrows			
	Intake valves	Canals, buckets/ motorized pump,	Drip Irrigation			
Small Reservoirs	Intake Valves	canals	furrows	Tomatoes, Onions, lettuce Pepper, local vegetables , cabbage,	0.05-0.5	Government, Development agencies and managed by WUA or Individuals
	Motorized water Pumps	Water hose	furrows		0.1-1.0	
	bucket	bucket	trenches		0.01-0.05	
Riverine Water	Motorized water pumps	Water hose	furrows	Tomatoes, onion, pepper	0.5-6.0	Private development and managed privately / Farmer group
Riverine Alluvial Dugout	Motorized water pumps	Water hose	furrows	Tomatoes, okro, pepper	0.1-1.0	Private Development and managed privately / Farmer group
Dugouts	Motorized water pumps	Water hose	furrows	Tomatoes, onion, pepper	0.1-1.0	Development is by Private, Government and Donor Agencies. managed privately / Farmer group
	Buckets and watering cans	Buckets and watering cans	trenches		0.01-0.05	

Temporal Shallow Wells	Rope and Bucket	Buckets	trenches	Tomatoes, pepper	0.04-0.2	Private Development and managed privately / Farmer group
Permanent Shallow Wells	Rope and Buckets	Buckets	trenches	Tomatoes, pepper	0.01-0.2	Private Development and managed privately / Farmer group

Chapter 6

PRODUCTIVITY OF IRRIGATION TECHNOLOGIES IN THE WHITE VOLTA SUB-BASIN⁴

6.1 INTRODUCTION

Studies have shown that an increase in irrigation productivity which results in improved farm income creates an increase in demand for local non-tradable goods and services, which offer labour opportunities to the poorest segments of the rural population, promotes local agro-enterprises and stimulates the agricultural sector as a whole (Lipton et al., 2003; Smith, 2004; Hussain et al., 2004). In most parts of sub-Saharan Africa, increasing agricultural productivity is often the only way out of poverty, and new irrigation development can be a springboard for economic development (Faurès et al., 2007). In the face of many disappointing experiences with irrigation development in sub-Saharan Africa, investing in irrigation requires empirical evidence of the potential productivities of the prevailing irrigation technologies, and a comparative analysis to inform irrigation policy.

So far little is known on the productivity of irrigation technologies adopted by smallholder farmers and the factors influencing productivity in the Volta basin. Few research activities have been conducted on the productivity of small and medium reservoirs in the White Volta sub-basin. Faulkner (2008) looked at the performance of two small reservoirs (Tanga and Weega) in the Upper East Region of Ghana and found that because of the high water availability in the Tanga system water management was relaxed, which resulted in inefficient irrigation water-use methods. By virtue of this the Tanga system was less profitable in water and land. Faulkner (2008) argues that the increased profit per unit of cultivated land was not due to water stress or irrigation technique or management but rather due to differences in fertilizer, pesticide and seed inputs. Mdemu (2008) found that the contribution of irrigation to tomato production in the Upper East Region of Ghana was high, that irrigation plots were over-irrigated by 11 to 70%, and that water use efficiencies were higher under small reservoir irrigation than in systems with large reservoirs. Both studies only considered irrigation technologies that sourced water from reservoirs. Meanwhile there are other

⁴ This chapter is based on Ofosu, E. A., van der Zaag, P., van de Giesen, N., Odai, S.N., 2010. 'Productivity of Irrigation Technologies in the White Volta basin'. *Physics and Chemistry of the Earth* 35: 706-716.

prevailing irrigation technologies with different water sources in the White Volta sub-basin which also need to be investigated. Also the different aspects of the technologies such as water source, water consumption, farm size and fertilizer input on the productivity of technologies, essential information for improving irrigation productivity, were not analysed. Finally, a general comparison of all prevailing irrigation technologies, using productivity factors is necessary to assess the strength and weaknesses of the various irrigation technologies to help guide irrigation development policies.

The focus of this chapter therefore is to assess the productivities of the prevailing irrigation technologies and the contributing factors to the difference in productivities using common parameters. This demands the selection of a common irrigated crop practised under all the prevailing irrigation technologies which happens to be tomatoes.

6.2 METHODOLOGY AND DATA COLLECTION

The study involved a ground survey that identified all irrigation technologies practised in the watersheds. On the basis of the survey a target number of farmers were allotted for various irrigation technologies within each watershed for data collection. Within each watershed a number of irrigation sites were selected for each irrigation technology. Knowing the target number for each irrigation site a random sampling was employed in selecting farmers. However, the leaders (i.e. executive members of WUA at small reservoirs and senior farmers at shallow wells) at the irrigation sites were instrumental in convincing fellow farmers to assist in the research. This resulted in site leaders influencing the selection of farmers.

Not all selected farmers could read and write, yet both literate and illiterate farmers were selected. In some instances only one farmer was educated amongst a group of farmers within the same location. Literate farmers and educated children of illiterate farmers were trained to enter the records of the daily activities and were given notebooks. In other situations, literate farmers were asked to assist their fellow illiterate farmers in recording their daily activities. In view of these difficulties not all data were required from illiterate farmers such as pumping duration, water level measurements and other field measurements. In such instances the records provided by the literate farmers were used to represent all farmers. The records made by farmers were inspected every fortnight. Field assistants also visited farmers on a weekly basis to assist them in measurements and the recordings. Some of the measurements such as irrigation water use were taken at the beginning, the middle and the end stages of the irrigation season.

A preliminary survey was conducted in the 2006/2007 irrigation season on a total of 85 tomato growing farmers selected from the Ghana section of the study area but only 51 of the records could be used as a result of missing

records and unreliable information. With the experience obtained from the 2006/2007 season, the number of farmers was increased to 120 in the 2007/2008 season maintaining most of the farmers used in the previous season and also farmers were selected from the Burkina Faso section of the study area. At the end of the season 114 of the farmers notebooks could be retrieved. The reason is that some travelled with their notebooks at the end of the season, some also lost their notebooks due to rain and fire while others left their farms in the middle of the season due to several reasons thus stopped recording and took the books away. Out of the 114 farm notebooks, 90 contained complete data sets and were found useful, while the remaining had information gaps. The records of the 90 farmers of the 2007/2008 irrigation season were finally used for the analysis (Table 6.1).

Table 6.1: Tomato farmers surveyed and analysed for the 2007/2008 season.

Area	Technology (water source)	Catchment Area			Total
		Anayari	Atankwidi	Yarigatanga	
Upper East	Small reservoirs	25/15	0	22/20	47/35
Region,	Permanent shallow wells	12/7	0	0	12/7
Ghana	Large reservoirs	0	0	6/6	6/6
	Riverine water	0	0	11/8	11/8
	Temporal shallow wells	0	8/8	0	8/8
	Riverine alluvial dugouts	0	17/16	0	17/16
Southern	Small reservoirs	0	7/4	0	7/4
Burkina Faso	Permanent shallow wells	0	8/4	4/2	12/6
Total		37/22	40/32	43/36	120/90

a/b: a represents surveyed farmers, b represents analysed farmers

The data collected were diverse but common for all irrigation technologies. It included primary and secondary data/information from the farmers, farmer organisations and related institutions such as the Ministry of Food and Agriculture (MOFA) and the Irrigation Development Authority (IDA). The methodology employed include daily recording of activities (water consumption, time input, farm inputs, operating costs and sales), field interviews (farmers, farmer organisations and related institutions), field counts, plot size measurement, irrigation water-use measurements, yield measurements and market information.

6.3 FIELD RESULTS

This section analyses the data of tomato farmers listed in Table 6.1 for the 2007/2008 irrigation season. The investments in water and water infrastructure for various technologies were analysed including the seasonal expenditure on water per each technology. Also seasonal application of water, fertilizer and pesticides were estimated for the various irrigation technologies.

The productivities (land and water) of the irrigation technologies were compared. A regression analysis was used to generate a relationship between crop yield and fertilizer input, water source and water application method. The final stage of the analysis looked at the socio-economic impact of the irrigation technologies in terms of farmer profit, labour creation and the involvement of female farmers. This section starts with describing the various irrigation technologies, distinguishing their various sources of water.

The data analysis was aggregated for irrigation technologies and country, meaning that farmers using the same technology on one side of the border were assessed together irrespective of the watershed they were located in. All data are analysed based on the farm size of the farmer and results have been normalised for a 1ha farm size.

6.3.1 Investments in water and seasonal expenditure on water

Investment in infrastructure and equipment for irrigation is either by government, development agency or private individual or group of individuals. In the White Volta sub-basin governments and development agencies invest in the development of large reservoir irrigation schemes and small reservoirs, while other technologies in the sub-basin are developed by private individuals or farmer groups. From Table 6.2, investing in the large reservoir is cheaper than the small reservoir as a result of the economies of scale. The bigger the irrigation project the cheaper the cost per unit area. This is comparable to the difference in cost of irrigation development in sub-Saharan Africa and other developing countries mentioned in Chapter 3.

Farmers irrigating from the large reservoir scheme are charged US\$56/ha for irrigating a tomato crop, US\$42/ha for rice and US\$28/ha for vegetables. This fee has to be paid before the irrigation commences. Under the small reservoir irrigation technologies water levies are charged differently. While at some small reservoirs water is charged per bed (US\$0.2/bed size of 1m x 50m), at others farmers are charged per plot (US\$1/plot area of 0.05 ha), and the rest are charged a general fee irrespective of farm size cultivated (US\$2/farmer/season). These water levies are used for the maintenance of canals and organisational activities and are reviewed upwards almost every year by the Water User Associations (WUAs).

Table 6.2: Cost of water-use for irrigation technologies in Upper East Region and Burkina Faso.

Irrigation technology	Investment cost (\$/ha)	Lifespan (years)	Depreciation cost - [X] (\$/ha/yr)	Maintenance cost - [Y] (\$/ha/yr)	Water-use cost - [Z] (\$/ha/yr)	Total cost [X+Y+Z] (\$/ha/yr)	Seasonal Expenditure (\$/ha/yr)
UPPER EAST REGION							
Small reservoir	33,000	25	4,650	100	47	4,797	47
Permanent shallow well	4,800	30	672	400	0	1,072	400
Large reservoir	15,000	50	2,029	150	57	2236	57
Riverine water	1,700	8	360	50	550	960	600
Temporal shallow well	1,200	0.5	1,200	0	0	1,200	1,200
Riverine alluvial dugout	700	5	200	50	755	1,530	1,330
	525	0.5	525				
BURKINA FASO							
Small reservoir	38,000	25	2,500	100	80	2,680	80
Permanent shallow well	6,500	30	385	600	0	985	600

^a petrol pump, pipes

^b constructing the dugout

In the remaining technologies, which are riverine water, riverine alluvial dugouts, temporal shallow wells and permanent shallow wells, a farmer individually decides when and how to irrigate. Most of these farmers are either landowners or are related to the landlord. In some instances the farmers rent the land from the landlord for just the dry season. All these farmers do not pay a water levy but rather invest in water abstraction equipments, infrastructure (permanent and temporal) and energy to be able to irrigate the crops.

Table 6.2 shows the investment cost and seasonal expenditure on water (abstraction and distribution) incurred on the various irrigation technologies for tomato cultivation.

The infrastructure and equipment used in the irrigation are affected by wear and tear or obsolescence over an accounting period called depreciation which

reduces their economic value and productivity annually (Lund, 1989). The annual capital costs of the irrigation facilities are estimated using a discount rate based on the National Central Bank discount rate of December 2007 (Ghana – 13.5%/yr and Burkina Faso – 4.25%/yr, CIA – The World Factbook, 2009). The economic lifetime of small reservoirs is chosen as 25 years based on the fact that many of the reservoirs that were constructed in the 1950s, 1960s and 1970s in the Upper East Region of Ghana were non-functional by the 1980s and had to be rehabilitated in the 1990s by the World Bank and FAO. The economic lifetime of the large reservoir was chosen as 50 years based on the design life of the reservoir and that of the remaining technologies were obtained from field interviews.

The annuity factor, a , was determined from the following equation:

$$a = \frac{i \times (1+i)^n}{(1+i)^n - 1} \quad (\text{Equation 6.1})$$

where i is the discount rate and n is the economic life (years).

The annual capital cost or depreciation is then calculated by multiplying the investment cost with the annuity factor a . The sum of the annual maintenance cost, annual depreciation cost and the operating and maintenance cost of the facility gives the total annual expenditure on irrigation water by the technology (Grant et al., 1990).

Table 6.2 shows that the small and large reservoir are the most expensive technologies in terms of investment, operation and maintenance of irrigation water infrastructure and technology with the riverine water irrigation being the least (about 20% of the small reservoirs). Interestingly, the less expensive technologies in terms of investment are developed privately while small and large reservoirs are mostly developed by the government. This shows that irrigation development policies should aim at promoting more affordable shallow well technologies compared to very expensive small and large reservoirs.

Also the seasonal expenditure on water-use by farmers, which includes the amount of money spent on water abstraction and maintenance by the farmers either as water levy, on fuel, pump repairs or digging every season, reveals that the riverine alluvial dugout technology and temporal shallow well are the most expensive technologies with the cheapest being the small and large reservoir irrigation (25% of the riverine alluvial dugout) which are mostly developed by government and development agencies. The major contribution to the high seasonal expenditure on water for these irrigation technologies is energy and labour.

6.3.2 Plot size and fertilizer use

Within the study area, the measured farm sizes for small reservoirs range from 0.005-0.58 ha, 0.005-0.09 ha for permanent shallow wells, 0.125-1.0 ha for large reservoirs, 0.2-1.0 ha for riverine water, 0.006-0.08 ha for the temporal shallow wells and 0.05-0.7 ha for riverine alluvial dugouts.

The application of chemical fertilizers and agro-chemicals is common to all irrigation technologies in the sub-basin. The survey in the three watersheds showed that 100% of farmers use NPK, 32% use Urea and 59% use Sulphate of Ammonia for their crops. In both countries less than 10% of farmers use manure to support their chemical fertilizer because most farmers gather animal droppings during the dry season for their rainy season farming. Fertilizer application is an expensive component of irrigation farming. The cost of fertilizer was fairly stable during the 2007/2008 irrigation season; the cost of NPK (15-15-15) was US\$0.50/kg, US\$1.12/kg for Urea and US\$0.64/kg for Sulphate of Ammonia.

After the fruiting of the tomatoes the farmers spray the tomatoes with other yield inducing chemicals such as *harvestmore*, *superforce*, *19-19-19* and *growfull*. The quantities applied per farm area however differed from farmer to farmer due to differences in individual financial capacity and the perception of adequacy. For this reason the nutrient intake by the crops differs from farmer to farmer which translates to yield differences.

The farmers control diseases and pests with agrochemicals, which are applied at different quantities by the farmers and this is also based on differences in farm sizes financial capacity and experience.

6.3.3 Amount of water applied by irrigation technologies

Watering of crops is the main activity of irrigation farming throughout the season. Water applied differs for each technology and depends on the water application method and water availability. The watering schedules for small and large reservoirs are determined by the WUA and the management of the large irrigation scheme respectively. There are no measures to ensure or regulate the quantity of water per plot, rather farmers decide on the quantity of water they apply on their farms without regulation or technical advice. The WUAs plan their own water scheduling for the irrigation season based on the water level in the reservoir at various stages of the season. As a result the water schedule differs among the small reservoirs and can change during the irrigation season.

Farmers using shallow wells and abstracting water with rope and bucket water their crops twice a day (morning and evening), every day or thrice a

week. The bucket sizes range from 8 to 14 litres. Farmers use their own discretion to decide how many buckets of water are needed per bed, and depend, among others, on the crop type and the dimensions of the bed.

In general farmers try to be efficient in water-use due to the scarcity of water in the dry season. Farmers who abstract water with motorized pumps try to be extra efficient in energy consumption due to the cost of fuel. Similarly, farmers applying water manually are also efficient because they apply water directly to the roots of the crops.

Figure 6.1 show the amount of water applied per irrigation technology and the corresponding expenditure on water. The cost of water is not related to the volume of water applied but rather to the technology.

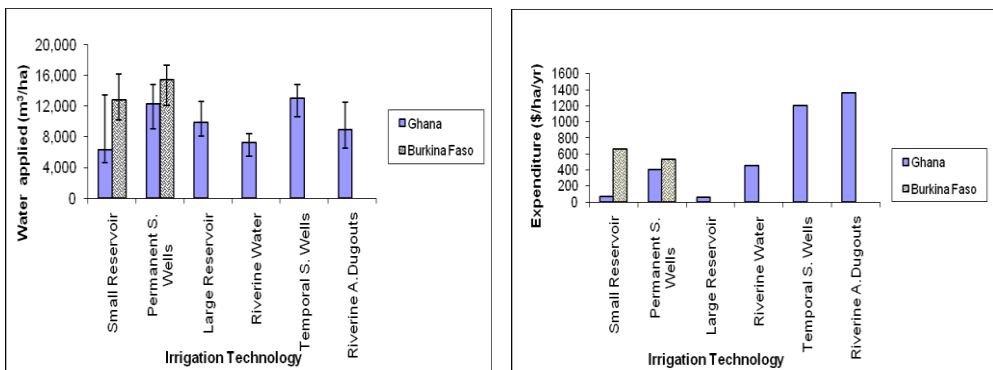


Figure 6.1: a) Seasonal irrigation water applied; b) Seasonal expenditure on irrigation water.

6.3.4 Crop productivity

The productivity of the irrigation technologies is measured in terms of crop yields. The yields of the crops were measured in the field by weighing harvested products on the farm. Tomatoes are harvested and sold in boxes/crates, basins or buckets. (There are two different sizes of boxes/crates (105 kg and 156 kg of tomatoes), while a basin carries 34 kg and the bucket carries 21 kg of tomatoes.) Farmers were provided with field-books in which they recorded harvesting dates; the amount of boxes/bucket/basin harvested; the type of box; number of labourers employed, labour cost and selling price. Farmers gave the labourers who helped in the harvesting about 2 kg each of tomatoes at the end of each harvesting day as part of their wages. These were also factored into the computation of the total yield (Figure 6.2a). Also the amount (by weight) of fertilizer applied was estimated (Figure 6.2b), showing that fertilizer applications tend to be very high: on average more than 1,000 kg/ha. Comparing Figure 6.2a & b suggests a positive correlation between crop yield and the amount of fertilizer applied.

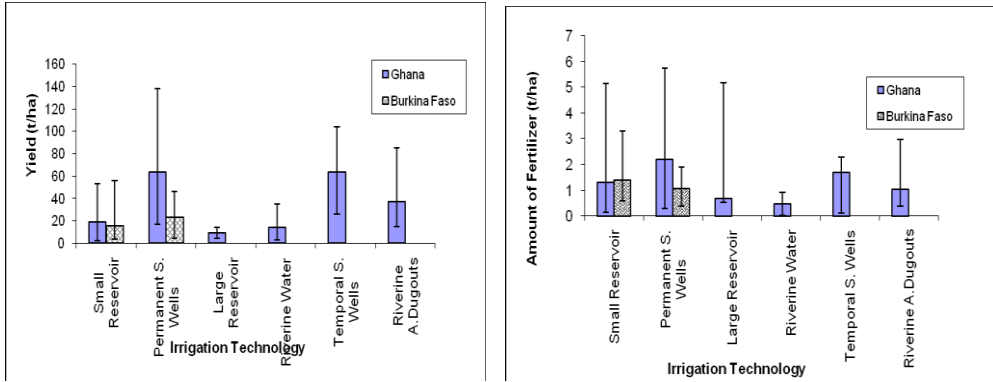


Figure 6.2: a) Average tomatoes yield for 2008; b) Fertilizer input for tomatoes.

6.4 DATA ANALYSIS

This section analyses the factors affecting the yield of all the technologies using a simple regression analysis model. It also analyses the water productivity of all the technologies as well as the value of water obtained. The final analysis concerns the socio-economic impact of the various irrigation technologies.

6.4.1 Analysis of crop yield of irrigation technologies

A regression analysis was performed on all 90 tomato farmers included in the analysis to establish the relationship between crop yield and other input parameters, such as fertilizer, water consumption, water source, and water application method, characteristic of the different irrigation technologies in the sample. The following mathematical equation was established:

$$Y = -2.2 + 201.4 \times A_f + 17.7 \times D_grw + 17.6 \times D_man \text{ (Equation 6.2)}$$

$$r^2 = 0.76$$

where: Y = crop yield (kg/m²)

A_f = amount of fertilizer applied (kg/m²)

D_grw = dummy variable for if the source of water is groundwater (D=1) or surface water (D=0)

D_man = dummy variable for if water is applied manually (D=1) or mechanically (D=0)

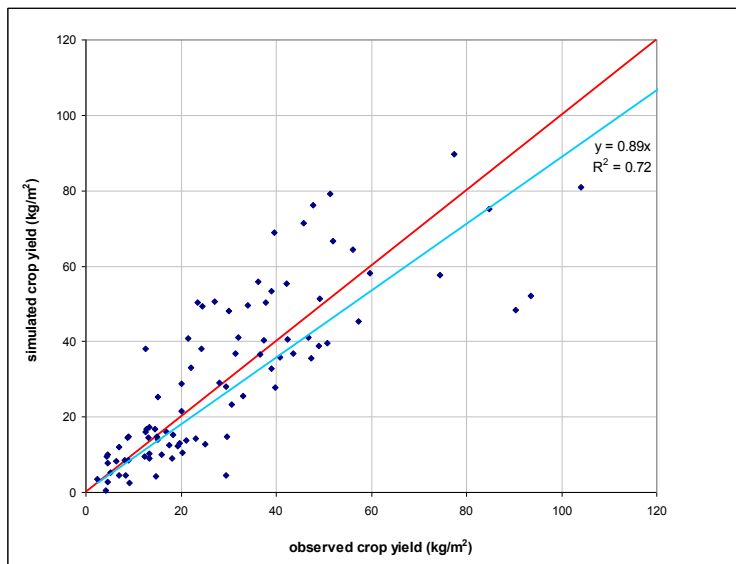


Figure 6.3: Performance of a regression analysis of crop yield of irrigation technologies.

Further statistical analysis on the results showed that the estimates of the parameters are significant at 5% level. Figure 6.3 shows the relationship between observed and simulated crop yields of all 90 farmers included in the analysis.

Equation 6.2 shows that the amount of fertilizer applied to the crop has a significant impact on crop yield: 1 kg/m² of chemical fertilizer applied results in a yield increase of 200 kg/m² tomatoes per season. This figure is higher compared to the O/N (output/nutrient) ratio in West Africa for other crops such as maize (range of 0-54) and groundnuts (range of 4-21) (Yanggen et al., 1998), implying a high yield response to fertilizer for tomatoes in the study area. The Value/Cost Ratio (VCR), which is a rudimentary indicator of potential profitability, is also measured based on the yield response to fertilizer, the cost of fertilizer (see Section 6.3.2) and the sales value of tomatoes (see Figure 6.4b). The VCR for applying fertilizer to the tomato crop ranges from 5-120 in the study area. According to Kelly (2005) the rule-of-thumb for VCRs is that they must be at least two before a farmer will consider fertilizer use, while in high-risk production environments the minimum VCR for adoption may be 3 or 4. This implies that fertilizer use in tomato production has a high profitability in the study area.

Equation 6.2 indicates that irrigation technologies that rely on groundwater achieve significantly higher crop yields than those relying on surface water. We have no satisfactory explanation of this finding, but it may be associated with factors that are associated with irrigation technologies that abstract groundwater rather than the groundwater itself. Equation 6.2 also indicates

that manual abstraction technologies are more productive than motorised abstraction (pumps). This is perhaps because manual application of water by bucket is more precise and closer to the roots, which enhances crop production.

6.4.2 Water productivity

Water productivity is a measure of performance generally defined as the physical quantity or economic value generated from the use of a given quantity of water (Molden et al., 2003). Increasing water productivity to obtain higher output or value for each drop of water use is key to the efficient use of water in the sub-basin and therefore a very important factor in the comparative analysis of irrigation technologies. The productivity of the various irrigation technologies in the sub-basin is an important variable for decision on up-scaling irrigation technologies: the higher the productivity of a technology, the more efficient the scarce water will be used.

Water productivity equals the crop yield divided by the volume of water applied. The average water productivity can then be computed for each technology (Figure 6.4a). This water productivity approach helps to compare the water management weaknesses of the various technologies and gives an idea of the improvement required to make the irrigation technology water efficient.

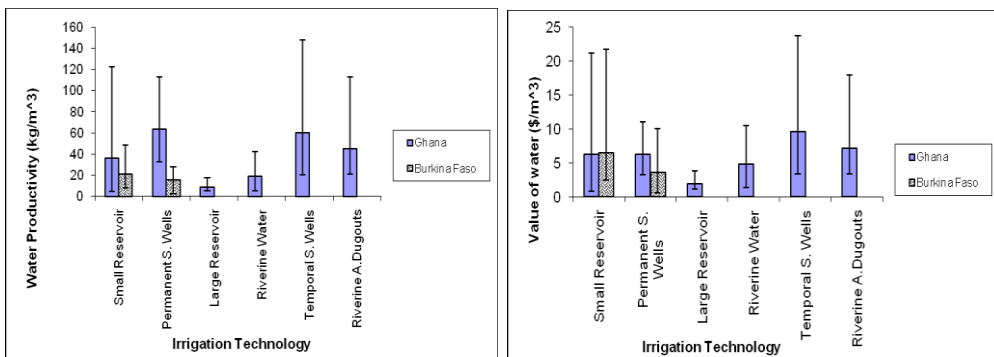


Figure 6.4: a) Water productivity for tomatoes in 2008; b) Value of water for tomato production in 2008.

Figure 6.4a shows that the temporal and permanent shallow wells (producing 60 kg of tomatoes per m³ of water applied), and riverine alluvial dugouts (45 kg/m³) are the most water productive technologies in the Upper East Region of Ghana. However the same cannot be said of permanent shallow wells in Southern Burkina Faso. Water productivity of permanent shallow wells and small reservoirs in Southern Burkina Faso are about 50% and 30% of that in the Upper East Region. The large reservoir irrigation scheme is the technology with the lowest water productivity (9 kg/m³). This confirms the

results of Mdemu (2008) who found that the water productivity of a small reservoir (Dorongo dam) was higher than that of a large reservoir scheme (Tono) in the Upper East Region of Ghana. The observed water productivity for the shallow wells are higher than most published figures and are most probably due to the high fertilizer application on these fields. For example in Molden et al. (2007) the fertilizer application ranges from 9kg/ha in sub-Saharan Africa to 135kg/ha in South-East Asia resulting in a water productivity for tomatoes ranging from 5-20 kg/m³.

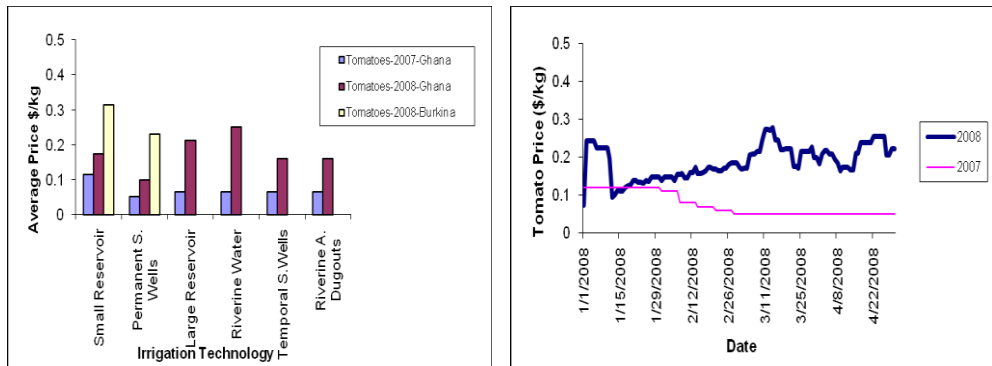


Figure 6.5: a) Farm-gate prices for tomatoes in 2007/2008; b) Trend of farm-gate prices for tomatoes in 2007/2008.

The value of water obtained under tomato cultivation by these irrigation technologies is estimated using the average market price of tomatoes and their corresponding water productivities per each technology. Figure 6.5a & b give the recorded on-farm tomato prices for various irrigation technologies and the average tomato market prices for 2007 and 2008. These figures show that the market prices are not the same for all irrigation technologies and that they fluctuate throughout the harvesting season. Also the market prices of tomatoes depend on the location of the technology. Technologies located close to the main road attract higher market prices from traders while those further away from the main road have lower market prices. Those close to the main road have easy access to traders from southern Ghana while those further away have difficulty in accessing traders from southern Ghana and are sometimes compelled to sell to the local market at lower prices.

6.4.3 Economic impact of irrigation technologies

Due to the semi-arid nature of the sub-basin which is characterised by short rainy seasons coupled with the fact that over 85% of the inhabitants practice subsistence farming, there are little employment opportunities during the dry season. This accounts for the high rural-urban migration during the dry season to do menial jobs in the urban centres. Creating job opportunities for the inhabitants during the dry season improves local livelihoods and thus reduces poverty. The additional income made by the farmer and labourer

through irrigated farming goes to support their families (in education, feeding, shelter and health), thereby reducing poverty in society in general.

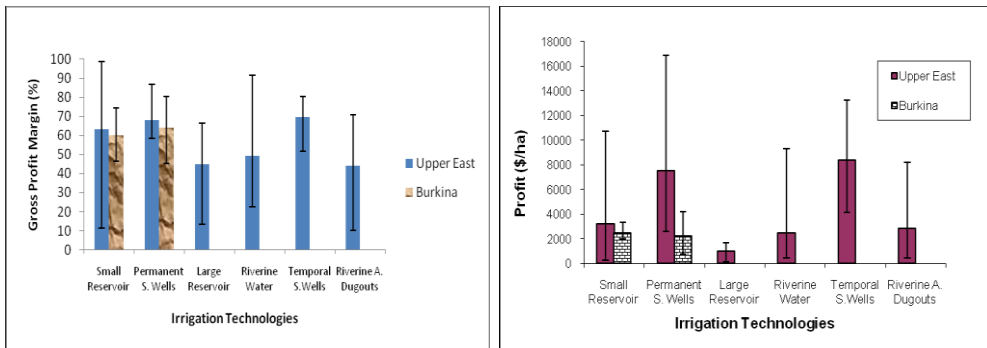


Figure 6.6: a) Gross profit margin for tomato production; b) Farmer profit for tomato production.

Figure 6.6a shows that the large reservoir irrigation farmer has the lowest profit margin amongst all the irrigation technologies. The temporal and permanent shallow wells have the highest profit margins making the two technologies the most economically viable irrigation technologies. Interestingly, despite the relatively large farm plots of the large reservoir irrigation scheme, the profit made per farmer is almost equal to that of the temporal shallow well farmers. The average profits for the season were for small reservoirs US\$420/farmer, permanent shallow wells US\$225/farmer, large reservoir irrigation US\$470/farmer, riverine water US\$1,050/farmer, temporal shallow wells US\$420/farmer and riverine alluvial dugouts US\$620/farmer. Thus unless the productivity of the large irrigation scheme is improved the users are not better off than those using more expensive technologies on comparatively smaller plots.

6.4.4 Social impact- employment/labour and women participation

The operational costs spent on labour hired from the inhabitants of the sub-basin during the irrigation season helps reduce poverty in the sub-basin. The irrigators employ basically the youth and women. Typically, the youth are hired as farm assistants by farmers using riverine water, large irrigation schemes and the riverine alluvial dugouts. Also the youth are hired for land preparation, transplanting, weeding, digging and harvesting. Women are mostly hired for transplanting and harvesting of tomatoes, rice and pepper by farmers.

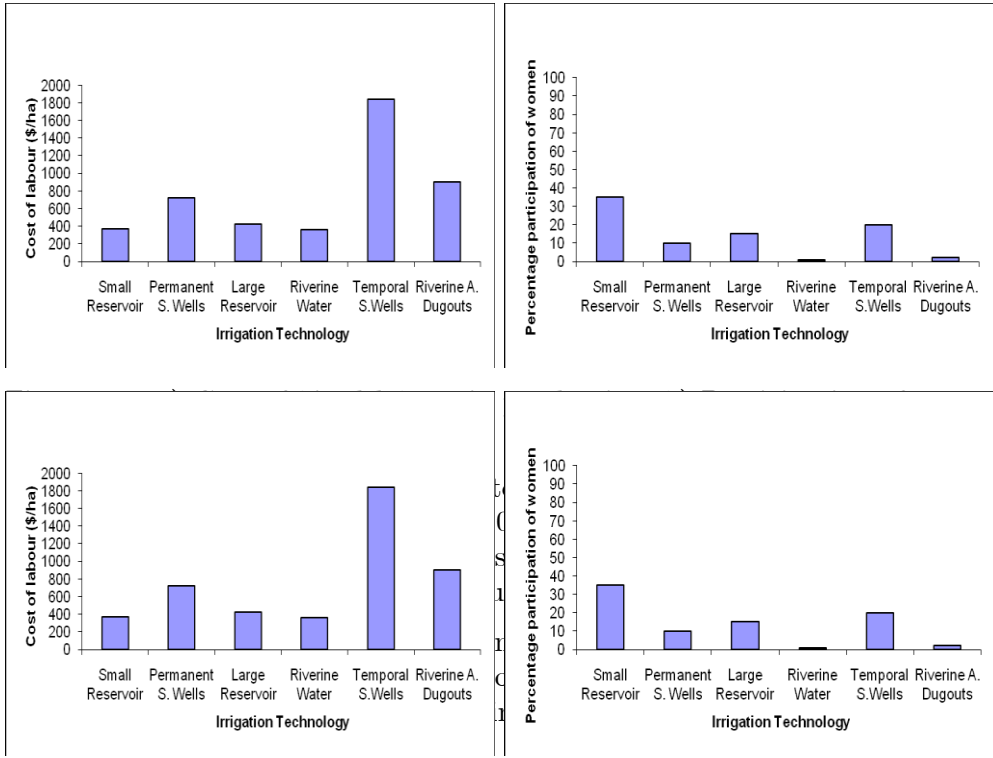


Figure 6.7 Figure 6.7b it is observed that some technologies are more favourable towards women and may be due to factors such as existing land tenure arrangements, cost of the technology and the motivation they may be receiving from the men. The promotion of irrigation technologies should consider associated factors that will improve women participation.

Table 6.3: Comparison of irrigation technologies using productivity factors.

Parameter	Small Reservoir	Permanent Shallow Wells	Large Reservoir Scheme	Riverine Water	Temporal Shallow Wells	Riverine Alluvial Dugouts
Development and management	Very expensive; developed by government and NGOs, managed by the community	Manageable cost, developed and managed by individuals and farmer groups	Very expensive; developed by government and managed by public institution.	Manageable cost, developed and managed by individuals and farmer groups	Manageable but expensive due to short life-span of wells; developed and managed by individuals	Expensive due to short life-span of dugouts, labour and energy cost; developed and managed by individuals
Plot size	Has relatively small farm sizes which are manageable by the poor farmer	Has relatively small farm sizes which are manageable by the poor farmer	Has relatively large farm sizes which requires more financial resource for the user	Has relatively large farm sizes which requires more financial resource for the user	Has relatively small farm sizes which are manageable by the poor farmer	Has relatively small farm sizes which are manageable by the poor farmer
Fertilizer & chemical input	Adequate amounts are applied due to relatively small farm plots	Adequate amounts are applied due to relatively small farm plots	Poor farmers are not able to provide adequate amount as a result of large farm plots	Poor farmers are not able to provide adequate amount as a result of large farm plots	Adequate amounts are applied due to relatively small farm plots	Adequate amounts are applied due to relatively small farm plots
Water use	The cost of water-use is the cheapest. Water-use is controlled and not flexible	The cost of infrastructure is manageable. Water-use is uncontrolled and flexible	The cost of water-use is the cheapest. Water-use is controlled and not flexible	The cost of infrastructure is manageable. Water-use is uncontrolled and flexible	The cost of infrastructure is manageable. Water-use is uncontrolled and flexible	Water abstraction cost is expensive. Water-use is uncontrolled and flexible

Parameter	Small Reservoir	Permanent Shallow Wells	Large Reservoir Scheme	Riverine Water	Temporal Shallow Wells	Riverine Alluvial Dugouts
Crop yield	Has good crop yield	Has very high crop yield	Has the least crop yield	Has low crop yield	Has very high crop yield	Has high crop yield
Water productivity	Has good water productivity and good value of water	Has the highest water productivity, but value for water is reduced by poor market for products	Has the least water productivity as well as low value for water	Has low water productivity but good value for water due to good market for products	Has very high water productivity and good value for water	Has good water productivity and good value of water
Poverty reduction	Creates more employment per unit area for farmers especially women ; profit of about US\$400/farmer/season	Creates more employment per unit area and has profit of about US\$220/farmer/season	Low profits are recorded especially by poor farmers. Provides income to society through labour generation; profit of US\$450/farmer/season	Low profits are recorded especially by poor farmers. Provides income to society through labour; profit of about US\$1050/farmer/season	Creates more employment per unit area for farmers (both gender); profit of about US\$420/farmer/season	Good profits, provides a lot of employment for farmers and labour for the youth. Low women participation; profit of about US\$600/farmer/season

6.5 CONCLUSION

A summary of the strengths and weaknesses of the irrigation technologies in the sub-basin in terms of productivity is presented in Table 6.3. Both the farm records and the regression analysis have shown that apart from water being a pre-requisite for successful irrigation adequate fertilizer application is the major factor to achieving high irrigation productivities. Farmers are willing to apply fertilizer because of high returns to the investment, and this is facilitated by a relatively strong and predictable market for tomatoes.

The impact that an irrigation technology has on the irrigation productivity has got to do with the control over the water resources by the farmer and the size of the farm irrigated by the technology. Technologies characterised by relatively small farm sizes are better managed by the surveyed farmers because they are able to provide adequate water and crop nutrients thus resulting in higher productivity. The large irrigation scheme where farm plots are relatively large has a low productivity (in terms of land, water and profit margin).

The most productive irrigation technologies are the temporal and permanent shallow wells, followed by the riverine alluvial dugout. Moreover, these highly productive irrigation technologies also achieve good profit margins and provide income opportunities to the wider society in terms of labour and also have higher women participation. This confirms the claim by Chambers (1988) that small farms can be more efficient than large farms, and the claim of Obeng-Asiedu (2004) that small-scale technologies can be profitable, financially sustainable and able to do better than large scale irrigation schemes in the Volta basin.

The findings imply that in order to achieve high impact, irrigation development in sub-Saharan Africa should consider the economic status of the users and their ability to make the best out of the technology in terms of productivity. Also, the technology should give control over the water to the farmer. The resulting economic activities have a large positive spinoff in terms of job opportunities, especially for the youth. Also, participation of female farmers was significant in most technologies surveyed.

Finally apart from technologies that depend on reservoirs, all other technologies are farmer driven and required no government support. This ongoing type of endogenous irrigation development in the study area provides a strong backing that the way forward in sub-Saharan Africa is for governments to create policies that facilitate poor farmers becoming irrigation entrepreneurs. Such policies should aim to enhance the reliability

156 Productivity of Irrigation Technologies in the White Volta sub-basin

of markets (both input and output) as the driving force, and facilitate people's access to land and water. The role of access to credit and agricultural extension services in irrigation development remains unclear.

Chapter 7

PAST AND FUTURE TREND OF IRRIGATION DEVELOPMENT IN THREE CATCHMENTS OF THE WHITE VOLTA SUB-BASIN

7.1 INTRODUCTION

In sub-Saharan Africa there is great potential for expansion of irrigated agriculture. The average rate of expansion of the irrigated area over the past 30 years was 2.3 percent per year. Expansion slowed to 1.1% per year during 2000–2003 but has since picked up as a result of renewed investments by multilateral and bilateral donors and foundations (You et al., 2010). For the NEPAD and Commission for Africa to achieve the MDG target, irrigated agriculture will need to grow at an annual rate of about 5% which is unprecedented.

The achievement of this target requires an assessment of the factors that have influenced past trends of irrigation development. It also requires identification of additional interventions needed to accelerate the future expansion and the potential influence of such interventions. There are triggers that can influence the upscaling of irrigation development which need to be harnessed to help achieve irrigation targets. For example, the rural economy in Sub-Saharan Africa is boosted as smallholders benefit from the opportunity to produce irrigated vegetables for the growing domestic market (de Fraiture et al., 2007). Estimates show that by 2030 60% of the world's people will live in cities (Molden et al., 2007). As a result Sub-Saharan Africa can take advantage of this trend to trigger the upscaling of irrigated vegetable production by using rural economies.

A typical example of the upscaling of vegetable irrigation is observed in the Upper East Region of Ghana and southern parts of Burkina Faso; all in the White Volta sub-basin. Here, the demand for vegetables in the urban centres of southern Ghana has triggered the upscaling of irrigation development during the past two decades (Namara et al., 2010; Namara et al., 2011). It is interesting to use this positive development to help bring out some of the strategies that are needed in boosting irrigation development across sub-Saharan Africa.

Previous chapters have described the various irrigation technologies that have emerged out of this development and also identified why newly

introduced technologies have been adopted by the users. This chapter seeks to investigate the trend of the upscaling of these technologies and also the factors (physical, technological, social and economical) that have contributed to these developments. The chapter goes further to identify some triggers and interventions that can possibly influence future trends of irrigation development in the study area.

The aim of this chapter is to improve our understanding of what sustainable irrigation development would mean in the context of the White Volta sub-basin.

The objective is first to establish the historical trend of irrigation in the study area and identify the factors (physical, technological, social and economical) and interventions that have influenced this trend. Second, the study seeks to project the observed trend into the future, taking into account the irrigation potential in the three catchments, possible future interventions, and policy-related issues.

7.2 METHODOLOGY

The study was conducted in three catchments of the White Volta sub-basin, being the Anayari, Atankwidi and Yariatanga catchments where several irrigation technologies have been observed. Data used for the study were obtained from: farmer interviews, institutional interviews (Ministry of Food and Agriculture (MOFA) and Ghana Irrigation Development Authority (GIDA)), field surveys and observations, ground-truthing; research reports, project and country reports and satellite images (2003, 2005, 2007 and 2010).

The first objective of this chapter, the study of historical trends of irrigation development, involved a combination of data and satellite image analyses. The analysis was based on information on irrigation development in the study area from the 1950s to the present.

The image analysis used a series of satellite images of the study area in combination with ground-truthed data and field observations. Different types of satellite images for this analysis were available for the study area. These include Land-sat (from 1979 to present), Aster images (from 1990 to present) and spot-images (from 1990 to present). Due to the resolution of some of these image types (Land-sat: 30mx30m; Aster: 20mx20m and Spot: 10mx10m or 5mx5m) and the relatively small sizes of most small-scale irrigation systems (0.01-0.7ha), it was impossible to detect most small-scale irrigation activities in the study area with the Land-sat and Aster images. Annual irrigation activities are intensive between late December and late February, thus satellite images for irrigation analysis have been taken within

this period. Spot images for the study area lacked quality or fell outside the required period. The most reliable source of satellite images was Google Earth which had historical images from 2003 to present within the required period and with a resolution of 5mx5m.

The Google Earth images for 2003, 2005, 2007 and 2010 were screen-printed at high resolution and later merged. The irrigation activities observed in the Google earth images were delineated with the help of ground observations.

The forecasting of future irrigation development is based on the following factors: historical trend, irrigation potential, possible future interventions (policies, investments and technology), and emerging issues (economy, markets and entrepreneurship) (Shah, 2003; Faurès et al., 2007; Molle and Berkoff, 2006).

7.3 PAST TREND OF IRRIGATION DEVELOPMENT IN THE WHITE VOLTA SUB-BASIN

Irrigation development in the White Volta sub-basin started during the colonial era by the colonial governments and continued through the post-colonial era by governments in partnership with development agencies. In recent times private-led irrigation development has also been significant in the sub-basin.

Governments started with the development of small-reservoirs and dugouts purposely for domestic water-use, livestock and irrigation. The development of small-reservoir based irrigation systems in Burkina Faso began in the 1940s. In 1991, 1100 village dams had been built in Burkina Faso, mainly for cattle and drinking water purposes (Sally, 1997). Presently, many dams in Burkina Faso are built or converted to function also as reservoirs for irrigation water (van de Giesen, et al., 2001). Currently there are over 1700 small-reservoirs developed in Burkina Faso with half of them located in the White Volta sub-basin (Cecchi et al. 2009; Boelee et al., 2009).

In Ghana, the development of small-reservoirs and dug-outs began in the early 1950s for the same reasons as in Burkina Faso. Presently there are about 200 small reservoirs developed in the Ghana section of the White Volta sub-basin. Data compiled by GIDA in 1994 showed that there were about 73 dugouts in the Upper East Region. Literature (Ofori et al., 2006) shows that by 2003 there were over 850 dugouts in the Northern and Upper East Regions of Ghana.

The governments of Ghana and Burkina Faso have also developed large-scale irrigation schemes in the White Volta sub-basin. The large-scale irrigation schemes developed in the White Volta sub-basin of Ghana are the Vea (850

ha), the Tono (2490 ha) and the Bontanga (450 ha). In the White Volta sub-basin of Burkina Faso, the large-scale irrigation schemes developed include the Bagre (2140 ha) and Sourou (2000 ha).

In this section two kinds of analysis are used in assessing the historical trend of irrigation development in the basin. The first employs data on irrigation development from literature and country reports. The second employs the use of historical satellite images combined with ground-truthing to map out irrigated areas in the study area from 2003 to present. The trend analysis is limited to the three catchments, where detailed studies have been conducted and quality satellite images were used for the analysis. The study assumes that the trends experienced within the three catchments are similar to the general trend in the White Volta sub-basin.

7.3.1 Data Analysis of Irrigation Development in the study area

This section analyses the recorded and reported irrigation development in the three catchments (Anayari, Atankwidi and Yarigatanga). Data is obtained from research papers, project reports, the Ministry of Agriculture and Ghana Irrigation Development Authority. Information on irrigation development is collated to develop the trend of irrigation development in the study area and also to deduce the area covered with irrigation over the years.

Table 7.1 Small and Large Reservoir Irrigation systems in the entire study area

Catchment	Anayari	Atankwidi	Yarigatanga		Total
	Small-Reservoirs	Small-Reservoirs	Small-Reservoirs	Large-Reservoir	Small-Reservoirs
1951-1960	5	2	1	0	8
1961-1970	1	1	5	0	7
1971-1980	0	0	2	Vea scheme	2
1981-1990	0	3	0	0	3
1991-present	0	0	0	0	0
TOTAL	6	6	8	1	20

The records obtained provide information on the formally developed irrigation systems such as small reservoirs, large reservoirs and dugouts. Records from GIDA show that there are 31 small reservoirs, 1 large reservoir and 23 dugouts developed in the study area (Figure 2.7). Out of the 31 small

reservoirs developed, 20 are used for irrigation (Table 7.1). The records include the years that the systems were developed but not the irrigated areas developed. Due to the lack of records on the irrigated areas, an average figure from an earlier study was used. Birner et al. (2005) investigated 25 small reservoirs in the Upper East Region and identified that the average size of land irrigated by a small reservoir was 8.5 ha.

7.3.2 Satellite Image Analysis of Irrigation Development in the Study Area

The satellite image analysis is intended to trace the irrigation footprints within the study area. The Google Earth images obtained over the years (2003, 2005, 2007 and 2010) were limited in aerial coverage over the study area. For consistent analysis, observation windows common to all the years were outlined for all three catchments (see the red outlines in Figure 7.1 and Figure 7.2) and used as the area of analysis. Thus the trend of irrigation development was analysed for about 30% of the Anayari catchment, 100% of the Atankwidi and 30% of the Yarigatanga catchment. The image analysis for the Anayari catchment could be carried out on all the four years but for the Atankwidi and Yarigatanga catchments it could be carried out for 2005, 2007 and 2010.

In the Google Earth image, all irrigation systems observed are traced and coloured. These include the large-scale irrigation, small reservoir irrigation, shallow wells irrigation and riverine pump irrigation. Irrigation activities are grouped into two types: government-led and private-led irrigation systems. There are two reasons for grouping these irrigation systems as such. Firstly, the driving forces behind the development of these technologies are different. Differentiating the two types gives more clarity as to which type of investment is behind the expansion of irrigation in the study area. Secondly some of the shallow groundwater technologies such as temporal shallow wells, permanent shallow wells and riverine alluvial dugouts are mixed up in the same location and as such cumbersome to distinguish on the image. To make the distinction between irrigation technologies simple a common factor for these technologies is used. The common factor amongst these technologies is that they are all private-led, thus the choice of private-led and government-led irrigation systems.

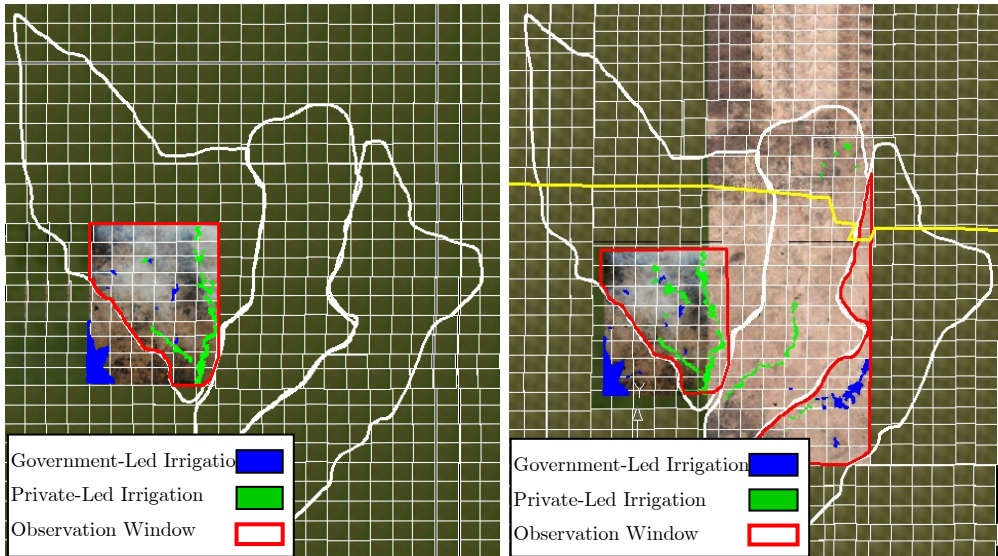


Figure 7.1: Irrigated areas in observed in 2003 and 2005 (images taken on 16-01-2003 and 27-01-2005).

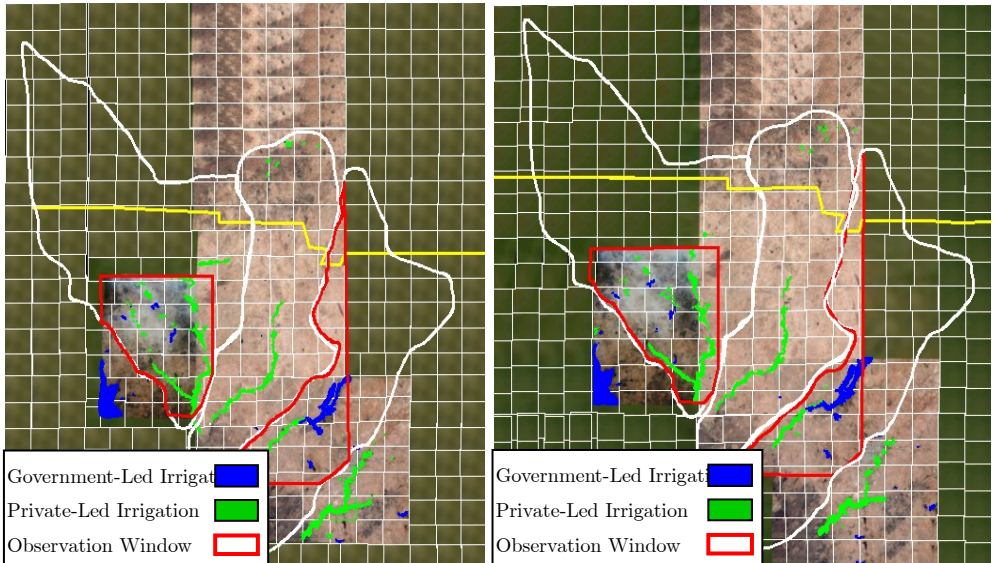


Figure 7.2: Irrigated areas observed in 2007 and 2010 (images taken on 10-01-2003 and 27-01-2010).

The private-led irrigation systems are located along stream channels and flood plains where groundwater levels are high. Another location where there is expansion in private-led irrigation systems is downstream of the large-

reservoir irrigation scheme. Farmers make use of return flows from the large-reservoir irrigation scheme for private irrigation farms. A consistent expansion of private-led irrigation systems is observed from the Google earth images from 2003 to 2010. The irrigation developments along the streams continue to expand over the years. However, there are some stream channels and flood plains where more irrigation can be developed but which currently remain untouched.

Irrigated areas observed in the satellite images were estimated. Due to the methodology used in producing images in Figure 7.1 and Figure 7.2, the scale of the images could not be determined. However, knowledge of the size of the Vea irrigation scheme was used as a benchmark in estimating the area of other irrigation sites. The irrigated areas were divided into smaller pixels and the trapezoid method was applied in estimating the area. Table 7.2 shows the irrigated areas estimated from the satellite images.

Table 7.2: Estimated irrigated areas from satellite images

Catchment	Anayari Catchment (ha)		Atankwidi Catchment (ha)		Yarigatanga Catchment (ha)	
Observed Area (%)	30%		100%		30%	
Irrigation Type	Government-led Irrigation	Private-led Irrigation	Government-led Irrigation	Private-led Irrigation	Government-led Irrigation	Private-led Irrigation
2003	60	380	n/a	n/a	n/a	n/a
2005	65	420	2	191	153	20
2007	44	485	2	230	326	104
2010	40	483	2	224	355	155

The observed irrigated areas for Anayari and Yarigatanga catchments are extrapolated to cover the total catchment area based on ground observations. In the extrapolation, the irrigated area by small reservoirs in the satellite observation is considered to be proportional to the total catchment area. Private-led irrigation is more intense at the downstream portions of the catchment, as a result in the extrapolation, the intensity of private-led irrigation in the unobserved areas is estimated to be half of the observed. Table 7.3 shows the irrigated areas for the extrapolation.

Table 7.3: Extrapolated irrigated areas from satellite images

Catchment	Anayari Catchment (ha)		Atankwidi Catchment (ha)		Yarigatanga Catchment (ha)	
Considered Area (%)	100%		100%		100%	
Irrigation Type	Government-led Irrigation	Private-led Irrigation	Government-led Irrigation	Private-led Irrigation	Government-led Irrigation	Private-led Irrigation
2003	200	760	n/a	n/a	n/a	n/a
2005	217	840	2	191	174	41
2007	147	970	2	230	348	208
2010	133	966	2	224	379	230

7.3.3 Past Trend of Irrigation Development in the study area

This section estimates the general trend of irrigation development within the study area by combining results from the data analysis and satellite image analysis. The trend analysis starts from 1950 when the development of small reservoirs for irrigation began in the study area.

In this trend analysis, the developed irrigated areas are distinguished from the actual irrigated areas. This distinction is relevant for the government-led irrigation systems (Table 7.4). For example, the actually irrigated area in the Vea scheme fluctuates with time, as are the areas irrigated from the small reservoirs. The government started irrigation development from the 1950s with small reservoirs, followed by the development of the Vea scheme in 1980. Table 7.4 shows that irrigated areas in the government scheme have never reached the developed level.

Table 7.4: Government and private-led irrigated areas in the study area.

Year	Government-led Irrigation (ha)				Private-led Irrigation {C} (ha)	Total Irrigated Area {A+B+C} (ha)
	Developed Irrigation Areas (Small & Large Reservoir Irrigation Systems*)	Veia irrigated areas		Small Reservoirs Irrigated Area {B}		
		ICOUR Records	Satellite Image {A}			
1950-1960	68	n/a	n/i	n/i	n/i	n/i
1961-1970	128	n/a	n/i	n/i	n/i	n/i
1971-1980	993	450	n/i	n/i	n/i	n/i
1981-1990	1017	404	n/i	n/i	n/i	n/i
1991-1995	1017	294	n/i	n/i	n/i	n/i
1996-2000	1017	331	n/i	n/i	n/i	n/i
2003	1017	377	n/i	n/i	n/i	n/i
2005	1017	111	145	248	1076	1469
2007	1017	340	312	185	1408	1905
2010	1017	350	345	164	1420	1929

n/i, represents no image

* obtained from records on irrigation development

The expansion of private-led irrigation systems in the study area could not be established due to lack of data. Interviews conducted in the study area have revealed that the spread of the private-led irrigation technologies began in the mid 1990s. It would have been interesting if useable spot images could have been obtained for this period. From the satellite image analysis an average growth rate of 5.7%/a of private-led irrigation in the study area was observed from 2005-2010. With regards to government-led irrigation development, there were no new additions. Rather the area irrigated by small reservoirs decreased, and this may be due to infrastructural challenges associated with the small reservoirs as a result of age and lack of maintenance. However, the Veia irrigation scheme which irrigated 17% of the developed area in 2003 increased to about 41% in 2010. The irrigated area in Veia observed from the image analysis, is comparable to the records of ICOUR, albeit that the latter are slightly lower than what was observed by the images. This may be due to the fact that ICOUR used information on registered farmers for the season, which does not necessarily represent all farmers in the scheme (from interviews the Veia management claimed that on average only about 80% of farmers are registered). It should be noted, however, that this is not reflected in Table 7.4, because results in Table 7.4 represent irrigated areas within the observation window which cuts off

portions of the Veia scheme (see Figures 7.2 and 7.3). ICOUR records on irrigated areas in Veia show a general decline over the past 30 years.

The average irrigation growth rate in the study area is 5.6%/a over 5 years. The major contributor to this trend is the upscaling of private-led irrigation systems. Private-led irrigation is 74% of the total irrigated area in the study area. Comparing this to the reported maximum rate of irrigation development (2.3%/a) across sub-Saharan Africa makes the growth in the White Volta sub-basin impressive (You et al., 2010). Most of the studies conducted across sub-Saharan Africa have focused on formal irrigation schemes. This study shows that the contribution of private-led irrigation is significant in the study area. It is therefore important to consider such private led (and sometimes called informal) irrigation development in all parts of sub-Saharan Africa. The potential for the upscaling of private-led irrigation is high and thus factors influencing the past trend are worth investigating. Findings can help inform policy making in support of irrigation development.

7.3.4 Factors Influencing Past Trend

Having established the historical trend of irrigation development in the study area, this section tries to identify and assess the factors that have influenced the past trend of irrigation development. The factors identified are: (1) rising demand for vegetable products in the urban centres of southern Ghana, (2) challenges farmers had with existing government-led irrigation systems, (3) availability of appropriate irrigation technologies, (4) favourable land-tenure system, and (5) availability of cheap labour and farm inputs.

Market for Vegetables

The major contributor to the expansion of irrigation in the study area is the rising demand for vegetable products in the urban centres of southern Ghana. The increasing rate of urbanisation in Ghana, coupled with increasing population has both contributed to the increasing demand for vegetables. There are three major sources, of vegetables (especially tomatoes) for urban centres in Ghana (coastal area, middle-belt and Upper East Region). Each of these centres has a specific production period. From the month of January to early May the main source of tomatoes is the Upper East Region; from May to early September the production area of tomatoes is the middle-belt of Ghana (Ashanti, Eastern and Brong-Ahafo Regions) and from September to December it is the coastal belt (Keta and its surrounding areas). Therefore the Upper East Region is assured of reliable markets every year (see Figure 7.3a). The production season of the

Upper East Region is within the dry-season therefore requiring irrigation for vegetable production.

Apart from tomato production, the Upper East Region and countries such as Burkina Faso and Mali are the main sources of supply of onions for the urban centres of Ghana.



Figure 7.3: a) Women from southern Ghana buying tomatoes from the Upper East Region; b) Small reservoir with breached dam wall.

Challenges associated with Government-led Irrigation systems

For a very long time the government had been the main investor in irrigation infrastructure in the study area. The management of these schemes are centralised and managed by government agencies. While the demand for vegetables increased, farmers had challenges with the use of some of these government-led irrigation systems which affected their productivity. The large-scale irrigation scheme had unresolved land-tenure problems which denied local farmers access (Tate and Lyle, 1982). Also the rigid control of irrigation water supply by the management of the large-reservoir irrigation schemes did not necessarily conform to specific farmer demands.

Some of the small-reservoirs that had been developed had major infrastructural problems and could not be used (see **Figure 7.4:b**). The developed irrigable areas of some small reservoirs limited the addition of more farmers who were willing to farm. The best that Water User Associations could do was to reduce farm plots of existing farms to accommodate new ones.

This led to farmers seeking for alternative irrigation systems where they could gain and maintain control over the water resource and also develop

land as much as they could afford. Some farmers purchased motorized pumps to enable them to pump water directly from small reservoirs and for conveyance to land they personally developed outside the officially developed areas, by which they “jump” the water queue (Figure 7.5b). In other areas farmers looked for access to groundwater sources for irrigation farming (Figure 7.5a).



Figure 7.5: a) Temporal shallow wells being used for tomato production; b) Motorized pumps being used at small-reservoirs for irrigation.

Availability of appropriate irrigation technologies

The availability of appropriate technologies is another significant factor that has influenced the trend of irrigation development in the study area. As farmers sought for alternative irrigation technologies they ended up improvising some locally available technologies which aided them in abstracting and applying water to their crops. The most prevalent of these technologies is the rope and bucket. This technology aided them in harnessing shallow groundwater for irrigation. The advantages of using this technology are that it is cheap, locally available and does not need skill in its application. This made it easily adaptable by the local farmers. Also the availability of motorized pumps on the local market encouraged farmers to explore the options of riverine pump irrigation. This also gained grounds. The initial capital cost is relatively high compared to other technologies; thus, it is not as common as the rope and bucket.

Favourable land-tenure system

Irrigation farming in the area is done mainly by the youth. Most lands are owned by the household heads with the majority of them being elderly men. The existing land-tenure arrangement in the study area enables the youth to hire land on temporal bases for dry-season irrigation. This also enables

women who don't own land in the study area to access land for dry-season irrigation. Thus women participation in these irrigation developments (about 30% of temporal shallow well farmers are women) is encouraged.

The temporal land arrangement however prevents most farmers from investing in permanent infrastructure for their irrigation activities. Permanent infrastructure, such as permanent shallow wells, is only developed by some landowners.

Availability of labour, energy, farm inputs and credits

The availability of some important factors of production has also enabled the emergence of these new irrigation technologies in the study area. All of the available technologies require the use of labour and/or energy to apply water to irrigation plots. For example the digging of wells and dugouts is labour intensive. Fortunately there is abundant labour available for such activities during the January-April season. Farmers have significantly depended on such labour for the development of these irrigation technologies.

Also farmers need to have reliable access to farm inputs such as seeds, fertilizer, chemicals and machinery. In the study area, access to these inputs is good as well as the servicing of farm equipment, which is provided by the private sector. Irrigation farmers in the study area thus have access to sufficient labour, fuel for motorized pumps, chemicals, fertilizer, seeds and servicing of farm equipments. The ability of some farmer groups to access credits from banks, relatives and friends has also contributed to the current trend of irrigation development in the study area.

7.4 VARIABLES INFLUENCING FUTURE IRRIGATION DEVELOPMENT

The future trend of irrigation development in the study area is likely to be affected by some more variables than those already discussed. These variables include the availability of water and suitable irrigable land, policy interventions, technology, output markets and, finally, reliable support services.

7.4.1 Irrigation Potential of the Study Area

Irrigation potential simply refers to available land suitable for irrigation and for which sufficient water is available (FAO, 1995b). However, irrigation potential is not straightforward and implies a series of assumptions about irrigation techniques, investment capacity, national and regional policies,

social, health and environmental aspects, and international relationships, notably regarding the sharing of waters (IFPRI, 1995). It is an important indicator to help assess future irrigation development.

Few studies on irrigation potential have been conducted in the study area. The first study was conducted by the Water Research Institute of Ghana as part of the Water Resources Management Study of the Volta Basin. In this study the irrigation potential of the White Volta sub-basin of Ghana was estimated as 314,000ha (6% of the catchment area) (Wiafe, 1997).

It is not the objective of this chapter to conduct a detailed irrigation potential assessment of the study area. Therefore the study adopts the irrigation potential of 6% estimated by the Water Resources Management Study. Since the study area is located in the White Volta sub-basin it is likely to have similar irrigation potential characteristics as the basin in general.

Comparing the potential with the developed area implies that over 80% of the potential irrigable area is still undeveloped. Thus there is high opportunity to upscale irrigation in the study area.

The question should be asked whether there are sufficient water resources to realise the irrigation potential. Here only some general calculations will be made.

The average annual rainfall in the study area is about 1100mm/a. The average annual groundwater recharge in the study area is about 66mm/a (Martin, 2006). Using a crop water requirement of about 900mm/season (including transpiration and evaporation) the groundwater irrigation potential of the study area amounts to 6.3%. It should be noted that other competing groundwater uses can reduce this potential.

The annual runoff coefficient in the study area is about 13% (Martin, 2006). If, say, only 10% of this runoff could be stored in reservoirs the irrigation potential can be further boosted by 1.6%.

This simple analysis shows that there are sufficient water resources to fully support the irrigation potential of about 6% of the catchment area.

7.4.2 Drivers for the Upscaling of Irrigation Development

Literature has shown that several drivers led to the large public investments in irrigation in the second half of the 20th century. The drivers include global

efforts (external drivers) to increase staple food production, ensure food self-sufficiency and avoid famine (Faurès et al., 2007; Carruthers et al., 1997).

Similarly there are drivers that are likely to influence the future expansion of irrigation in sub-Saharan Africa which need to be identified and utilized. Researchers still see that there are reasons why investment in irrigation should continue to increase. Some of the reasons identified in the literature are that: (1) irrigation is a pathway for poverty reduction; (2) irrigation is needed for the changing food preferences and changing social priorities; (3) to preserve and modernize the present stock of irrigation; (4) increase in competing water uses demand improving irrigation productivity; and (5) need to respond to climate change impacts (Faurès et al., 2007; Bakker et al., 1999; Molle and Berkoff, 2006 and Quiggin and Horowitz, 1999).

Using the above listed drivers and the past trend as a backdrop, the study summarises the potential drivers likely to influence future trend of irrigation in the study area as: (1) expansion of output market for irrigated products; (2) appropriate and affordable irrigation technologies; (3) government policies and interventions (infrastructure, subsidies, poverty reduction strategies, climate adaptation measures, emerging trends of irrigation management, etc); and (4) reliable farmer support environment.

Expansion of Markets for Irrigated Products

The potentials of output market for irrigated products are likely to increase in the near future and as such capable of influencing future irrigation development in the basin. Future markets for vegetables are expected to increase due to: (1) the rural-urban migration, by 2030 60% of the world's people will live in cities; (2) population growth; (3) changing food preferences (Figure 7.5b) and changing social priorities; (4) achievement of the millennium development goals; and (5) regional integration and free trade policies. A typical example is that exotic vegetables for export markets being introduced in the basin by some NGOs, in particular the Trade and Investment Program for a Competitive Export Economy (TIPCEE). TIPCEE facilitates access to the markets for local farmers.

Another major market influence is the rehabilitated Pwalugu Tomato Factory (Figure 7.5a) which has a capacity of processing 500 Tonnes of tomatoes per day. The current tomato production in the study area is far below the capacity of the factory. This implies that expansion of tomatoes production in the basin can continue before it fully satisfies the factory's demand alone.



Figure 7.6: a) Rehabilitated Pwalugu Tomato Factory; b) Farmers cultivating vegetables such as cabbage for the urban population.

Once farmers are convinced of a reliable output market for their products, they are likely to jump to the opportunities and invest in expansion of their irrigation farms. The market opportunities of the future are therefore likely to further expand irrigation development in the basin. There are indications that the successful operation of the factory may even result in the all-year round cultivation of tomatoes in the study area (Ghana News Agency, 2010).

Appropriate and affordable irrigation technologies

The availability of appropriate and affordable irrigation technologies is one of the factors that influenced the current trend of irrigation development. Farmers are likely to explore more efficient and affordable irrigation technologies in the future. In recent times NGOs such as TIPCEE are introducing modern irrigation technologies (drip irrigation) to support farmers in producing exotic vegetables for export markets (Figure 7.6). A few pilot projects were identified in the study area. TIPCEE expects that local farmers will develop interest in the new technologies and adopt them.

As farmers seek for more reliable sources of water supply they are likely to invest in more efficient irrigation technologies especially with regard to groundwater abstraction. Also farmers are likely to invest in technology that can abstract groundwater at deeper levels and higher volumes for expanded irrigation fields.



Figure 7.7: Pilot project of drip irrigation systems in the Vea Scheme introduced by TIPCEE.

Government Policies and Interventions

In the 1950s-1980s government policies influenced irrigation development in the sub-basin. Some of these policies and interventions have either favoured expansion of irrigation or resulted in a reduction of irrigation. Government investment in irrigation infrastructure has upscaled irrigation development in the past while the removal of agricultural subsidies in the past reduced farmer capacity which affected agricultural productivity.

The desire of governments of sub-Saharan Africa and the African Union Commission to achieve the Millennium Development Goals is a major influence on most government policies. One of the strategies being employed to achieve the targets is upscaling of irrigation across sub-Saharan Africa (de Fraiture et al., 2007; GPRS, 2005). This is likely to lead to increased government investment in irrigation infrastructure, farmer capacity building, appropriate technology and road infrastructure linking production centres to markets. Governments are also likely to provide support for poor farmers to facilitate their ability to engage in irrigation farming thereby improving their living standards.

If these interventions should be implemented by governments, then current irrigation developments in the basin are likely to continue. However, the lack of effective institutions to manage these interventions can become a disincentive to the expected expansion of irrigation.

The recent trend of irrigation management transfers in countries like Mali and Mexico may also affect future irrigation development. The desire by donor agencies and governments to transfer management of public irrigation schemes to farmers is fast gaining grounds. Despite the fact that there are

mixed successes of such transfers, the policy is nevertheless being pushed by many players.

The conventional wisdom that dominated much official irrigation development in the 1950s and 1960s was that irrigation systems required centralized control. Water was a strategic resource over which the state assumed ownership, and water control was a public good, which the state provided. In that era farmer participation was limited to small-scale traditional systems, now farmer participation and even control has become a major component of policies for irrigation development and reform. Under these management reforms farmer participation has moved from a peripheral issue in irrigation management to centre stage (Meinzen-Dick, 1997). Financial pressures to cut government subsidies for irrigation and to improve the management and sustainability of irrigation systems have given impetus to this trend.

Programs to promote farmer involvement range from Participatory Irrigation Management, with farmer input as a supplement to agency management, to Irrigation Management Transfer, in which farmers assume full responsibility for Operation and Maintenance of specific units of systems (Meinzen-Dick, 1997). In the Philippines management transfers enabled the farmers to mobilize resources, undertake contracts, and take on a wider variety of irrigation tasks. The Philippines' experience has had a profound demonstration effect. Impact evaluations showed that there were clear gains, to the farmers as well as to the agency, which more than offset the cost of the program (Bagadion & Kortzen 1991). Also in Sri Lanka participatory management of irrigation schemes involving Farmer Organisations demonstrated improvements in irrigation and other input supplies to their members, but long-range funding of O&M remained problematic (Kloezen 1995). Results of management transfers which took place in Senegal have been mixed. Pump operators responsible to farmers improved the quality of service on many schemes, but the withdrawal of government maintenance services for pump engines led to serious problems and sometimes even to crop failures (Wester et al., 1995). Success stories of management transfer which have taken place in Mexico and Mali have demonstrated the capacity of farmer management of even large irrigation schemes (Meinzen-Dick, 1997; Aw and Diemer, 2005).

Similar signs of these transfers have been expressed by the current management of the Vea and Tono Irrigation Schemes in the basin. Farmers are being organized into Farmer Organizations shifting from the village committee system that has been applied for thirty years. The implications of these transfers are unknown because the success of the reforms will depend

on several factors. A successful management reform is likely to improve the conditions of the large-scale irrigation system which has so far not realised its full potential. Successful reforms which result in improved productivity of government-led irrigation systems may motivate more investment in the development of new irrigation systems.

Reliable Support for Irrigation Farming

Irrigation farmers will continue to rely on labour, energy, input markets and credit support for their activities. The reliability of these essentials is very important for future irrigation development in the sub-basin. As farmers desire for new technologies the sustainability will depend on available support services such as maintenance and skilled labour for such technologies. Also affordable and reliable credit sources are likely to boost the ability of farmers to invest more in irrigation development. Farmers may explore more ways of accessing credits or farm inputs on credit basis for their irrigation.

The risk of seeking credits for irrigation activities cannot be overlooked. Farmers who borrow money for irrigation are likely to run into debts if they fail in making profits. This can result in demoralising the farmers from investing in irrigation, thereby causing a decline in development and production. A loss of profit for tomatoes farmers in 2003 due to output market failure resulted in farmers deserting their farms. This can be deduced from the drop in cultivated areas of the Veia Irrigation scheme from 2003 to 2005 (see Table 7.4). Similar losses resulted in two farmers committing suicide in the Upper East Region of Ghana in 2009 (Daily Guide, 2009).

7.5 FUTURE IRRIGATION DEVELOPMENT IN THE WHITE VOLTA SUB-BASIN

Irrigation development in the basin started in the early 1950s with the construction of small reservoirs. This was followed by the development of the large-reservoir irrigation schemes between 1960 and 1980. The period in which private-led irrigation systems started could not be established from the satellite images due to lack of suitable images and sufficient spatial resolution. Interviews conducted in the study area revealed that private-led irrigation systems intensified in the mid 1990s due to rising demand for vegetables in the urban centres of southern Ghana. The challenges associated with government-led irrigation systems, the advent of appropriate irrigation technologies, a favourable land-tenure system and an enabling local support environment, which include labour, technical services and farm inputs on the

local market, all played major roles in achieving growth rates of 5.7%/a of private-led irrigation systems achieved in the basin during the past two decades. Currently private-led irrigation represents about 74% of total irrigation in the study area. Government-led irrigation systems (small and large reservoirs), in contrast, experienced a general decline in irrigated area over the past three decade. This is mainly due to infrastructural and institutional challenges. So far, the full potential of developed government-led irrigation systems has not been realised. The basin experienced an overall annual irrigation growth rate of 5.6%/a from 2005 to 2010.

This chapter found that over 80% of the potential irrigable area of the basin remains undeveloped. This provides opportunities for future investments in irrigation by both the private sector and government. A combination of the factors identified may further upscale irrigation development beyond the growth rates experienced in the recent past. This expected growth is however subject to effective management of the existing irrigation infrastructure.

The factors that have influenced the past trend are likely to sustain the current state of irrigation in the basin. However additional factors are likely to increase irrigation development beyond the current growth rate in the near future. The additional factors include, expanding markets for irrigated products, introduction of new irrigation technologies, government policies and interventions and emerging trends of irrigation management. Advantage must be taken of these opportunities to upscale irrigation development in the basin knowing that more than 80% of the irrigation potential in the basin remains untapped, and that there seem to be sufficient water resources available to fully support this potential.

The implications of the future trend should however not be overlooked. This is because the upscaling of irrigation in the basin has direct impact on the competing water uses, downstream water uses and the environment. Also the possible implications of climate change on water availability should not be forgotten. There is therefore the need to investigate the possible impact of the upscaling of irrigation development. This will be addressed in the next chapter.

Chapter 8

IMPACT OF INTENSIFYING IRRIGATION DEVELOPMENT AND IMPLICATIONS FOR SUSTAINABLE WATER RESOURCES MANAGEMENT IN THE WHITE VOLTA SUB-BASIN

8.1 INTRODUCTION

Global efforts aimed at ensuring food sufficiency by increasing staple food production have adopted irrigated farming as one of the main strategies. Approximately 70% of the world's irrigated land lies in Asia, where it accounts for almost 35% of cultivated land. In sub-Saharan Africa less than 5% of the cultivated area is irrigated (Molden et al., 2007). Regions such as South-East Asia have almost exhausted their irrigation development potential, making the potential irrigable land in Sub-Saharan Africa a major hope for the world in terms of feeding the future population (FAO, 2006b). Meanwhile, irrigation development in sub-Saharan Africa has been slow, resulting from several unresolved factors. However, there are encouraging signs of isolated cases of successful irrigation development across sub-Saharan Africa which serve as examples for upscaling irrigation.

One of such cases is the private-led irrigation development in the White Volta sub-basin using shallow groundwater and reservoirs for vegetable production to feed the urban population of southern Ghana. The current irrigation activities are seasonal and sustainable. Shallow groundwater abstraction for irrigation takes place in the dry-season. In the event where farmers are not successful in abstracting shallow groundwater they abandon the irrigation for that season. This activity does not have negative impact on long-term sustainability on the groundwater resources of the basin since the aquifers are refilled during the rainy season. However, there is potential for the introduction of new irrigation technologies such as tubewells in the sub-basin and their further expansion. Some shallow groundwater irrigation farmers have expressed interest in acquiring technologies such as permanent tubewells for irrigation. Such technology can be applied in almost any place within the catchment and throughout the whole year unlike the current technologies. This has implications for the long-term sustainability of the

groundwater source. Due to the competing water needs and upstream-downstream implications of increasing water uses, there is the need to assess the potential impacts of intensifying irrigation development and the implications for sustainable water resources management in the sub-basin.

The implications of expanding irrigation development amidst the competing uses of water in the sub-basin (including downstream impacts) raise concerns for sustainable water resources development and management. Especially the impact on the Akosombo Dam located downstream of the White Volta, which is used for hydro-power generation, needs to be considered. This chapter assesses the impact of intensifying irrigation development on the groundwater and surface water resources. This is essential for planning for sustainable water resources development in the sub-basin.

The study is conducted in three transboundary neighbouring watersheds within the White Volta sub-basin located in the Upper East Region of Ghana and southern Burkina Faso where almost all types of irrigation technologies in the sub-basin are found.

The implications of the expansion of irrigation development in the sub-basin are potentially large, ranging from environmental, institutional, hydrological and social to economic impacts. Intensification of irrigation development can create localised as well as large-scale challenges. The localised challenges include competition for the same resource between neighbouring farmers. The large-scale challenges relate to the water availability for other competing uses located in different parts of the basin. The objective of this study is not to study the localised effect of intensifying irrigation development but rather to look at the large-scale impact of irrigation development on the water resource, and on competing downstream water uses. The final objective is to identify the implications of the impact on water resources management of the sub-basin.

The chapter begins with a description of the methodology and data used for the study. The next section describes the set-up of the WEAP model, followed by the modelling results of a number of scenarios. The results of the model are discussed on the basis of a comparison with simple water balance calculations. The implications of these results on downstream water availability are then assessed, with a focus on hydropower generation at Akosombo dam. The benefits from upstream irrigation developments are then compared with the costs of reduced hydropower generation downstream. Finally conclusions are formulated concerning future irrigation development in the White Volta basin.

8.2 METHODOLOGY AND DATA COLLECTION

The study involved data collection and modelling followed by analysis of modelling results. The data collected range from water users and their demand, dam and reservoir characteristics, groundwater storage data, water supply sources and return flow receivers, streamflow data and climate data such as rainfall and evaporation. Field surveys and field measurements were conducted to estimate irrigation water consumption and extent of irrigation development for various irrigation technologies. The extent of irrigation development of various technologies were verified with data from the Ministry of Agriculture (MOFA) and Agricultural Extension Officers and were confirmed with satellite images taken over the study area within the same period. Dam and reservoir characteristics were obtained from institutional reports. Information on groundwater availability was taken mainly from the water balance study conducted in the Atankwidi catchment by Martin (2006).

There was lack of adequate data for a full rainfall-runoff analysis. Two years of streamflow data were available for two of the catchments (Yarigatanga and Atankwidi) and 44 years of rainfall data from the closest station to the catchments. As a result only two years of rainfall and streamflow data could be used for the rainfall-runoff analysis.

The Water Evaluation and Planning software (WEAP) modelling software was used for analysing the impact of upscaling irrigation development. WEAP is a tool for examining alternative water development and management strategies (WEAP, 2009). It operates on water balance accounting principles. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. It is not reliable for detailed hydrological and water quality analysis, but it has the flexibility of working with other hydrology and water quality software such as Modflow and QUAL2K.

The analysis using the WEAP model involved five steps, beginning with the parameterization of the model, followed by the calibration and validation stages, then the development of scenarios, and finally the analysis of the results.

Analysis of the impact on Lake Volta and on hydro-power generation was based on a historical data set of lake levels, turbine releases and electricity generation, and the development of a straightforward spreadsheet-based Waflex model (Savenije, 1995).

8.2.1 Domestic, Livestock and Urban water demand

Groundwater is the main source of domestic water for inhabitants within the catchment. The Bolgatanga Township, however, depends on the Vea dam for its urban water supply. Water demand figures for domestic and urban water supply were obtained from the housing and population census data of the year 2000 and existing figures on per capita water consumption for domestic and urban water demand.

Official records show that an amount of $0.15\text{Mm}^3/\text{month}$ is pumped from the Vea dam for the Bolgatanga water supply. In the 2000 Census, the Bolgatanga municipality had a population of 50,000 and a growth rate of $2.5\%/a$. The average water consumption is $100\text{L}/p/\text{day}$. The domestic water consumptions for the inhabitants of the three catchments were computed using a daily water consumption of $35\text{L}/p/\text{day}$ and a population density of $100\text{people}/\text{km}^2$ based on the 2000 Census figures for the Upper East Region.

Water demand for livestock was estimated using livestock density of up to 100 cattle per km^2 (National population census, 2000) and daily water consumption of $60\text{L}/\text{head}$ (Markwick, 2007). The main sources of water for livestock are small reservoirs, large reservoirs and directly from streams. During the dry season the streams are dry so the livestock depend on the reservoirs for water supply.

8.2.2 Irrigation water demand

Irrigation water demand for various irrigation technologies were calculated based on irrigation water applied by farmers which were computed from field observations on irrigation technologies during the period 2006-2008. The water demand patterns of the irrigation technologies were obtained from field studies. Irrigation is carried out in the dry season which is mainly from October to April; there are however differences in the demand patterns for the various technologies. The total irrigated areas in the three catchments were obtained from field observations, official records from the Ministry of Agriculture, Agricultural Extension Officers and the Irrigation Company of the Upper Region (ICOUR) and satellite image analysis. The water demand per irrigation technology is shown in Table 8.1.

Table 8.1: Irrigation water demand data for WEAP modelling.

Irrigation Technology	Small Reservoirs	Permanent Shallow Wells	Large Reservoir		Riverine Water	Temporal Shallow Wells	Riverine Alluvial Dugouts	
	tomatoes	tomatoes	tomatoes	rice	tomatoes	tomatoes	Tomatoes	
Crop	tomatoes	tomatoes	tomatoes	rice	tomatoes	tomatoes	Tomatoes	
***Irrigation water requirement (IW) (mm/season)	470	440	490	1054	490	440	440	
Water abstraction (W.) (mm/season)	640	1550	980	1550	640	1310	900	
Irrigation Efficiency (I = IW/W)	0.73	0.28	0.50	0.68	0.77	0.34	0.49	
***Transpiration (T)	490	481	513	1100	513	481	481	
*Potential Yield Range (Ton/ha)	40-60	40-60	40-60	6-8	40-60	40-60	40-60	
Measured Yield (Ton/ha)	20	65	9	4.5	15	62	40	
Evaporation and Return Flows (ER = W - T) (mm/season)	150	1069	467	450	127	829	419	
^a Evaporation (E = 0.5*ER) (mm/season)	75	535	234	225	64	415	210	
Evaporation + Transpiration (E+T) (mm/season)	565	1016	747	1325	577	896	691	
Water Consumption (W = (E+T)/W) (%)	88	66	76	85	90	69	77	
**Potential Crop Evaporation (mm)	640	700	640	1320	640	682	682	
Irrigated Area (ha)	Anayari	217	220	0	0	0	380	240
	Atankwidi	2	21	0	0	0	100	70
	Yarigatanga	29	3	65	80	40	1.5	0.5
	TOTAL	248	244	145		40	481.5	310.5

* Source: FAO (1992); # source: Ofori et al., (2010) ^a source: Burt, 1999, **source : Hargreaves, G. H., 1974. *** Source: CROPWAT

The water abstraction in Table 8.1 is obtained from field measurements conducted in the three catchments (see section 6.3.3 for details). The water abstraction is the total amount of water abstracted by the farmer and it includes consumptive and non-consumptive uses. Water abstraction figures for the technologies are from the Ghana fields except for permanent shallow

well which is from the Burkina Faso fields. The reason is that the other technologies are more prevalent (approximately 90%) in the Ghana section of the three catchments while the permanent shallow well is more prevalent (approximately 85%) in Burkina Faso.

Irrigation water requirement in Table 8.1 is derived from CROPWAT. Transpiration is equated to the sum of irrigation water requirement and effective rainfall during the irrigation season. The irrigation efficiency is the ratio between the irrigation water requirement and water abstracted. The Evaporation represents the non-productive water losses from the soil and canals. Return flows were not measured. Following Burt (1999), the return flow is estimated at 50% of excess water.

8.2.3 Groundwater characteristics

According to studies conducted by Martin (2006) Regolith aquifers in the weathered zone overlying Precambrian basement rocks serve as the main source of groundwater in the study area and large parts of the Volta basin. The depth of the aquifer varies from 3m to 51m and averages 18m. The long term groundwater recharge rate is approximately 6% of average annual rainfall and equals 66 mm/a. Total current groundwater abstraction is 4 mm/a in the study area. Martin (2006) also showed that a 20% reduction in rainfall results in a 30% reduction of groundwater recharge.

Long-term monthly rainfall data was obtained for Vea, located in the Yarigatanga catchment, over the period 1961-2005. The groundwater storages for the three catchments were estimated using an average aquifer depth of 18m, porosity of 8% and the catchment area.

8.2.4 Rainfall-Runoff Co-efficient

Runoff generation in semi-arid areas typically follows a distinct pattern. The first rains at the start of the rainy season wet up the soil that is dried out after the dry season. These rains produce very little runoff. Only after the soils are above field capacity does water flow from the watershed to streams. Studies conducted in the Volta Basin showed that the rainfall runoff coefficient for the Volta Basin varies between 7% and 57% (Van de Giesen et al., 2001). The water balance of the Atankwidi catchment by Martin (2006) shows that, in the Atankwidi catchment 23% and 11% of annual rainfall ends up as surface run-off in a wet year and a dry year, respectively, the long term average of surface-runoff is 13%, approximately 40% of surface run-off consists of interflow (shallow sub-surface flow), while the main fraction is direct surface run-off and base flow from groundwater is negligible.

According to Martin (2006), groundwater contribution to streamflow is negligible, but this may be due to the fact it was not observed at the sub-catchment level such as Atankwidi. The contribution of groundwater to streamflow may be observed at a larger scale such as the the sub-basin level.

8.3 MODEL DEVELOPMENT

The WEAP model entails several steps. The first step is the parameterization of the study area and the time frame. Next is to create the current account which adopts the existing situation of the start year. This forms the basis for the modelling process. It is used for the calibration of the model to mimic the existing situation of the study area. The current account is then validated with another set of data for a different year. An automatic reference scenario is generated from the current account upon which scenarios can be created. The scenarios are used to explore the impact of “what if situations” such as change in demand, policies, water supply, climate change, alternative assumptions or policies on water availability. The final stage is the evaluation of the scenarios with regard to water sufficiency, demand coverage, sustainability and sensitivity of the model to uncertainty in key variables.

This section describes the manner in which WEAP works, the model setup and how the model is developed up till the reference scenario.

8.3.1 Overview of WEAP Model

WEAP operates on the basic principle of a water balance and is applicable to municipal and agricultural systems, single catchments or complex transboundary river systems. Moreover, WEAP can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, vulnerability assessments, and project benefit-cost analyses (WEAP, 2009).

In WEAP all elements (rivers, supply sources, demand nodes, reservoirs, and gauges) have to be created. Data can be entered or imported into WEAP. Demand priorities are assigned to demand nodes and supply preferences assigned to water supply sources. The Demand Priority represents the level of priority for allocation of constrained resources among multiple demand sites. WEAP will attempt to supply all demand sites with highest Demand Priority, then moving to lower priority sites until all of the demands are met

or all of the resources are used, whichever happens first. The Supply Preference parameter allows users to define which source should be used in priority to supply water to a demand site. WEAP will attempt to supply all of the demand with sources having highest preference level, only using lower-level sources if the high-level sources do not have sufficient supply (WEAP, 2009).

When the WEAP model is run it simulates monthly time steps of each year, each scenario and all aspects of the water system, including demand site requirements and coverage, streamflow, in-streamflow requirement satisfaction, and reservoir storage.

Model results can be generated in WEAP in the form of tables and charts. The results in table formats can be imported into Microsoft excel for processing.

8.3.2 Model setup

The WEAP model was setup to best fit the water resources and water-use of the study area. The study models the expected level of irrigation development and other water uses over a period of 20 years with changing climatic conditions. The water year for the study area is May to April. Data for the 2005/2006 water year is used for the current account. The model represents: (1) the three catchment areas together with their characteristics; (2) the surface water and groundwater characteristics (quantity); (3) the water uses and their corresponding sources as well as return flows; (4) the water reservoirs in the catchments; (5) water losses (evaporation and return flows); (6) hydrological interactions between streamflow and groundwater; and (7) the rainfall variability in the study area.

In the WEAP model setup, in each of the three catchments, the main river has three tributaries. This is a simplification of the actual situation, where the river has several small tributaries on which the small reservoirs have been developed. As a result the small reservoirs are also lumped onto the tributaries. In the WEAP model a combined set of tributaries also have their small reservoirs lumped onto the resulting tributary. In lumping the small reservoirs, their volumes V (in m^3) and surface areas A (in m^2) are summed up separately then compared with the small reservoir characteristics developed by Liebe et al. (2005) and confirmed by Annor et al. (2009) (Equation 8.1). The volume elevation curve is then generated from Equation 8.2 which Liebe et al. (2005) used, with d being the maximum depth (m). The volume elevation curve of the lumped small reservoirs is also guided by the stochastic analysis performed on an ensemble of reservoirs in the Upper

East Region to determine the relationship between average volume and average depth (van de Giesen et al., 2008).

$$V = 0.00857 \times A^{1.4367} \tag{Equation 8.1}$$

$$V_{\text{half pyramid}} = 1/6 \times A \times d \tag{Equation 8.2}$$

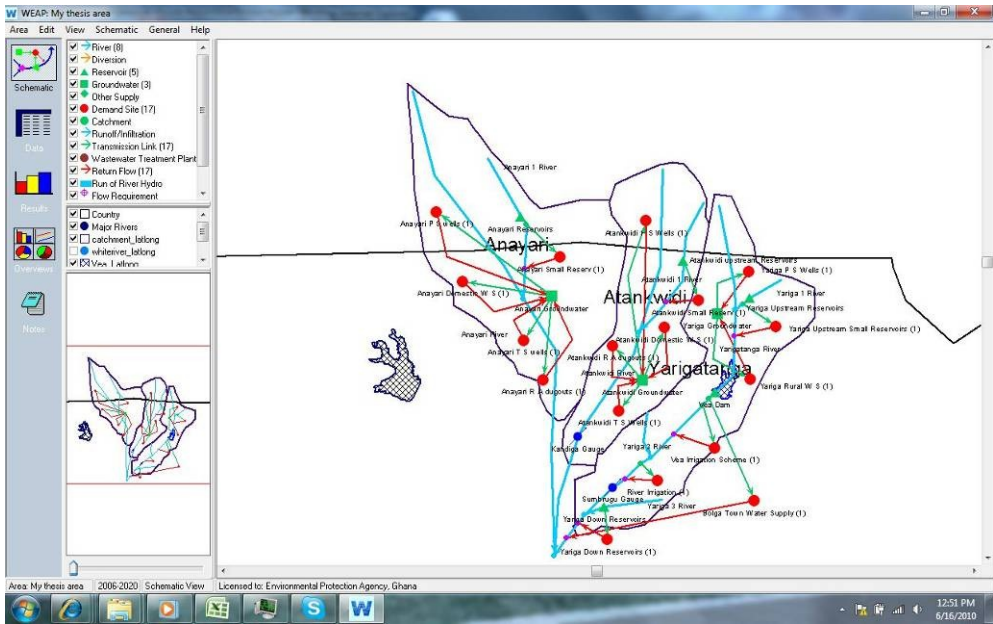


Figure 8.1: Schematic layout of catchment and modelled parameters in WEAP.

The various demand nodes are placed in the catchments and connected to their water supply sources. Each demand is assigned an allocation priority, water consumption, percentage consumption and annual demand pattern. Unused water by the demand nodes is returned to water sources which receive the return flows as observed in the field. For example, return flows from groundwater irrigation technologies are returned back to the groundwater source (Figure 8.1).

The streamflow values for the various streams are estimated from the rainfall-runoff coefficients, monthly rainfall values and catchment areas of the streams. The streamflow values are entered as headflows for the streams. Other parameters such as reservoirs and stream gauges are also positioned on the streams.

After setting up the WEAP model, it is then calibrated for the streamflow values to mimic the recorded streamflow at the measuring gauges. The calibrated model is then validated using the data set for 2004/2005. After a successful calibration, the current year is modified to generate a reference scenario upon which other scenarios can be developed. The reference scenario adopts the natural climatic variations projected over the study time frame. In the reference scenario, the long-term annual mean rainfall for the study area was used for the streamflow generation. The water year method was used to modify the streamflow and groundwater recharge to depict the climatic conditions of the projected study period. Thereto, five climatic conditions (very dry, dry, normal, wet and very wet) were defined with factors that were used for generating streamflows. The determination of these factors is discussed in a later section.

Finally future scenarios based on policies, technological development and climate change which affect demand, supply and hydrology were built on the reference scenario.

8.3.3 Parameterization of the study area

The schematic layout of the area in WEAP uses a Geographic Information System (GIS) based interface. The three sub-catchments were digitised as vector files using GIS including the streams and large reservoirs in the study area. They are added as vector layers in WEAP to form the background.

Table 8.2: Modelled parameters for the three catchments.

Parameters	Anayari Catchment	Atankwidi Catchment	Yarigatanga Catchment
River/stream	Anayari stream and three tributaries	Atankwidi stream and three tributaries	Yarigatanga stream and three tributaries
Groundwater source	Groundwater storage and recharge	Groundwater storage and recharge	Groundwater storage and recharge
Reservoirs	Three small reservoirs.	Three small reservoirs.	Vea dam and three small reservoirs.
Gauging Station	none	Kandiga station	Sumbrungu station
Demand Nodes	TSW, PSW, small reservoirs, Rural domestic & livestock	TSW, PSW, small reservoirs, RAD, Rural domestic & livestock	TSW, PSW, large irrigation, small reservoirs, riverine water, Bolgatanga supply, Rural domestic & livestock.

TSW – Temporal Shallow Wells, PSW – Permanent Shallow Wells, RAD – Riverine Alluvial Dugouts

The rivers, tributaries, groundwater source, reservoirs, gauging stations, demand nodes, transmission and return flow links are then created for each

catchment (Figure 8.1). The details of the catchment system parameters are provided in Table 8.2.

8.3.4 Current accounts/Calibration

The objective of the calibration is to adjust streamflow parameters (run-off coefficient) so as to reproduce observed streamflow readings in the catchments. Monthly streamflow for 2005/2006 recorded at Kandiga gauging station for the Atankwidi catchment and that recorded at Sumbrungu gauging station for the Yarigatanga catchment were used for the calibration. There are no streamflow recordings on the Anayari River.

In the streamflow calibration, the rainfall-runoff coefficients were estimated from the streamflow and rainfall data for 2005/2006. Following results validated for complete Volta Basin by Andreini et al., (2000), standard fractions of runoff per month were used as headflows. The headflows were entered in the model with other data being streamflow gauges, water demand for irrigation activities, livestock and domestic water needs for the year 2005/2006. The initial reservoir level for Vea was obtained from the management of the Vea dam. The rainfall-runoff coefficients were manually adjusted for the model to produce streamflow values close to the measured streamflow values at the gauges. The rainfall-runoff coefficients obtained after the calibration are shown in Table 8.3.

Table 8.3 Rainfall-Runoff coefficient obtained after calibration.

	Final Rainfall-Runoff Coefficient obtained from calibration			
	Anayari	Atankwidi	Yarigatanga (Area outside the irrigated lands)	Yarigatanga (Irrigated lands in Vea scheme)
Catchment Area (km ²)	464	275	202	150
May	0.1	0.1	0.08	0.15
June	0.15	0.15	0.2	0.25
July	0.2	0.2	0.24	0.33
August	0.45	0.45	0.4	0.4
September	0.38	0.38	0.35	0.35
October	0.25	0.25	0.25	0.25
November	0.03	0.03	0.03	0.03
December	0	0	0	0
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
Average	0.130	0.130	0.129	0.147

In Table 8.3 the Yarigatanga catchment is divided into two parts (irrigated lands in the Vea scheme and area outside the irrigation scheme) and given

separate rainfall-runoff coefficients. Due to the irrigation activities that take place in the dry season in the Vea scheme the soil-moisture conditions and land cover of the scheme differs from the areas outside the scheme which explains the different rainfall-runoff coefficients. The rainfall-runoff coefficients for Anayari are assumed to be the same as that of Atankwidi as they have similar characteristics. The annual average of the rainfall-runoff coefficient for the three catchments is almost equal to the long-term average (0.13) estimated by Martin (2006). This makes the runoff-coefficients suitable for the analysis of scenarios which depend on long-term characteristics of the study area. The results are further considered reliable, considering the fact that, the 2005/2006 was a normal rainfall year (this is shown in next section). Results of the calibration are shown in Figure 8.2.

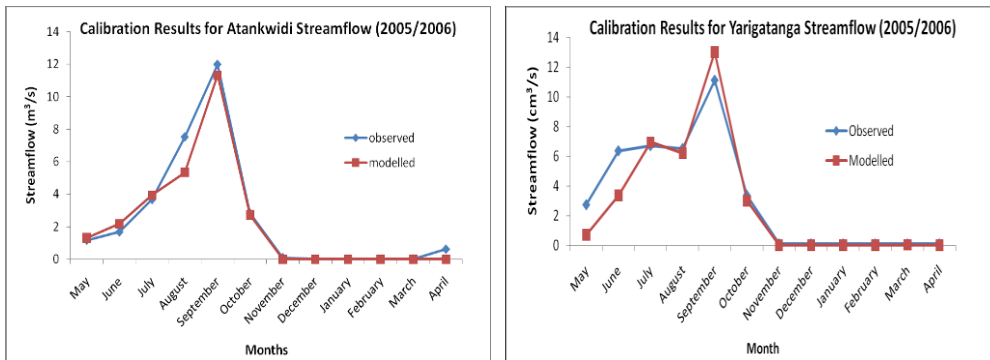


Figure 8.2: Calibrated streamflow; a) Atankwidi; b) Yarigatanga

For the Atankwidi catchment, the modelled streamflow values are close to the observed streamflow (Figure 8.2). The modelled streamflow for the Yarigatanga catchment differed significantly from the observed streamflow values for the months of May, June and September. This may be due to reasons other than rainfall-runoff generation.

8.3.5 Validation

The calibrated model results were then validated on streamflow records of 2004/2005 (Figure 8.3). In the Yarigatanga catchment, the modelled streamflow is higher in the months of July, August and September than the observed. The significant difference in the streamflow values for the Yarigatanga catchment can be attributed to the presence of the reservoir. The Yarigatanga catchment has much more reservoir storage ($20 \times 10^6 \text{m}^3$) than Atankwidi ($0.2 \times 10^6 \text{m}^3$). The reservoir buffers the runoff for the Yarigatanga catchment, but this could not be modelled due to lack of data.

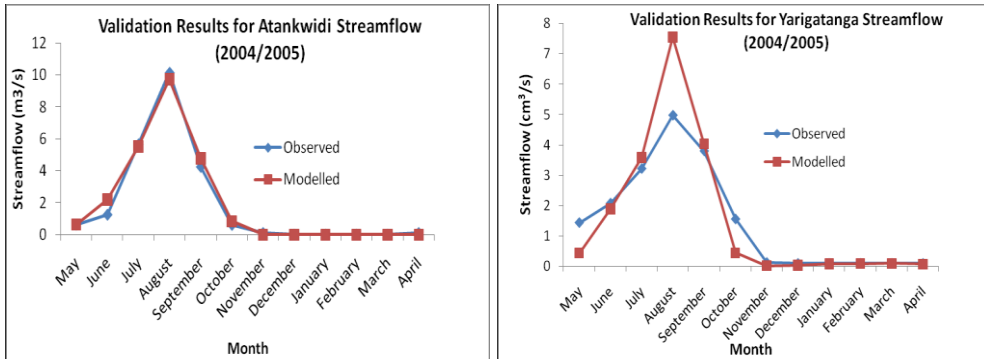


Figure 8.3: Validated streamflow; a) Atankwidi; b) Yarigatanga

The lack of adequate data is the major reason for the errors encountered in the hydrological model. However, since the objective of the study is to look at the impact of irrigation, the results on irrigation impact can be relied upon.

8.3.6 Reference scenario

The “Current Account” year is the base year of the model where data is added. A “Reference” scenario is established from the *Current Account* to simulate likely evolution of the system without intervention. After using rainfall and streamflow values of 2005/2006 to calibrate the model, the *Current Account* was modified to use long-term mean rainfall values for the streamflow generation. The long-term annual rainfall is then modified annually over the projected study period using the water year method to depict predicted climatic variations.

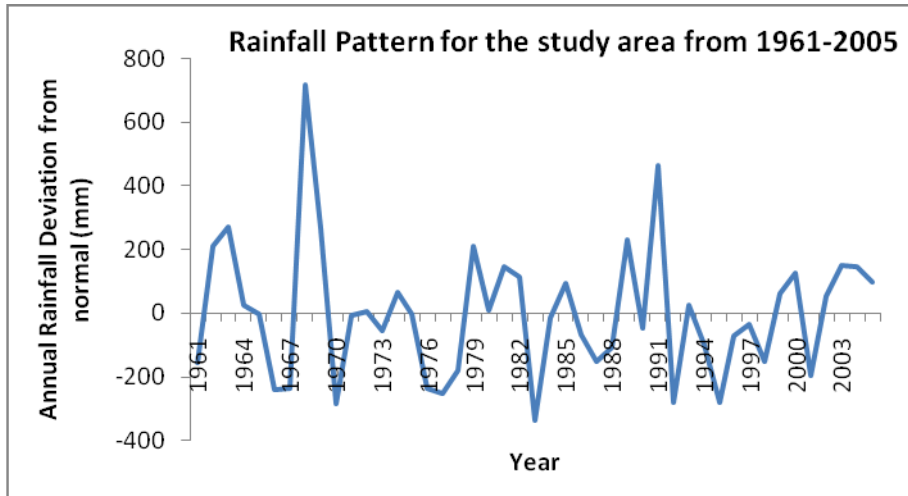


Figure 8.4: 45-year annual rainfall deviation from the normal for study area.

The water year method uses natural climatic variations for the reference scenario. A synthetic time series of 20 years was generated based on an analysis of the recorded rainfall pattern from 1980 to 2000. The natural climatic variations were chosen to depict the recorded rainfall pattern from 1980 to 2000 for the study area, where both extreme hydrological events (very dry and very wet years) were experienced (Figure 8.4).

Andreini et al., (2000) showed that the rainfall-runoff pattern of the Volta Basin is non-linear. The hydrology in the Volta Basin can be described as a bucket type model/threshold. The model shows that after a particular rainfall threshold is reached, about half of the additional rainfall becomes runoff. Therefore, small changes in total rainfall can result in large changes in total runoff. This accounts for yearly variability in rainfall runoff coefficients.

The factors used for the climate variability were: very dry year = 0.76, dry year = 0.89, wet year = 1.09 and very wet year = 1.27. These factors were estimated by ranking the rainfall figures of Bolgatanga from 1961 to 2005. The top 20% was classified as being very wet; the next 20% as wet, the middle 20% being normal, the fourth 20% being dry and the last 20% being very dry. The average of the ratio between the rainfall figures and the long-term mean was used as the modifying factor for the classification.

Table 8.4: Range of rainfall and modifying factors for climatic variations

Climate Variations	Very Wet	Wet	Normal	Dry	Very Dry
Range of Rainfall (mm/a)	1248-1818	1151-1247	1050-1150	920-1049	762-919
Modifying factors for rainfall	1.27	1.09	1.00	0.89	0.76
Modifying factors for groundwater recharge and streamflow	1.42	1.15	1.00	0.86	0.69

According to the study of Martin (2006) and van de Giesen et al., (2001), groundwater recharge and streamflow varies much more from year to year than rainfall. Therefore the climate modifying factors for the rainfall will have to be modified to depict variations in streamflow and groundwater recharge. Martin (2006) found that in the study area a 20% reduction in annual rainfall resulted in a 30-60% reduction of annual groundwater recharge. Moreover, runoff coefficients varied from 11% to 24% for dry and wet years, respectively. This information could not provide specific modifying factors for groundwater recharge and streamflow; however it did guide the modification of factors due to rainfall variation. The study assumed the same modifying factors for groundwater recharge and streamflow due to lack of data (Table 8.4).

Apart from the domestic and urban water demands which vary from year to year because of the population growth rate, all other demands and factors remained the same in the reference scenario. The reference scenario results show that all water demands are met with no significant impact on groundwater and surface water resources.

8.4 SCENARIOS DEVELOPMENT AND ANALYSIS

In WEAP scenarios are developed to simulate likely evolution of the system which may be due to a range of future possibilities. First, a reference scenario was established from the current accounts which specifies the projected period for scenario analysis (WEAP, 2009). The scenario analysis was aimed at possible future situations in the year 2025. The reason for choosing 2025 is based on the historical development of irrigation in the study area. The expansion of irrigation development in the sub-basin has been going on in the past two decades based on certain factors. “What if” scenarios representing increase in irrigation, changes in policy and technology were modelled based on the reference scenario. The “what if” scenarios considered in the analysis include:

- 1) The situation in 2025 if irrigation continues to expand at the current rate of 5%/a;
 - 2) The situation in 2025 if irrigation expands at a rate of 10%/a;
 - 3) Sustainable irrigation development by 2025:
 - a. 10% of the catchment area is put under groundwater irrigation and 2% under surface water;
 - b. Improving groundwater and surface water irrigation efficiency to 70%;
 - c. 8% of catchment under groundwater irrigation and 2% under surface water with improved irrigation efficiency;
 - 4) Impact of variations in groundwater recharge on model results.
- In the scenario analysis the impact of each of these scenarios on water demand coverage for various water uses, groundwater and surface water sources is investigated. Finally, WEAP is used to investigate the sustainable level at which groundwater can be used for irrigation development amongst other uses in the study area.

8.4.1 The situation in 2025 if irrigation should have expanded at a rate of 5%/a

The first scenario considered for the analysis is based on the current growth rate of irrigation in the three catchments. The previous chapter found that the irrigated area in the three catchments has been growing at about 5.6%/a since 2005. In this scenario, 5% growth is applied to both surface and groundwater irrigation. The growth is projected to 2025 and the extent of irrigation that is anticipated at 2025 is determined. The extent of irrigation at 2025 is then simulated in the model to determine the impact.

Table 8.5: Input values for 5% annual growth in irrigation at 2025

		Small Reservoirs	Permanent Shallow Wells	Large Reservoir		Riverine Water	Temporal Shallow Wells	Riverine Alluvial Dugouts
Crop		tomatoes	tomatoes	tomatoes	rice	tomatoes	tomatoes	tomatoes
Water abstraction (mm/season)		640	1550	980	1550	640	1310	900
Irrigation Efficiency		0.73	0.28	0.50	0.68	0.77	0.34	0.49
Water Consumption (%)		88	66	76	85	90	69	77
Irrigated Area (ha)	Anayari	585.9	594	0	0	0	1026	648
	Atankwidi	5.4	56.7	0	0	0	270	189
	Yarigatanga	78.3	8.1	216	175.5	108	4.1	1.4

Impact on groundwater source

The impact of this scenario on groundwater is shown in Figure 8.5. The figure shows seasonal drops in groundwater storage during the irrigation season which is completely replenished during the rainy season. This trend is observed in the Anayari and Atankwidi catchments where groundwater abstraction for irrigation activities is very active.

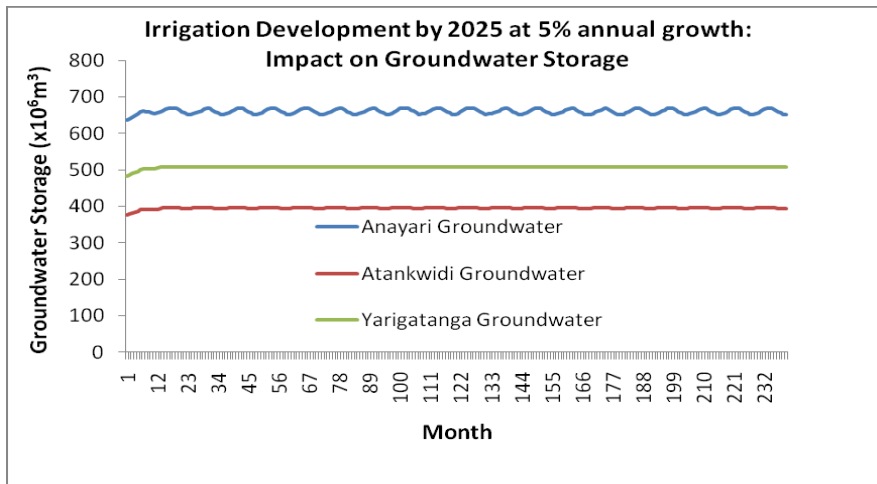


Figure 8.5: Impact of 5% annual growth of irrigation on groundwater storage

Thus groundwater can sustain this extent of irrigation development, however, significant seasonal drops in groundwater storage will be observed for the Anayari catchment, implying that irrigators may need technologies that abstract groundwater at deeper levels than the current situation.

Impact on surface water

The impact of this scenario on surface water is shown in Figure 8.6. In the Atankwidi catchment there is no difference between streamflow under this scenario and the current situation. But in the Yariatanga catchment it is observed that there is a slight drop in the streamflow during the month of July. This is the period of the year when small reservoirs and groundwater sources are filled. There is a drop of 3.9% of the total streamflow for the Yariatanga catchment.

In the Yariatanga catchment, groundwater irrigation is minimal while surface water irrigation is maximum compared to the other two. This implies that the drop in streamflow is used in filling up the reservoirs of the Yariatanga catchment. The reason why no such observation was made in

the Atankwidi catchment is that the reservoir storage in the Atankwidi catchment has negligible impact on streamflow and that in the WEAP model groundwater is unconnected to the surface water.

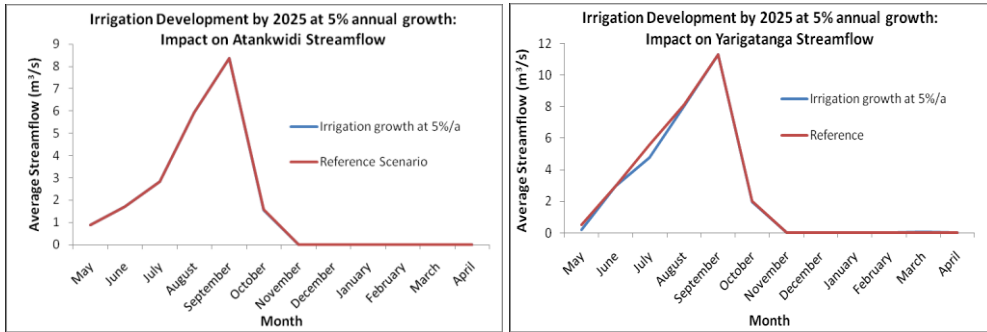


Figure 8.6: Impact of scenario 1 on streamflow; a) Atankwidi; b) Yarigatanga

8.4.2 The situation in 2025 if irrigation should have expanded at a rate of 10%/a

This scenario is included based on the consideration that the current rate of irrigation growth may increase in the near future. The scenario represents measures that improve the current rate of irrigation expansion in the study area. In this scenario all existing irrigation systems grew at 10% annually except large-scale irrigation. Currently there are no future plans to develop large-scale irrigation schemes and it seems unlikely that there will be such expansion. The large-scale irrigation was expanded up to the maximum irrigable area of the Vea Scheme.

Table 8.6: Input values for 10% annual growth in irrigation at 2025.

		Small Reservoirs	Permanent Shallow Wells	Large Reservoir		Riverine Water	Temporal Shallow Wells	Riverine Alluvial Dugouts
Crop		tomatoes	tomatoes	tomatoes	rice	tomatoes	tomatoes	tomatoes
Water abstraction (mm/season)		640	1550	980	1550	640	1310	900
Irrigation Efficiency		0.73	0.28	0.50	0.68	0.77	0.34	0.49
Water Consumption (%)		88	66	76	85	90	69	77
Irrigated Area (ha)	Anayari	1581.9	1603.8	0	0	0	2770.2	1749.6
	Atankwidi	14.6	153.1	0	0	0	729	510.3
	Yarigatanga	211.4	21.9	510	340	291.6	10.9	3.6

Impact on groundwater source

Figure 8.7 shows the impact of this scenario on groundwater source. The results show unsustainable groundwater use in the Anayari catchment, while that of Atankwidi and Yarigatanga is sustainable. The results imply that, if irrigation should increase at 10% annually, the unsustainable limit of groundwater use will be reached before 2025 in the Anayari catchment. This scenario gives reason for investigating the sustainable limit of irrigation development considering water resources availability, in particular groundwater.

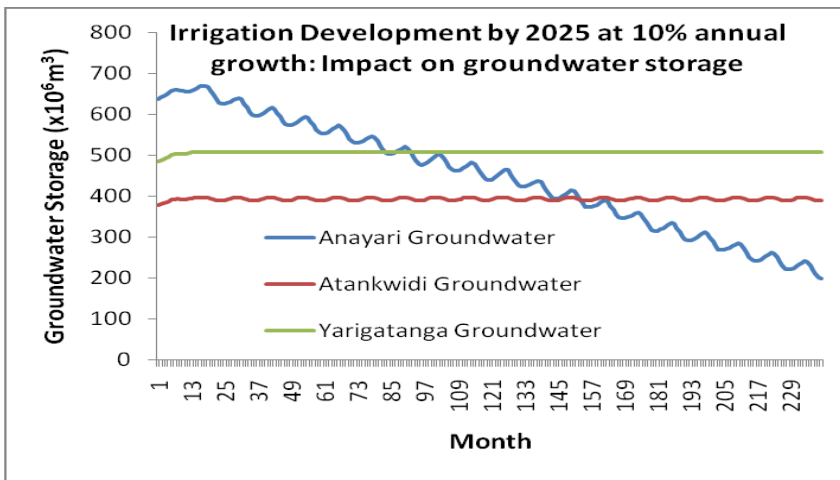


Figure 8.7: Impact of scenario 2 on groundwater storage.

Impact on surface water source

The impact of this scenario on surface water sources was also investigated. Figure 8.8a shows no significant impact on the Atankwidi streamflow. A significant drop in streamflow is observed in the Yarigatanga catchment from May to August when reservoirs are filling up (Figure 8.8b). This reduces the total annual streamflow in the Yarigatanga catchment by 8.7%.

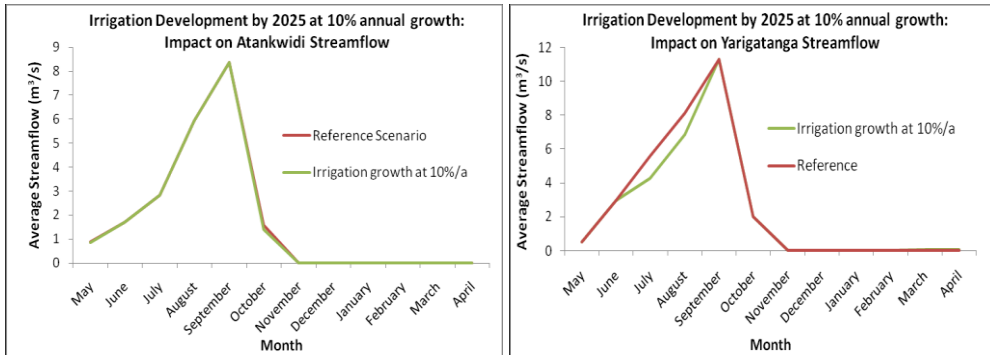


Figure 8.8: Impact of scenario 2 on streamflow; a) Atankwidi; b) Yarigatanga

The results reveal potential reduction of streamflow availability for downstream water uses due to increasing reservoir development in the catchment. The results show that in the Atankwidi catchment there is more room for reservoir irrigation development than in Yarigatanga.

8.4.3 Investigating sustainable groundwater and surface water use for irrigation

This scenario investigates the sustainable levels that groundwater and surface water can be used for irrigation for the study area. In this scenario initial estimates of 10% and 2% are made as the extent of groundwater and surface water irrigation coverage in the study area respectively. The extents of irrigation coverage are maintained throughout the study period without any increase in annual irrigation.

In the estimation of the irrigation areas for this scenario, the current irrigated areas are upscaled to equal the scenarios percentage coverage. The upscaling is based on some limiting factors such as bio-physical, economical and land-tenure which are likely to affect and constrain expansion factors. As a result the expansion factors differ for the various irrigation technologies. The expansion factors and their limiting factors are listed in Tables 8.7 and 8.8. In the Anayari and Atankwidi catchments 66 and 53 new small reservoirs will have to be developed, respectively, to achieve 2% coverage of surface water irrigation. This is based on an average irrigable area of 10ha per small reservoir (current average stands at 8.5ha). For the Yarigatanga catchment, the current developed surface water irrigation exceeds the 2% target, thus no additional development is added. However it is expected that if the whole irrigable area of the Vea scheme is utilised, riverine irrigation downstream of the Vea scheme can triple due to additional excess water from return flows. Even though this scenario is not expected to be achieved within

the study period, it nevertheless generates useful information for water resources management in the sub-basin.

Table 8.7: Current groundwater irrigation and potential expansion up to 10% of catchment area.

Groundwater irrigation Technologies							
Catchment	Catchment Area (Km ²)	Irrigation Technology	Current Area (Km ²)	Potential For Expansion	Limiting Factor(s) for Expansion	Scale for Factor	Projected Area (Km ²)
Anayari	464	Permanent Wells	2.20	High	Finance, Land tenure	7	14.40
		Temporal Wells	3.80	High	Suitable Land	5.5	20.90
		Riverine Dugout	2.4	Average	River Channel	4.3	10.32
		TOTAL	8.40				46.62
Atankwidi	275	Permanent Wells	0.21	High	Finance, Land tenure	16	3.36
		Temporal Wells	1.00	High	Suitable Land	16	16.00
		Riverine Dugout	0.70	Average	River Channel	12	8.40
		TOTAL	1.91				27.76
Yarigatanga	352	Permanent Wells	0.03	High	Finance, Land tenure	750	22.50
		Temporal Wells	0.015	High	Vea Scheme	700	10.50
		Riverine Dugout	0.005	Average	Vea Scheme	400	2.00
		TOTAL	0.05				35.00

Table 8.8: Current surface water irrigation and potential expansion up to 2% of catchment area

Surface Water Irrigation Technologies						
Catchment	Irrigation Technology	Current Area (Km ²)	Potential For Expansion	Limiting Factor(s) for Expansion	Additional development (quantity)	Projected Area (Km ²)
Anayari	Small Reservoirs	2.17	Low	Financial, Social and environmental	66	9.37
Atankwidi	Small Reservoirs	0.02	Low	Financial, Social and environmental	53	5.50
Yarigatanga	Small Reservoirs	0.29	Low	Financial, Social and environmental	none	0.29
	Riverine Water	0.40	Low	Excess water from Ve'a Irrigation scheme	Scale Factor of 3	1.20
	Large Reservoir	1.45	unplanned		none	

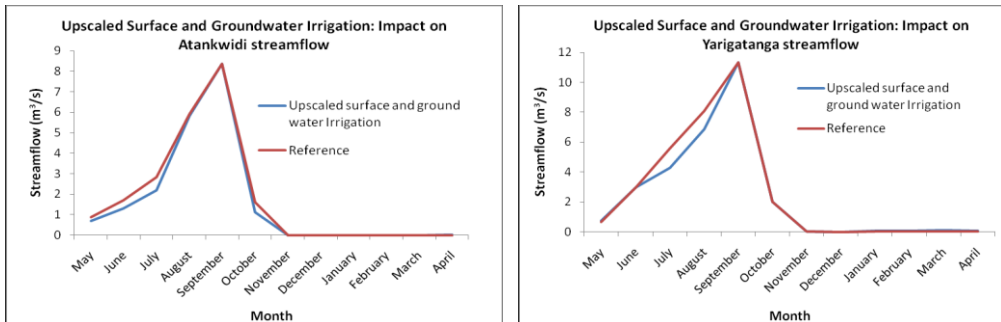


Figure 8.9: Impact of scenario 3a on streamflow; a) Atankwidi streamflow; b) Yarigatanga

Figure 8.9 shows a reduction in streamflow due to the upscaling of irrigation development according to Tables 8.7 and 8.8. From the model results, annual streamflow drops of 7.5% and 8.5% are observed in the Yarigatanga and Atankwidi catchments, respectively. Since base-flow in the study area is negligible (Martin, 2006), the reduction in streamflow estimated by the model is basically due to the upscaling of surface water irrigation. The impact of groundwater on streamflow will be estimated using simple water balance analyses (see next section).

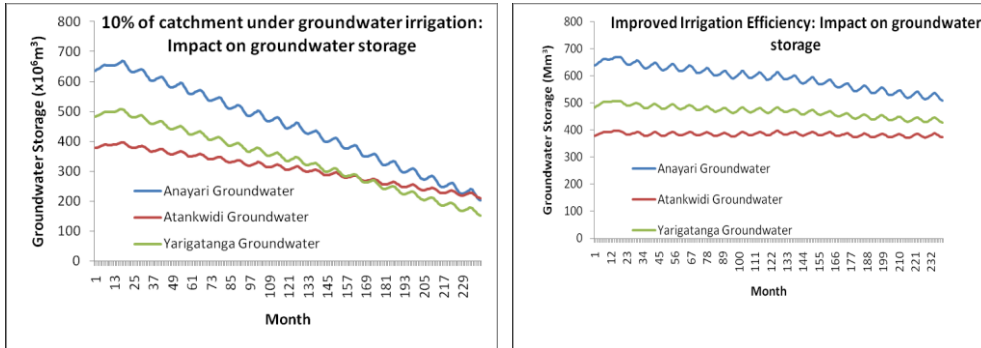


Figure 8.10: a) Impact of scenario 3a on groundwater storage; b) Impact of scenario 3b on groundwater storage.

Figure 8.10a shows that if 10% of the catchment is irrigated using groundwater, there will be unsustainable use of groundwater in all three catchments. A second scenario was analysed in which an improvement in groundwater irrigation efficiency was considered. For reasons of simplifying the analysis, a second scenario considers a future situation where the irrigation efficiency for all technologies is 70%. This scenario is a possible future scenario where irrigation policies can place benchmarks for improved irrigation efficiencies. Table 8.9 shows how the improvement in irrigation efficiency was estimated.

Table 8.9: Input values for 70% Irrigation Efficiency

	Small Reservoirs	Permanent Shallow Wells	Large Reservoir		Riverine Water	Temporal Shallow Wells	Riverine Alluvial Dugouts
Crop	tomatoes	tomatoes	tomatoes	rice	tomatoes	tomatoes	tomatoes
Water abstraction (mm/season)	671	629	700	1506	700	629	629
Irrigation water requirement (IW) (mm/season)	470	440	490	1054	490	440	440
Irrigation Efficiency	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Transpiration (T)	490	481	513	1100	513	481	481
Evaporation and Return Flows (E+R) (mm/season)	181	148	187	408	187	148	148
Evaporation (E) (mm/season)	91	74	94	204	94	74	74
Evaporation + Transpiration (mm/season)	581	555	607	1304	607	555	555
Consumption (%)	87	88	87	84	87	88	88

The impact of the improvement in irrigation efficiency of groundwater irrigation still showed unsustainable use of the groundwater source (see Figure 8.10b). Another scenario was developed in which the 10% area coverage was reduced to 8% coverage, while maintaining the improvement in irrigation water-use efficiency. Under this scenario stable groundwater storage was achieved over the study period implying sustainable groundwater use (see Figure 8.11). The results show that for sustainable groundwater use for irrigation, the threshold is about 8% of the catchment provided irrigation efficiency is about 70%.

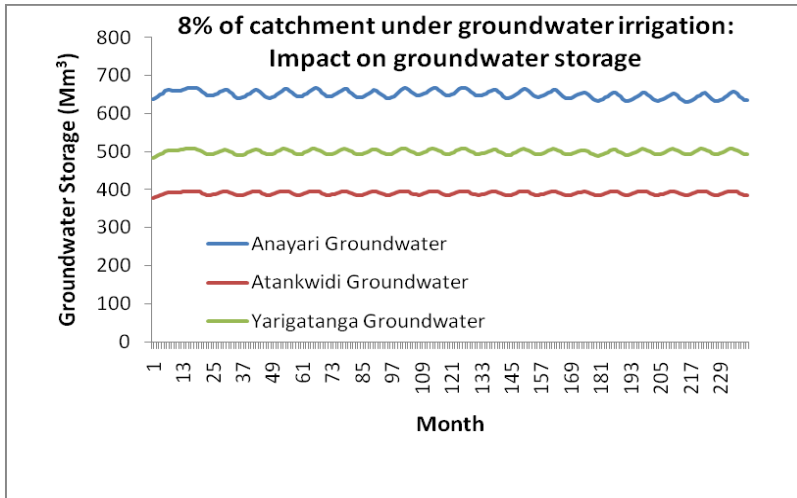


Figure 8.11 Impact of scenario 3c on groundwater storage

8.4.4 Impact of variations in groundwater recharge on model results

The data used in the model are averages of observed figures. The next stage of the impact analysis was to assess the sensitivity of modelling results on assumed rates of groundwater recharge. A reduction in groundwater recharge is not a likely future scenario because climate change is likely to increase recharge. So this scenario should be seen as a worst possible case scenario, assuming the present trend of more concentrated rainfall is reversed and total rainfall becomes less.

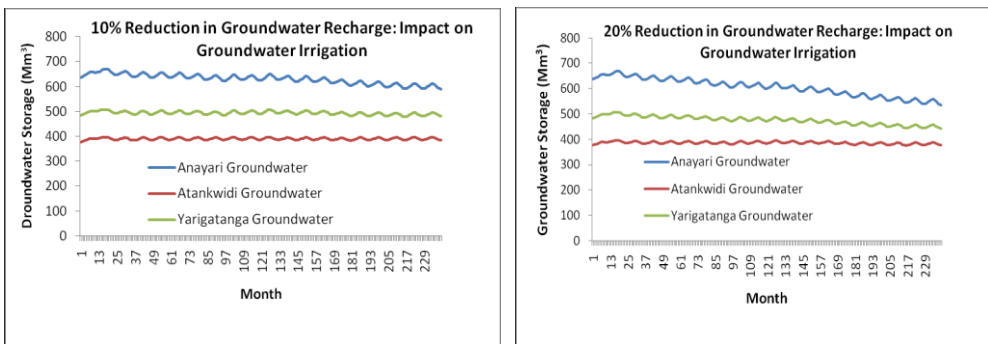


Figure 8.12: a) Impact of reducing groundwater recharge by 10% on groundwater irrigation; b) Impact of reducing groundwater recharge by 20% on groundwater irrigation

The analysis looks at two scenarios where groundwater recharge is reduced by 10% and 20%. This analysis is performed on the scenario in which the threshold for sustainable groundwater irrigation was achieved.

In the results (Figure 8.12), an unsustainable condition is experienced in the groundwater storage of Yarigatanga and Anayari catchments for both scenarios, meaning that the sustainability of groundwater irrigation development is sensitive to the groundwater recharge rate.

8.4.5 Water Balance Analysis of Scenarios

In the scenarios modelled so far using WEAP, all results are based on calculations internal to the model. To verify the model results simple water balances on all scenarios were calculated.

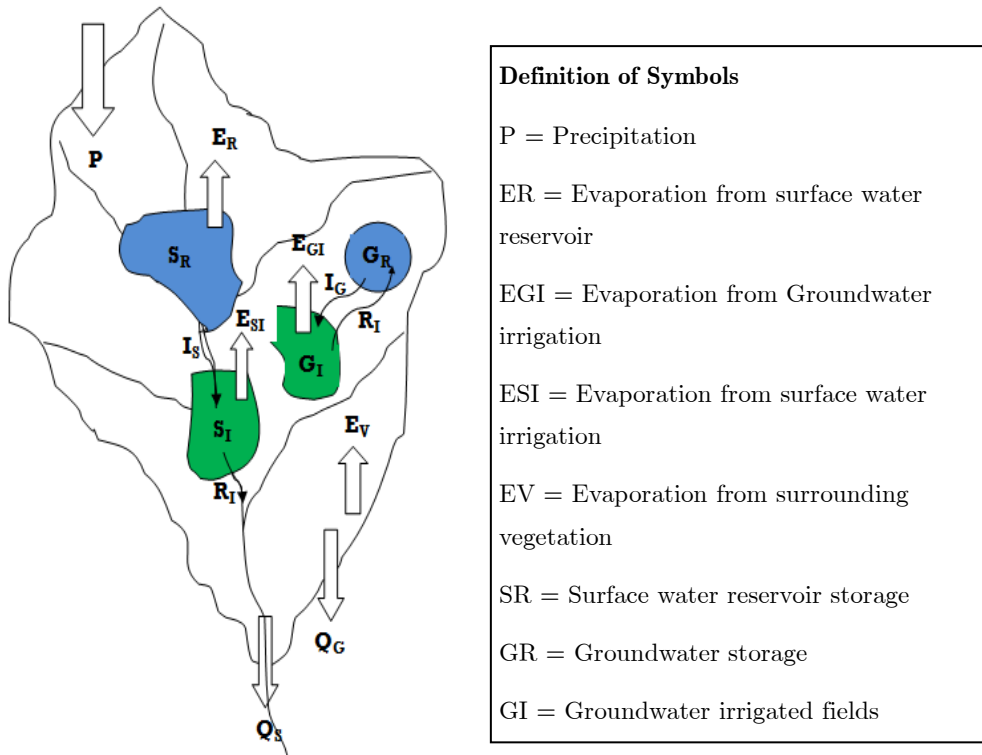


Figure 8.13: Water Balance of the catchment.

The water balance analysis is based on Figure 8.13 and is performed at 3 levels: the catchment level which is considered as closed with no outside inflows, and the irrigation level for both surface water and groundwater. The general water balance used is:

$$\text{Input} - \text{Output} = \text{Change in Storage} \quad \text{Equation 8.3}$$

Water Balance at Catchment level:

$$P - (E_R + E_{SI} + E_{GI} + E_V + Q_S + Q_G) = \Delta S/\Delta t \quad \text{Equation 8.4}$$

Water Balance at groundwater irrigation level:

$$P + I_G + R_I - E_{GI} = \Delta G_R/\Delta t \quad \text{Equation 8.5}$$

Water Balance at surface water irrigation level:

$$P + I_S - E_{SI} - E_R = \Delta S_R/\Delta t \quad \text{Equation 8.6}$$

Table 8.10: Monthly Evaporation from reservoirs

Months	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Reference Evaporation (mm/month)	177.0	184.0	210.0	190.0	180.0	153.0	141.0	130.0	131.0	143.0	147.0	156.0
Long-term mean Rainfall (mm/month)	2.0	9.7	51.9	101.0	134.0	147.2	158.7	151.9	207.7	105.4	23.1	8.8
Net Evaporation (mm/month)	175.0	174.3	158.1	89.0	46.0	5.8	-17.7	-21.9	-76.7	37.6	123.9	147.2

The water balance calculations were performed to determine the water losses due to irrigation activities. From Equation 8.5, the water losses due to groundwater irrigation are the evaporation (E_{GI}) from irrigated fields. From Equation 8.6, the water losses due to surface water irrigation equal the direct evaporation from the surface reservoir (E_R) and the evaporation (E_{SI}) from the irrigated fields. Evaporation from the surface reservoir equals the net evaporation between the reference evaporation and direct rainfall on the surface of the reservoirs (see Table 8.10).

The evaporation from irrigated fields and evaporation from surface reservoirs for all scenarios are shown in Table 8.11.

Table 8.11 Total Evaporation from surface (E_{SI}) and groundwater irrigation (E_{GI}) and Evaporation from reservoirs (E_R)

	Water Losses due to Evaporation from Surface water and Groundwater Irrigation Fields and surface reservoirs (x10m/a)								
Scenarios	Anayari Catchment			Atankwidi Catchment			Yarigatanga Catchment		
	Surface Water E _s	Ground Water E _g	Surface Reservoir E _r	Surface Water E _s	Ground Water E _g	Surface Reservoir E _r	Surface Water E _s	Ground Water E _g	Surface Reservoir E _r
Reference	1.18	7.99	0.86	0.01	1.74	0.09	1.71	0.05	2.28
Irrigation in 2025 @ 5%/a Growth	3.13	21.19	1.77	0.03	4.61	0.09	4.35	0.14	2.35
Irrigation in 2025 @ 10%/a Growth	7.94	49.60	3.57	0.07	11.69	0.10	9.92	0.35	2.35
Groundwater & surface water irrigation @ 8% and 2% respectively,	5.10	29.60	2.48	2.99	17.23	1.75	6.84	23.06	2.08

Evaporation losses from surface reservoirs and water abstracted from surface reservoirs directly reduce surface water runoff for downstream water uses. Groundwater abstractions directly affect streamflow in the catchment in the situation where groundwater contributes to streamflow. However, the study of Martin (2006) concluded that, baseflow in the study area is negligible. This would imply that groundwater abstractions for irrigation do not impact directly on the streamflow in the catchment. Meanwhile groundwater from the aquifer is discharged at unidentified locations within the basin which contributes to streamflow downstream. Therefore, groundwater abstractions for irrigation do reduce groundwater discharge from the aquifer thereby reducing streamflow downstream. However, the groundwater discharge contributing to streamflow downstream of the catchment is currently unknown.

Water abstracted from groundwater for irrigation results in a reduction of groundwater storage which is replenished during the rainy season with groundwater recharge. The groundwater recharge does not depend on the abstraction but on the aquifer, catchment characteristics and rainfall. In situations where annual abstractions exceed annual groundwater recharge, the natural annual groundwater recharge does not automatically increase to replenish the depleted groundwater resource. Therefore it is expected that

when annual abstractions exceed annual recharge (Anayari = $31 \times 10^6 \text{m}^3/\text{a}$, Atankwidi = $18 \times 10^6 \text{m}^3/\text{a}$ and Yarigatanga = $23 \times 10^6 \text{m}^3/\text{a}$) then an unsustainable groundwater condition is created.

Table 8.12: Comparison of Water losses between WEAP results and water balance analysis

Scenarios	Streamflow Losses for Scenarios Relative (Absolute) to the Reference Scenario (10m/a)					
	Anayari Catchment		Atankwidi Catchment		Yarigatanga Catchment	
	WEAP Model	Water Balance	WEAP Model	Water Balance	WEAP Model	Water Balance
Irrigation in 2025 @ 5%/a Growth	3.89	2.86	0.17	0.02	2.60	2.72
Irrigation in 2025 @ 10%/a Growth	12.76	9.47	0.77	0.07	7.86	8.30
Groundwater & surface water irrigation @ 8% and 2% respectively	6.53	5.54	6.35	4.64	5.63	5.08

Table 8.12 shows a comparison between the WEAP model results and the water balance analysis. Water losses from the WEAP modelling results are streamflow losses relative to the reference scenario. Water losses from the water balance analysis are evaporation losses from surface reservoirs and surface water irrigation fields.

The results show that the streamflow losses in the WEAP model are higher than that of the water balance for Anayari and Atankwidi catchments and for all their scenarios. The relatively low water losses in the water balance analysis results from the combined surface and groundwater use of the Riverine Alluvial Dugouts irrigation technology. In the WEAP Model this technology abstracts water from both the streamflow and the groundwater source with streamflow use having priority over groundwater use because the farmers exhaust the runoff in the streams before they start digging for groundwater. Thus the surface water use by the riverine alluvial dugouts also results in a reduction of streamflow. However, in the simple water balance analysis, the water source of the riverine alluvial dugouts was assumed as groundwater only.

The impact of the assumption made for the riverine alluvial dugout is observed in the results of the Yarigatanga catchment. In the first two scenarios (5% and 10% growth), the water losses estimated from the water balance are higher than that of the model. This is because, in the first two

scenarios, riverine alluvial dugouts are negligible in the catchment. In the last scenario where riverine alluvial dugout irrigation is significant, the water loss in the WEAP Model is higher than that of the water balance.

Thus to have a valid comparison, scenarios with negligible riverine alluvial dugout irrigation can best be used to explain the differences between the two methods. Such scenarios are the first two scenarios (5% and 10% growth) of the Yarigatanga catchment. From these two scenarios the water losses deduced from the water balance analysis are slightly higher than that of the WEAP model. This is because the WEAP model results report the average over the entire study period which has varying climatic conditions, while the water balance analysis is based on the long-term mean hydrological year. This average hydrological year is not representative for the entire period, because frequent slightly dry years are alternated by few very wet years (see Figure 8.4). This variation explains the higher water losses estimated by the water balance analysis.

From the above comparison and the reasons given for the differences between the two methods, it may be concluded that the WEAP model is more reliable than the simple water balance analysis. This is because the WEAP model is able to capture the complexities with the riverine alluvial dugouts irrigation and also provides results commensurate with the climatic condition over the study period. However, the water balance analysis also confirms a weakness of the WEAP model, namely that it considers groundwater to be unconnected to surface water, implying that water abstracted from groundwater for irrigation is not considered to have any impact on streamflow.

8.5 DISCUSSION OF THE RESULTS

The objective of this chapter is to assess the impact of increasing irrigation development in the White-Volta sub-basin. This section summarises the impacts on consumptive water use of the current and possible future irrigation developments. In a following section the impact on competing water uses downstream of the White Volta sub-basin will be assessed.

8.5.1 Current Level of Exploitation of Water Resources for Irrigation

Current irrigation covers 1% of the Anayari catchment area, 0.8% of Atankwidi and 2.6% of Yarigatanga. Because of the presence of the Vea dam in the Yarigatanga catchment, irrigation development depending on surface water is 90% of the current total with the remaining 10% depending on

shallow groundwater. However 85% of the current irrigation in Anayari and Atankwidi catchments depends on shallow groundwater.

The current trend of irrigation development demonstrates that inhabitants are willing to exploit the potential benefits of irrigated farming and therefore have resorted to affordable shallow groundwater irrigation technologies. This trend is likely to continue in the next fifteen years since most potential irrigable lands remain untapped. The results also show that the introduction of new technologies which abstract groundwater for irrigation beyond shallow groundwater levels is sustainable provided that abstractions do not exceed a certain threshold. One challenge is the impact this will have on farmers using traditional water abstraction methods which can only reach shallow groundwater. The localised impact of new irrigation technologies in abstracting groundwater for irrigation on various groundwater users was not addressed in this study and needs to be investigated.

The non-perennial nature of rivers in the study area is a major contributor to the intensifying shallow groundwater use for irrigation. Another reason is that the development of reservoirs (small and large) for irrigation is relatively expensive and cannot be borne by individual farmers. The government and development partners have been the major developers of reservoirs for irrigation. The development of more reservoirs in the next two decades for irrigation may continue but not comparable to the rate of development of the 1970s. There are however, a significant number of small reservoirs which are currently not functioning and which may be rehabilitated for irrigation purposes as has been done in recent times in the sub-basin (LACOSREP, 2000).

8.5.2 Impact of Intensifying Irrigation on Water Resources and Competing Water Uses

The model analysed three scenarios, 5% annual growth, 10% annual growth and sustainable level of irrigation development. Amongst the three scenarios the most realistic scenario is arguably the 5% annual growth in irrigation development. This impact analysis uses the 5% annual growth in irrigation development as the benchmark.

Impact of surface water irrigation

In the Atankwidi and Anayari catchments actual surface water irrigation is about 2ha (0.02%) and 217ha (0.3%) respectively. In the Yarigatanga catchment this figure is about 214ha (0.6% of the catchment). If current irrigation would grow at 5%/a, by 2025, surface water irrigation in the

Anayari catchment will be 371ha (0.8%), in the Atankwidi catchment 5.4ha (0.05%) and in Yarigatanga 578ha (1.6%). This results in reducing streamflow in the Anayari River by $3.8 \times 10^6 \text{m}^3/\text{a}$ (3.7%), in Atankwidi by $0.8 \times 10^6 \text{m}^3/\text{a}$ (1.2%) and in Yarigatanga by $2.6 \times 10^6 \text{m}^3/\text{a}$ (3.2%).

Impact of ground water irrigation

Current groundwater irrigation in the Anayari catchment is 840ha (1.80%), in Atankwidi catchment 191ha (0.69%) and in Yarigatanga catchment 5ha (0.01%). If current irrigation would grow at 5% then by 2025, groundwater irrigation in Anayari would have reached 4.86%, 1.86% in Atankwidi and 0.03% in the Yarigatanga catchment. These result in evaporation losses of $21.2 \times 10^6 \text{m}^3/\text{a}$ in the Anayari catchment, $4.6 \times 10^6 \text{m}^3/\text{a}$ in the Atankwidi catchment and $0.14 \times 10^6 \text{m}^3/\text{a}$ in the Yarigatanga catchment. These evaporation losses stem from groundwater that otherwise would contribute to streamflow in the basin. Therefore, streamflow contribution from the catchment is reduced by these evaporation losses. However, these evaporation losses are conservatively very high estimates. The fact remains that not every drop of water that is not used for irrigation would have made it to the Volta Lake.

Impact of upscaling irrigation in the White Volta sub-basin

The study area covers about 1% of the White Volta sub-basin. The trend of irrigation observed in the study area is similar to those in other catchments within the sub-basin. Therefore upscaling the results in the study area, gives a large-scale assessment of the impact of irrigation development in the sub-basin.

The White Volta sub-basin contributes 25% ($9.57 \times 10^9 \text{m}^3/\text{a}$) of the annual inflow into the Volta Lake. Thus a reduction in the streamflow from the White Volta sub-basin has a reduction factor of 0.25 on the total flow into the Volta Lake.

Using the 5% annual growth in irrigation as the benchmark for this analysis, the total water loss due to surface water and groundwater irrigation when the irrigation level in 2025 is attained equals $33.1 \times 10^6 \text{m}^3/\text{a}$ in the Anayari, Atankwidi and Yarigatanga watersheds. This is the total water loss due to irrigation in 1% of the total catchment area of the White Volta sub-basin. Upscaling to the entire White Volta sub-basin, results in annual streamflow reduction of $3.31 \times 10^9 \text{m}^3/\text{a}$ (35% of total streamflow) from the White Volta sub-basin. This is equivalent to 8.8% of mean annual water inflow into the Volta Lake; the largest water user being hydropower production at the Akosombo dam.

8.6 MANAGING TRADEOFFS BETWEEN UPSCALING IRRIGATION AND HYDROPOWER PRODUCTION

The results of this study compares to a similar study conducted by De Condappa et al. (2008) and Leemhuis et al. (2009) on the Volta Basin. Both studies provide insight into possible consequences of climate change and development of upstream small reservoirs on water allocated to the downstream Akosombo hydropower scheme. The study by De Condappa et al. (2008) defined a scenario of rapid increase in number of small reservoirs at a growth rate of 10% per year and simulated it over a study period of 2000-2020. The results showed that, the mean inflow to Volta Lake is reduced by about $0.8 \times 10^9 \text{m}^3/\text{a}$, which is about 2.1% of the mean inflow. The study area considered the entire upstream section of the Volta Lake and included both small and large reservoirs in Ghana and Burkina Faso of all sub-basins of the Volta basin.

In the present study, small reservoir irrigation development was assumed to grow at 5%/a, reaching its maximum in 2025. The maximum small reservoir irrigation attained in 2025 is simulated over 20 years and results in a reduction in streamflow of $1.17 \times 10^9 \text{m}^3/\text{a}$, which is about 3.1% of the total inflows into the Volta Lake. Even though this study covers only the White Volta sub-basin, it includes the impact of groundwater exploitation for irrigation on the Volta Lake. The overall water loss for hydropower generation is $3.31 \times 10^9 \text{m}^3 \text{ km}^3/\text{a}$, which is significant and has consequences on hydropower generation at the Akosombo dam. Thus co-ordinated management of all water uses in the sub-basin should address the consequences and the possible trade-offs between upstream and downstream water uses. The benefits of irrigation development upstream and of hydropower production downstream will be estimated and compared.

8.6.1 Benefits of Irrigation Development in the White Volta sub-basin

The increase in irrigated agriculture in the White Volta sub-basin has provided labour opportunities for the youth and women during the dry season who work on irrigation farms for daily wages. Owners of land close to river channels also seasonally rent/lease out their land to prospective irrigators at a fee and also obtain irrigated products from their tenants at the end of the season. The landowners also gain from these arrangements as irrigators plough the land at the end of the irrigation for the landlord making it ready for rainy season farming. There are other job opportunities created from dry-season irrigation in the White Volta sub-basin. This

includes the youth who load trucks for market women from southern Ghana who travel to buy vegetables and the middle-men who act as the mediators between market women and the farmers.

In the 2007/2008 dry season, income made by farm labourers on tomato irrigation farms ranged from 0.06-0.19 US\$/m³ of water consumed, while tomato farmers made a profit of 0.13-0.85 US\$/m³ of water consumed (Chapter 6 above). The gross profit margin of farmers ranged from 45-70%. Using vegetable production as the main crops produced in these irrigated areas and assuming that the water consumption and profit obtained for vegetables are the same as that of tomatoes (using the lower bound income and profit figures to cater for all vegetable crops), total water use of 3.31 x 10⁹ m³/a would translate into a profit of 429 million US\$/a for farmers and 198 million US\$/a as wages for farm labourers. It should be noted that the profit margin is very sensitive to market variations (Ofosu et al., 2010).

Inhabitants of the White Volta sub-basin are mainly subsistence farmers (85%). Due to the semi-arid nature of the sub-basin, there are few employment opportunities for the inhabitants during the dry-season. This accounts for the high rural-urban migration during the dry season to do menial jobs in the urban centers (Ofosu et al., 2010). Therefore the creation of job opportunities through irrigation is a major socio-economic benefit for the inhabitants of the sub-basin.

8.6.2 Benefits of Hydro-power production at Akosombo

The Akosombo dam was created in 1961, with the first phase completed in 1968 and the second in 1972. The dam has created the Volta Lake, which is the largest man-made lake in the world with a maximum surface area of 8,500km² and a maximum storage volume of 148 x 10⁹ m³. It has six turbine units with a total plant capacity of 1020MW. The maximum operating level of the dam is 84.73m and the minimum is 73.15m. The height above tailwater of the Akosombo dam is 73.20m. Based on a combined turbine efficiency of 0.93, and the maximum height, the power production is 0.186kWh/m³ (Obeng and Fiaigbe, 2005).

The Volta River Authority (VRA), a state-owned entity, is responsible for generation and transmission of electricity in Ghana. The Akosombo dam is the largest producer of electricity in Ghana. Electricity accounts for about 11% of the nation's total energy consumption. It is estimated that about half of this amount is consumed by residential consumers for household uses, while commercial and industrial users account for the rest. Deregulated

consumers such as mines and aluminium companies account for one third of total consumption. One industrial entity, the aluminium smelter VALCO, accounts for most of this amount when it is operating normally. With a customer base of approximately 1.4 million, it has been estimated that 45-47% of Ghanaians, including 15-17% of the rural population, have access to grid electricity, with a per capita electricity consumption of 358 kWh/a (Resource Center for Energy Economics and Regulation, 2005)

The Akosombo dam is the backbone of Ghana's industrialization and economic activities. It also supplies electricity to neighboring countries such as Togo and Benin. Other benefits include: lake transportation, increased fishing, new farming activities along the shoreline and tourism (Gyau-Boakye, 2001).

The cost of electricity production from hydropower in Ghana is 0.02-0.025 US\$/kWh and it is sold at a Bulk Electricity Price of below 0.04 US\$/kWh. The introduction of thermal plants for electricity production has increased the average production cost to 0.06 US\$/kWh and the Bulk Electricity Price to 0.048 US\$/kWh. Currently the End User Tariff is 0.082 US\$/kWh (Resource Center for Energy Economics and Regulation, 2005). So one cubic metre of water used for hydropower generates 0.186 kWh which creates 0.015 US\$/m³ of revenue. Note that this is one order of magnitude smaller than the lower bound profit generated from water used for tomato production.

8.6.3 Managing trade-offs between irrigated agriculture upstream and hydropower production downstream at Akosombo

The decrease in inflow into Lake Volta as a result of increased water consumption for irrigated agriculture will negatively impact on hydropower production. Reduced inflows may lead to reduced water levels which will reduce the energy head available for electricity generation. To estimate the impacts requires a representative data series of historical inflows into Lake Volta, water levels, and electricity production, as well as some climate data, characteristics of the lake and characteristics of the Akosombo plant.

A spreadsheet-based water balance model (Waflex, see Savenije, 1995) was developed that could reproduce the water levels, electricity generated and dam releases over the period 1985-1998. Since information on the dam operating policies was lacking, the model was based on historical hydropower generation data and other hydrological data obtained from the VRA and other institutions. Data obtained from the Volta River Authority (VRA) and the Hydrological Services Department in Ghana was used to create

Area-Volume and Area-Stage relationships for Lake Volta. The surface area (A in 10^6 m^2) - Volume (V in 10^9 m^3) relationship is given in Equation 8.7, and Equation 8.8 relates surface area (A in 10^6 m^2) and water depth y (m).

$$A = 155.1 \times V^{0.7921} \quad (R^2 = 1) \quad \text{Equation 8.7}$$

$$A = 129.01e^{0.0493y} \quad (R^2 = 0.9996) \quad \text{Equation 8.8}$$

Model results gave a good fit of observed and modelled water levels ($r^2=97.8\%$) and hydropower generation (99.8%). The Waflex model was then used to assess the impact of reduced inflows on hydropower generation. Figure 8.14 shows the impact of reduction in streamflow on reservoir storage and reservoir levels and hydropower generation. Figure 8.15 provides more detailed information on the effect of reduced inflows on the firm power generation capacity.

If total inflow would reduce by $3.3 \times 10^9 \text{ m}^3$ (fraction of historical inflow = 0.905), the average water level would drop by about 2.3m, average reservoir storage would reduce by $4.9 \times 10^9 \text{ m}^3$, electricity generation would drop by 518GWh/yr. The loss of revenue from hydropower generation at Akosombo due to the upstream irrigation in the White Volta sub-basin would thus be about 42.5 million US\$/a [calculated as $518 \times 0.082 = 42.5$].

As the net evaporation from the Volta Lake is estimated to be 265mm/a (Friesen et al., 2005), the reduced inflows may lead to some savings from the lake evaporation.

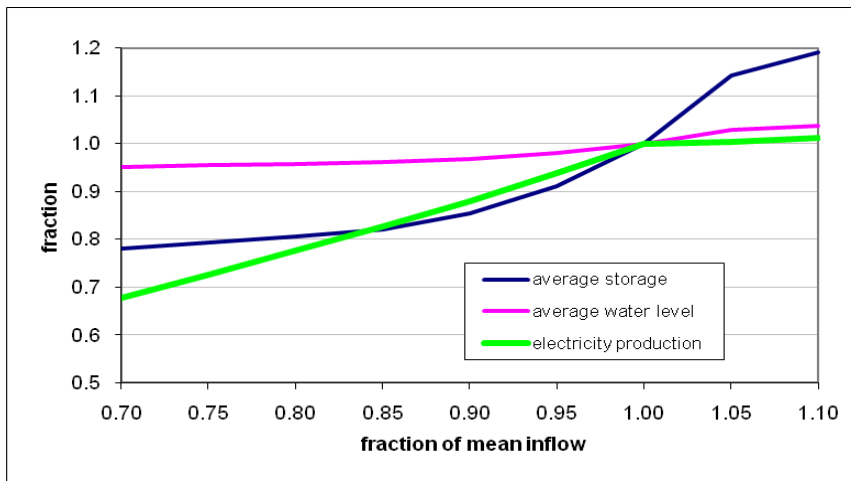


Figure 8.14: Impact of change in inflow into Lake Volta on water level, storage and electricity production, given historical operating policies.

From the financial analysis of the two competing water uses, it is clear that, more financial profits are made from upstream irrigation of vegetables (429 million US\$/a) than the benefits foregone (42.5 million US\$/a) for hydropower generation at Akosombo. The loss to hydropower generation is marginal compared to the total income generation for farmers and labourers in the poorest areas of the country.

The $3.31 \times 10^9 \text{ m}^3/\text{yr}$ reduction in inflow into Lake Volta results in saving $0.33 \times 10^9 \text{ m}^3/\text{yr}$ that would otherwise have been lost through evaporation from the Volta Lake - 10% of the reduced inflows is thus fully compensated by reduced evaporation losses, leading to an increase in water use efficiency at the basin scale.

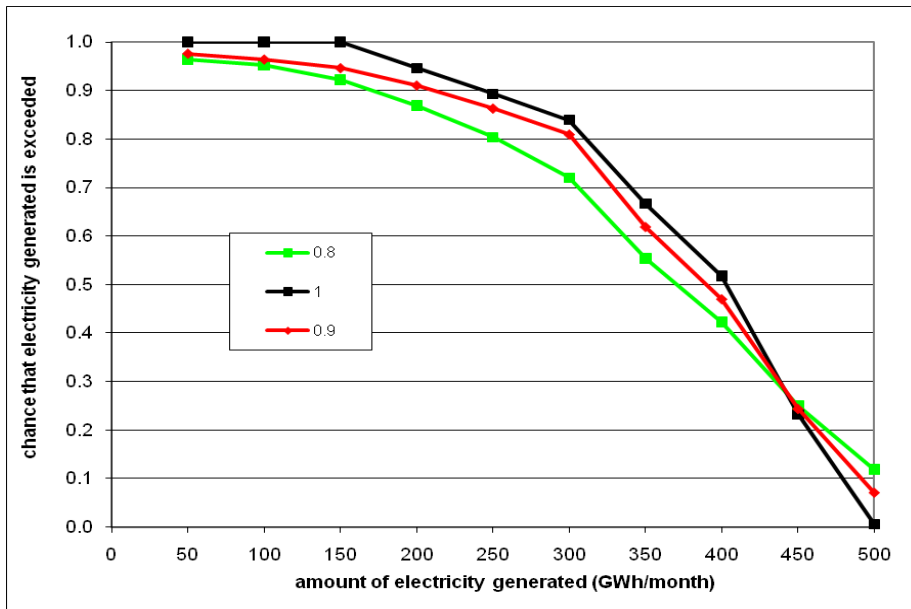


Figure 8.15: Impact of reduction of inflow into Lake Volta on hydropower generation at Akosombo.

From the above findings it may be concluded that upscaling of irrigation development in the White Volta sub-basin, maximizes the benefits from water resources in the Volta Basin. The results confirm the conclusions made by Leemhuis et al. (2009) that the impact of small reservoir development on the water resources of the Volta Basin is marginal compared to their benefits in securing food production and livestock during the dry season. However it is important to determine a ceiling above which no further upstream water uses should be permitted in order to ensure sustainable hydropower

production and protect riverine ecosystem services. Such a maximum development level should be decided by the Volta Basin Authority, in consultation with major stakeholders, including the Volta River Authority. Figures 8.14 and 8.15 can serve as an initial guide for determining such a threshold.

8.6.4 Implications for Sustainable Water Resources Management

The current level of irrigation development in the study area does not pose challenges to water resources management. It does not affect competing water uses neither does it impact on the sustainability of the water resources. Based on the current irrigation growth in the White Volta sub-basin of 5%/a, current irrigation may more than double by 2025. When this occurs, inflows into the Volta Lake will be reduced by about 8.8%. This has potential consequences on the hydropower generation at Akosombo.

The benefits obtained from irrigation upstream (financial and social), however exceed the financial benefits obtained from hydropower. This makes irrigation development more profitable and as such maximizes the benefits derived from the water resources of the basin. However it is important to manage the water resources such that irrigation development does not cause significant environmental harm nor significant economic harm to hydropower generation at Akosombo. This calls for prudent water resources management of the basin to ensure maximum benefits and long-term sustainability.

To achieve this, the following activities are recommended:

- Monitor water resource development in the White Volta sub-basin
- Monitor and quantify the competing water uses in the sub-basin
- Establish information flows between upstream and downstream water users
- Set up institutions at appropriate levels to ensure effective water resources management

8.6.5 Conclusions and Recommendations

The study has established that irrigation development in the three catchments studied is less than 2% of the total study area: 1% for Anayari, 0.8% for Atankwidi, and 2.6% for Yarigatanga. About 90% of all irrigation in Yarigatanga is sourced from surface water, while 85% of all irrigation in the Atankwidi and Anayari catchments is sourced from shallow groundwater.

There is a high potential for the upscaling of irrigation development in the basin. However there are sustainability limits for both surface water and

groundwater exploitation. Modelling results show that sustainable groundwater use can be achieved if not more than about 8% of the catchment is irrigated, at an irrigation efficiency of 70%. This ceiling is sensitive to groundwater recharge rates, which are affected by changing land-use practices and climate variability and change.

The outcomes of the WEAP model have been validated using a simple water balance approach. The validation revealed that the WEAP model ignores water losses due to groundwater abstraction, which is a serious weakness. Thus losses due to groundwater abstraction were computed using the water balance approach.

Based on the observed 5%/a growth rate in the White Volta sub-basin, the irrigated area is likely to more than double by 2025. When this occurs, inflows into the Volta Lake will be reduced by 8.8%. This has potential consequences on hydropower production at Akosombo dam.

Comparing the benefits of upstream irrigation to the losses suffered by hydropower production downstream of the sub-basin, vegetable farmers would make a profit of about 429 million US\$/a while hydropower production at Akosombo would lose 42.5 million US\$/a. The socio-economic benefits of irrigation upstream of the Volta Lake thus significantly exceed the financial loss to hydro-power production. This implies that if current development trends as studied in the three small catchments continue to develop for the coming 15 years, and are upscaled to the entire White Volta, then the negative downstream impacts are relatively small compared to the upstream benefits.

However, these conclusions are made based on reproducing historical electricity generation patterns. A much more detailed investigation is required that would include explicit operating policies of the Akosombo dam, and would be able to optimise operating rule that could minimise electricity losses in the face of reduced inflows.

The study has not considered the possible future developments in other sub-basins and the combined impacts of all upstream developments on the Akosombo dam. To be able to assess the impact, the following has to be done: (1) to conduct analysis similar to the present in all other sub-basins; and (2) to develop a dynamic water resources model to accurately assess the impact.

Finally objective criteria have to be developed, that are derived from policies, with which maximum upstream abstraction levels can be established, based on the above input data and models.

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

9.1.1 Irrigation Development in sub-Saharan Africa

Irrigation development in sub-Saharan Africa begun in the pre-colonial era and have continued through the colonial and post-colonial era with the majority of irrigation schemes developed by governments. In the last two decades, however, a significant amount of irrigation have been developed by private commercial farmers, outgrower farmers, small-holder individuals and communities as well as non-governmental organisations.

The rate of irrigation development in sub-Saharan Africa is the slowest compared to other regions of the world and can be linked to the following unresolved challenges: high development cost of irrigation, lack of access to credits for farmers, unreliable and unpredictable markets, ineffective institutions, low productivity, and finally, inappropriate technologies coupled with poor infrastructural maintenance.

The study identifies five success factors for irrigation development in sub-Saharan Africa and the enabling condition through which it can be achieved. These factors include (1) secure access to land and water, (2) appropriate technology, (3) predictable and stable input/output markets, (4) reliable farmer support environment, and (5) effective institutions and favourable policies. These factors function as a chain of shackles, the chain being as strong as the weakest shackle. This implies that in a given situation the weakest shackle has to be strengthened (adopted from Penning De Vries et al., 2005 and Vishnudas et al., 2007). This theory has been tested on some irrigation systems across sub-Saharan Africa with various degrees of success and has proven to reveal the sources of success and failure. The weakest shackle was found to be secure access to land and water followed by effective institutions and favourable policies. The strongest shackles are reliable farmer support environment and predictable and stable input/output markets.

9.1.2 Irrigation Development in the White Volta sub-basin

Irrigation in the White Volta sub-basin was initiated by the Governments of Burkina Faso and Ghana when they promoted the construction of small reservoirs, large reservoirs and dugouts since the early 1950s. During the past twenty years, however, the driving force behind irrigation development in the sub-basin has been predominantly private and by associations of individuals supplemented with some donor assistance. The trend of irrigation development in Burkina Faso and in Ghana is comparable. However the rate of development is more advanced in Burkina Faso compared to the Upper East Region in Ghana. This may be the result of the Burkina government's policy of improving the irrigation technologies initiated by private individuals and also equipping farmer groups to manage their irrigation systems.

In recent times the prospects of vegetable production has triggered the initiation and upscaling of several irrigation technologies in the White Volta sub-basin of the Volta Basin. These new irrigation technologies source their water from permanent shallow wells, temporal shallow wells, riverine water and riverine alluvial dugouts. The technologies have spread in the sub-basin because the direct control of water sources, either through groundwater pumping, drainage reuse or direct pumping from canals and rivers, has brought flexibility in water delivery to farmers that the large-scale surface distribution systems did not offer. The steadily growing market for vegetables in the urban areas of southern Ghana and the transfer of knowledge on irrigation technologies and farming have all contributed to the upscaling of irrigation technologies in the sub-basin. Meanwhile it has also brought challenges in managing irrigation development in the White Volta sub-basin, because of the uncoordinated irrigation water use and the rising competing uses of water.

A detailed and extensive survey of irrigation technologies was conducted in three small adjacent catchment areas in the White Volta sub-basin, namely Anayari (446 km²), Atankwidi (275 km²) and Yarigatanga (375 km²).

The survey revealed that those irrigation technologies characterised by relatively small farm sizes are best managed by the surveyed farmers. This is because these technologies enable farmers to provide adequate water and crop nutrients, thus resulting in relatively high levels of productivity. These highly productive irrigation technologies also achieve good profit margins and provide income opportunities to the wider society in terms of labour. Moreover, these technologies also have a relatively high participation of

women farmers. In contrast, the large irrigation schemes, where farm plots are relatively large, achieve low productivities (in terms of land, water and profit margin).

The findings imply that in order to achieve high impact, irrigation development in sub-Saharan Africa should consider the economic status of the users and their ability to make the best out of the technology in terms of productivity. Also, technologies with farmers controlling the water should be preferred. The resulting economic activities have a large positive spinoff in terms of job opportunities, especially for the youth and female farmers.

Finally apart from technologies that depend on reservoirs, all other technologies are farmer driven and required no government support. This ongoing type of endogenous irrigation development in the study area provides a strong backing that the way forward in sub-Saharan Africa is for governments to create policies that facilitate poor farmers becoming irrigation entrepreneurs. Such policies should aim to enhance the reliability of markets (both input and output) as the driving force, and facilitate people's access to land and water.

9.1.3 Impact of Upscaling Irrigation Development in the White Volta sub-basin

Current irrigation covers 1% of the Anayari catchment area, 0.8% of Atankwidi and 2.6% of Yarigatanga. Private-led irrigation is about 73% of the total irrigation in the study area and has been growing at a rate of 5.7%/a. Government-led irrigation systems (small and large reservoirs), in contrast, experienced a general decline in irrigated areas over the past three decades due to infrastructural and institutional challenges. The study area has experienced an overall annual irrigation growth rate of 5.6%/a from 2005-2010. The study area covers about 1% of the White Volta sub-basin. The trend of irrigation observed in the study area is considered to be similar in the other catchments within the sub-basin.

The factors that have influenced the past trend are likely to sustain the current state of irrigation in the basin. However additional factors such as expanding markets for irrigated products, introduction of new irrigation technologies, government policies and interventions are likely to increase irrigation development beyond the current growth rate in the near future.

If current irrigation would grow at 5%/a, by 2025, the level of irrigation would result in reducing streamflow from the study area by $33.1 \times 10^6 \text{m}^3$. This is the total water loss due to irrigation in 1% of the total catchment area of the White Volta sub-basin. Upscaling to the entire White Volta sub-

basin, results in annual streamflow reduction of $3.310 \times 10^6 \text{m}^3$ (35%) from the White Volta sub-basin. This equals 8.8% of mean annual water inflow into the Volta Lake; the largest water user being for hydropower production in the Akosombo dam.

It was estimated that a 8.8% decrease in inflows would result in a drop of electricity production of about 520 GWh/a and an average drop of the water level in Lake Volta of about 2.3m, assuming operating policies for electricity production would remain the same.

From the financial analysis of the two competing water uses, it is clear that, more financial profits would be made from upstream irrigation in tomatoes (429-2,805 million US\$/a) than the revenue loss (42.5 million US\$/a) due to reduced hydropower generation at Akosombo. The loss to hydropower generation is marginal compared to the total income generation for farmers and labourers in the poorest areas of the country. Moreover, an amount of $330 \times 10^6 \text{m}^3/\text{yr}$ otherwise lost to evaporation from the Volta Lake would be productively used in food production upstream. So in this case 10% of the reduced inflows is fully compensated by reduced evaporation losses, leading to an increase in water use efficiency at the basin scale. From the above findings it can be concluded that upscaling irrigation development in the White Volta sub-basin will maximize the overall benefits derived from water resources in the Volta Basin.

9.1.4 Sustaining Irrigation Development in the White Volta sub-basin

The current level of irrigation development in the study area does not pose challenges to water resources management. It does not affect competing water uses neither does it affect the sustainability of the water resources. Thus irrigation development can still be encouraged in the White Volta sub-basin.

Finally, effective water resources management of the Volta Basin is needed to ensure efficient, productive, sustainable and maximum benefits of water resources development. Effective collaboration between the White Volta Basin Board and the Volta River Authority is needed to maximize benefits from irrigation development and hydropower generation for socio-economic development.

9.1.5 Implications of results for other regions of sub-Saharan Africa

Different regions in sub-Saharan Africa are characterised with similarities in culture, farming practices, living standards, educational levels, technology, developmental needs, and institutional context. Thus lessons drawn from studies conducted in some parts of sub-Saharan Africa may be relevant to other regions. This implies that findings from this research conducted in a semi-arid climate with high poverty levels where farming is the main source of livelihood are not limited to the White Volta sub-basin only. The endogenous irrigation development dynamic found in the White Volta sub-basin contains some lessons that can be used to help improve irrigation development in other parts of sub-Saharan Africa.

The irrigation development trend found in the White Volta sub-basin is born out of a fairly robust and growing market demand in the urban areas of southern Ghana. Thus the main driving force of this development, and its associated innovative irrigation technologies, is the market for irrigated products. This phenomenon is common across sub-Saharan Africa where urbanisation is increasing rapidly. Other regions can take advantage of the increasing demand for irrigated crops, such as vegetables and rice.

Most of the recent irrigation technologies identified in the White Volta sub-basin are indigenous and locally managed. Farmers in the sub-basin have successfully managed these technologies because they are simple and relatively inexpensive. The farmers have also seized the opportunity of the presence of relatively cheap and abundant labour to develop some of these technologies. This is a major lesson for irrigation development in sub-Saharan Africa. Irrigation development policies must begin to look at how to empower local farmers to become entrepreneurs.

Several investments have been directed towards large-scale irrigation schemes which have not yielded expected benefits. The ongoing irrigation development in the White Volta sub-basin is self-initiated by local individuals without external or government support. This presents opportunities for governments to re-assess investments in irrigation development. For example, investments can be directed towards creating the enabling environment for irrigation development, such as stable and reliable markets, farmer accessibility to land and water, farmer support services and effective institutions. These are likely to trigger the entrepreneurship capabilities of farmers which will bring expansion of irrigation.

9.2 RECOMMENDATIONS

This study aimed at achieving an improved understanding of effective and sustainable irrigation development in the White Volta sub-basin. However there are other challenges to sustainable irrigation development which have not been captured in this study. A typical example is the impact of climate change on future water availability for irrigation and other competitive water uses in the sub-basin. Another scenario is the impact of upscaling irrigation development in Burkina Faso on competing water uses in downstream Ghana. There are other possible future scenarios which can be studied towards achieving sustainable irrigation development. There are also institutional challenges identified in the study area. The transboundary nature of the sub-basin demands effective collaboration and cooperation between Ghana and Burkina Faso to ensure commitment in keeping each other's needs into account. It is therefore recommended that future studies be conducted on the above topics to help achieve sustainable irrigation development in the White Volta sub-basin.

The study has not considered the possible future developments in other sub-basins and the combined impacts of all upstream developments on the Akosombo dam. To be able to assess the impact, the following needs to be done: (1) to conduct analyses similar to the present in all other sub-basins; and (2) to develop a dynamic water resources model to accurately assess the impact. It is important to determine a ceiling above which upstream water uses should not be permitted, not only to ensure sustainable hydropower production but also to sustain riverine ecosystems and the associated services. To achieve sustainable hydropower generation and irrigation development simultaneously, objective criteria have to be developed, that are derived from policies, with which maximum upstream abstraction levels can be established, based on the data and models developed by this and other studies. Setting maximum development levels is the mandate of the Volta Basin Authority, but should be done in close collaboration with the Volta River Authority and other key stakeholders in the Volta Basin.

9.3 LIMITATIONS OF THE STUDY

The findings of this study have some limitations. A major drawback is the lack of long-term streamflow measurements in the studied catchments, which prevented the development of a hydrological rainfall-runoff model. Also the interaction between surface water and groundwater in the sub-basin was unknown making it impossible to adequately model this interaction in WEAP.

The lack of good satellite images prevented a general assessment of the trend of irrigation development, both in the three catchment areas studied in detail, as well as for the entire White Volta sub-basin. Thus the extrapolation from the study area to the White Volta sub-basin had to be based on a rather crude assumption.

Finally, the language barrier between Ghana and Burkina Faso also posed a challenge. Despite of efforts to learn French, which is the language spoken in Burkina Faso, the period and nature of the study could not lead to a full mastering of the French language. As a result, useful publications in French on the part of Burkina Faso were not consulted.

9.4 INNOVATIONS MADE BY THE STUDY

This study has achieved its aim of enhancing the understanding of effective and sustainable management of irrigation development in the White Volta sub-basin. Apart from achieving the aim, the study has also made innovative contributions to sustainable irrigation development.

This study has determined the hydrological impact of irrigation development on hydropower generation. It also compares the socio-economic gains made from irrigation development with the financial loss to the hydropower generation as a result of increased water consumption upstream.

First, the study has identified: high development cost of irrigation, lack of access to credits for farmers, unreliable and unpredictable markets, ineffective institutions, low productivity, and finally inappropriate technologies coupled with poor infrastructural maintenance as challenges affecting irrigation development in sub-Saharan Africa. The study further found that the way forward for achieving sustainable irrigation development is by ensuring that these five essentials are provided: (1) secure access to land and water, (2) appropriate technology, (3) predictable and stable input/output markets, (4) reliable farmer support environment, and (5) effective institutions with favourable policies. These essentials function as a chain of shackles, the chain being as strong as the weakest shackle.

Second, the study found that those irrigation technologies characterised by relatively small farm sizes are better managed by local farmers because they are able to provide adequate water and crop nutrients thus resulting in higher productivity. Moreover, these highly productive irrigation technologies also achieve good profit margins and provide income opportunities to the wider society in terms of labour and also have higher women participation.

Third, some of the emergent irrigation technologies found in the study area have been described for the first time (Ofosu et al., 2010)

Fourth, the study also established that irrigation grew at a rate of 5% per year. If irrigation in the White Volta sub-basin would continue to grow at this rate, by 2025 irrigation would reduce streamflow from the White Volta sub-basin by 35%, which equals a 9% reduction in inflow into Lake Volta. The study established that the socio-economic benefits of upstream developments far outweigh the benefits foregone in electricity production at Akosombo.

Finally, the case of endogenous irrigation development in the White Volta clearly shows that irrigation policies must focus on empowering local farmers to become entrepreneurs.

REFERENCES

- Abernethy, C. L., Sally, H., Lonsway, K. and Maman, C., 2000. *Farmer-Based Financing of Operations in the Niger Valley Irrigation Schemes*. Research Report 37.: IWMI, Colombo.
- Adams, A., 1977. *The Senegal River Vally: what kind of change?* Review of African Political Economy, 10 (Sept-Dec), 33-59.
- Adu, S.V., 1995. *Soils of the Nasia basin, Northern Region , Ghana*. Memoir No 11. Soil Research Institute, Kwadaso, Kumasi.
- Agyepong, G.T., 1997. *Land use/Land cover; Volta Basin System*. Information Building Block, Ghana Water Resources Management Study Vol I, Accra.
- Albinson B.; and C. J. Perry. 2002. *Fundamentals of Smallholder Irrigation: The Structured System Concept*. Research Report 58. IWMI, Colombo.
- Annor, F. A., van de Giesen, N., Liebe, J., van der Zaag, P., Tilmant, A. and Odai, S. N., 2009. Delineation of small reservoirs using radar imagery in a semi-arid environment: A case study in the Upper East Region of Ghana. *Physics and Chemistry of the Earth*, 34 (4-5): 309-315.
- Aw, D. and Diemer, G., 2005. *Making a Large Irrigation Scheme Work: A case study from Mali*. The World Bank.
- Awulachew, S. B.; Merrey, D. J.; Kamara, A. B.; Van Koppen, B.; Penning de Vries, F.; Boelee, E.; Makombe, G. 2005. *Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia*. (Working paper 98), IWMI, Colombo.
- Bakker, M., Barker, R., Meinzen-Dick, R.S. and Konransen, F., eds. 1999. *Multiple uses of water in irrigated areas: A case study from Sri Lanka*. SWIM Report 8. International Water Management Institute. Colombo.
- Barry, B., Obuobie, E., Andreini, M., Andah, W., Pluquet, M., 2005 (Draft). *The Volta River Basin: Comparative Study of River Basin Development and Management*. Unpublished document. Comprehensive Assessment of Water Management in Agriculture. IWMI, Accra
- Barnett, T., 1984. Small-scale irrigation in sub-Saharan Africa: sparse lessons, big problems, any solutions? *Public Administration and Development*, Vol. 4, 21-47.
- Bell, M., R. Faulkner, R. Hotchkiss, R. Lambert, N. Roberts and A. Windram. 1987. *The Use of Dambos in Rural Development with Reference to Zimbabwe*. Final report of ODA Project R3869. Water Engineering and Development Centre (WEDC) Loughborough University UK.
- Berry, S. 1993. *No condition is permanent, the social dynamics of agrarian change in sub-Saharan Africa*. The University of Wisconsin Press, Madison.
- Birner, R., Schiffer, E., Asante, F., Osman, G. and McCarthy, N., 2005. *Governance Structures for Water Resources Management in the White Volta Basin, Ghana*.

- Integrating Governance and Modelling*. Unpublished document. Challenge Program on Water and Food. IWMI, Accra.
- Biodiesel Magazine, 2010. *Namibia to produce jathropa biodiesel*. Available at [<http://www.biodieselmagazine.com/articles/4170/namibia-to-produce-jatropha-biodiesel>]
- Boelee, E., Cecchi, P., Kone, A., 2009. *Health impacts of small reservoirs in Burkina Faso*. IWMI Working Paper Series 136, International Water Management Institute Colombo.
- Bouju, J. 1998. "Contrôle foncier et conflits pour les ressources : l'accès aux bas-fonds aménagés comme enjeu de pouvoir local." Referenced in Delville L. P., 2000. *Harmonising formal law and customary land rights in french-speaking West Africa*.
- Brammer, H., 1962. *Soils in J.B.Wills, Agriculture and land use in Ghana*. OUP. London.
- Brown, E. P., and R. Nooter. 1992. Successful small-scale irrigation in the Sahel. World Bank Technical Paper Number 171. Washington, D. C.: World Bank.
- Bruinsma, J., ed. 2003. *World Agriculture: Towards 2015/2030*. An FAO Perspective. London: Food and Agriculture Organisation and Earthscan.
- Burkina Faso. 1999. Reforme Agraire et Foncière du Burkina Faso (RAF) Loi n° 14 du 23 Mai 1999. Government of Burkina Faso, Ouagadougou.
- Burt, C. M., 1999. Irrigation water balance fundamentals. Presented at conference on benchmarking irrigation system performance using water measurement and water balances. San Luis Obispo, CA. March 10 USCID, Denver, Colo pp. 1-13. Available at <http://www.itrc.org/papers/irrwatbalance/irrwatbal.pdf>.
- Carruthers, I., Rosegrant, M. W. and Seckler, D., 1997. Irrigation and Food Security in the 21st Century. *Irrigation and Drainage Systems* 11: 83-101
- Carter, R. C., 1981. *Learning from irrigation experience – Northern Nigeria*. Paper presented to ICID Conference 4-6 April 1981, Southampton.
- Chambers, R., 1988. *Managing Canal Irrigation: Practical Analysis from South Asia*. New York Cambridge University Press.
- Chauveau, J.P. 1998. "La logique des systèmes coutumiers." Referenced in Delville L. P., 2000. *Harmonising formal law and customary land rights in french-speaking West Africa*.
- Cecchi, P.; Meunier-Nikiema, A.; Moiroux, N.; Sanou, B. 2009b. Towards an atlas of lakes and reservoirs in Burkina Faso. In: Boelee, E., Cecchi, P., Kone, A., 2009. *Health impacts of small reservoirs in Burkina Faso*. (IWMI Working Paper 136) Colombo.
- CIA – The World Factbook, 2009. <https://www.cia.gov/library/publications/the-world-factbook/print/gh.html>
- Commission for Africa. 2005. *Our common interest: Report of the Commission for Africa*. London: Commission for Africa.

- Daily Guide, 09/03/2009. *Farmers commit suicide*. Available at [<http://www.modernghana.com/news/205641/1/farmers-commit-suicide.html>]
- Dapaah-Siakwan, S.; Gyau-Boakye, P., 2000. Hydrogeologic framework and borehole yields in Ghana. *Hydrogeology Journal*, 8, 405-416
- de Condappa, D., Chaponnière, A., Andah, W., and Lemoalle, J., 2008. *Application of WEAP in the Volta Basin to model water allocation to the Akosombo hydropower scheme under different scenarios*. Presented at the 2nd International Forum on Food and Water, November 10-14, 2008, Addis Ababa.
- de Fraiture, C., Wichelns, D., Rockström, J. And Kemp-Benedict, E., 2007. *Looking ahead to 2050: scenarios of alternative investment approaches*. Chapter 3 in D. Molden (ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London: International Water Management Institute, Earthscan and Colombo. pp. 91-145
- Delville L. P., 2000. Harmonising formal law and customary land rights in french-speaking West Africa. In Toulmin C. and Quan J. (eds.), *Evolving land rights, policy and tenure in Africa*. DFID/IIED/NRI, London, pp. 97-121.
- Dembélé, Y. 1998. Main options in the Development and Management of Small-Scale irrigation systems in Burkina Faso. In: FAO Water report No.7 *Institutional and Technical options in the Development and Management of Small-Scale irrigation Systems*. Proceedings of the third session of multilateral cooperation workshop on Sustainable Agriculture. Forestry and Fisheries Development, 3-6 February 1998, Tokyo (Japan), 97-107.
- de Nooy, E.J.P., 1996. *Development of support structure for irrigated agriculture*. Report of the first mission during preparatory phase. Rome, FAO, AGLW: TCP/GHA/6613,
- de Zeeuw, F., 1997. Borrowing of Land, Security of Tenure ad Sustainable Land use in Burkina Faso. *Development and Change* Vol. 28, 583-595.
- DFID, 2003. *Comparative Study of Land Administration Systems: Case Study – Ghana*. Peer Review of World Bank Policy Research Report (PRR) on Land. UK Department for International Development (DFID).
- Dialla B. E., 2002. La sécurité foncière sur les périmètres irrigués du Burkina Faso: le cas de la vallée du Sorou. *Afrique et Développement*, Vol. XXVII Nos. 1&2 pp. 62-83.
- Diemer G., 1988. *Paradigms in Irrigation Development: A view from Africa*. Paper submitted to the open session on irrigation at the World Congress on Rural Sociology to be held in Bologna, Italy. 26 June – 1 July 1988.
- Drechsel, P.; Graefe, S.; Sonou, M.; Cofie, O. O., 2006. *Informal irrigation in urban West Africa: An overview*. (IWMI Research Report 102), IWMI, Colombo.
- Edwards, S. and van Wijnbergen, S., 1992. Disequilibrium and Structural Adjustment. In H. Chenery and T.N. Srinivasan, editors, *Handbook of Development Economics*. Elsevier. Amsterdam. 1481-1533.

- Evans, H.E. and Ngau P., 1991. Rural-Urban Relations, Household Income Diversification and Agricultural Productivity. *Development and Change* 22:519-545.
- FAO, (Food and Agriculture Organization of the United Nations) 1979. *Yield Response to Water*. FAO Irrigation and Drainage Paper. FAO. Rome.
- FAO, 1986. *Irrigation in Africa south of the Sahara*. Investment Centre Technical Paper Number 5. Rome: FAO.
- FAO, 1991. Land Resource Management Study. Report No: 103/91 CP-GHA 28. Rome: FAO.
- FAO, 1995a. Irrigation in Africa in figures. Report No. 7. Rome.
- FAO, 1995b. *Study of the irrigation potential for Africa*. Land and Water Development Division, FAO, Rome, Italy. Water Report no. 16.
- FAO, 1997. *Irrigation Potential in Africa: A basin approach*. FAO land and water bulletin 4. Rome, Italy.
- FAO 1998. *Supporting aquaculture development in Africa: Research Network on Integration of Aquaculture and Irrigation*. CIFA Occasional Paper No. 23 CIFA/OP23. A report prepared for the Inland Water Resources and Aquaculture Service of the FAO Fisheries Department. FAO, Accra.
- FAO, 2003. *World Agriculture towards 2015/2030: An FAO Perspective*. Rome and London. FAO and Earthscan publishers.
- FAO, 2005. *Irrigation in Africa in Figures*, Aquastat Survey-2005. FAO Water Report 29, Rome.
- FAO, 2006a. FAOSTAT. Statistical database. <http://faostat.fao.org/>.
- FAO, 2006b. *World Agriculture: Towards 2030/2050. Prospects for Food, Nutrition, Agriculture and Major Community Groups*. Interim report. Global perspective studies unit. Rome.
- Faulkner, J. W., Steenhuis, T., van de Giesen, N., Andreini, M., Liebe, J. R., 2008. Water use and productivity of two small reservoir irrigation schemes in Ghana's Upper East Region. *Irrigation and Drainage* 57: 151–163.
- Faulkner, J. W., Steenhuis, T., van de Giesen, N., Andreini, M., Liebe, J. R., 2008. Water use and productivity of two small reservoir irrigation schemes in Ghana's Upper East Region. *Irrigation and Drainage* 57: 151–163.
- Faurès J., Svendsen M., Turrall H., et al., 2007. *Reinventing Irrigation*. Chapter 9 in D. Molden (ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London: Earthscan and Colombo: International Water Management Institute; pp. 353-394
- Friesen, J., Andreini, M., Andah, W., Amisigo, B. and van de Giesen, N., 2005. *Storage capacity and long-term water balance of the Volta Basin, West Africa*. Proceedings of symposium S6 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005. IAHS Publ. 296.

- Fuest, V., Ampomah, B., Haffner, S.A., Tweneboah, E., 2005. *Mapping the Water Sector of Ghana*. An Inventory of Institutions and Actors. GLOWA Volta Project, Bonn, Germany.
- Gerstl, S.; Cissé, G.; Tanner, M. 2002. Economic impact of urban agriculture on home gardeners in Ouagadougou. *Urban Agriculture Magazine* 7:12-15.
- Ghana, 1960. Act 27. Stool Lands Act of Ghana, 1960. Parliament of Ghana, Accra
- Ghana, 1962a. Act 123. Administration of Lands Act of Ghana, 1962. Parliament of Ghana, Accra
- Ghana, 1962b. Act 125. State Lands Act of Ghana, 1962. Parliament of Ghana, Accra
- Ghana, 1987. L.I. 1350. The Irrigation Development Authority Regulations, 1987, Government of Ghana, Accra
- Ghana, 1994. Act 483. Land Commission Act of Ghana, 1994. Parliament of Ghana, Accra
- Ghana, 1996. Act 522. Water Resources Commission Act of the Republic of Ghana, 1996. Parliament of Ghana, Accra
- Ghana, 2001. L.I. 1692. The Water Use Regulations of Ghana, Parliament of Ghana, Accra
- Ghana News Agency, 2010. *Tomato Farmers Desperate*. Accessed on 18-08-2010. Available at <http://business.peacefmnonline.com/news/201008/71883.php>.
- GPRS (Ghana Poverty Reduction Strategy), 2003. *Ghana Poverty Reduction Strategy I (2003-2005): An agenda for growth and prosperity*. Volume I, Analysis and Policy Statement.
- Grant, E. L., W. G. Ireson and R. S. Leavenworth, 1990. *Principles of Engineering Economy*. Eight Edition. New York: John Wiley.
- Resource Center for Energy Economics and Regulation, 2005. Guide to Electric Power in Ghana. Institute of statistical, social and economic research, University of Ghana, Legon.
- Gujja B, Perrin M, 1999. *A Place for Dams in the 21st Century*. Discussion Paper. Washington, DC: World Wildlife Fund.
- Gyasi, O., 2005: *Report on Community Needs Regarding Water Supply in the Upper East Region of Ghana*. Project “Integrating Governance and Modeling”. Bolgatanga, Ghana.
- Gyau-Boakye, P. 2001. Environmental impacts of the akosombo dam and effects of climate change on the lake levels. *Environment, Development and Sustainability* 3(1): 17-29.
- Hargreaves, G. H., 1974. Estimation of Potential and Crop Evapotranspiration. *American Society of Agricultural Engineers Vol 17(4): 701-704*.
- Hoffman, B. and Heidhues. F., 1993. *Credit Access in the Informal Sector: A Case Study of Two Villages in the Province Oueme in Benin*. CIRAD. Montpellier.

- Hundertmark, W., Abdourahmane, A.T., 2003. *A diagnostic model framework for water use in rice-based irrigation systems*. Research Report 74. IWMI, Colombo.
- Hussain, I., M. A. Hanijra., 2004. Irrigation and poverty alleviation: review of the empirical evidence. *Irrigation and Drainage* 53 (1): 1-15.
- Hussain, I. 2005. *Pro-poor Intervention Strategies in Irrigated Agriculture in Asia. Poverty in Irrigated Agriculture: Issues, Lessons, Options and Guidelines (Bangladesh, China, India, Indonesia, Pakistan and Vietnam)*. Project Final Synthesis Report. IWMI, Colombo.
- ICID, 2000. *Role of Dams for Irrigation, Drainage and Flood Control, International Commission on Irrigation and Drainage*. Position Paper. New Delhi: International Commission on Irrigation and Drainage ICID.
- ICOLD – members Burkina Faso, 2001. *Position on the report from the World Commission on Dams*, “Dams and Development a new framework for decision-making, 2000”. Earthscan Publications Ltd, London and Sterling, VA. http://www.dams.org/report/reaction/icold_burkina_faso.htm
- ICOUR, 1995. Information handbook. Accra, Ghana.
- ICWE, 1992. The Dublin Statement and Report of the Conference. International Conference on Water and the Environment, Development Issues for the 21st Century. Dublin 26-31 January
- IFAD (International Fund for Agricultural Development), 1990. Upper East Region Land Conservation and Smallholder Rehabilitation Appraisal Report No 0244-GH, Vol. I
- IFAD, 2000. *Knowledge Management: A Thematic Review of IFAD Support for Water Management and Irrigation in East and Southern Africa*. Report No. 1034.
- IFAD, 2005. Upper East Region Land Conservation and Smallholder Rehabilitation Appraisal Report No 0244-GH, Vol. II
- IFPRI (International Food Policy Research Institute), 1995. *Water resources development in Africa: a review and synthesis of issues, potentials and strategies for the future*. Washington D. C.
- Inocencio, A.; Kikuchi, M.; Tonosaki, M.; Maruyama, A.; Merrey, D.; Sally, H.; de Jong, I. 2007. *Costs and performance of irrigation projects: A comparison of sub-Saharan Africa and other developing regions*. (IWMI Research Report 109), IWMI, Colombo. 81 pp.
- James L. G., 1993. *Principles of Farm Irrigation System Design*. Kreiger Publishing Company, Malabar, Florida.
- Johnson, S.H.III., 1997. *Management transfer in Mexico: A strategy to achieve irrigation district sustainability*. Research Report 16. IIMI, Colombo.
- Jones, W. I. 1995. *The World Bank and Irrigation*. Washington, D.C.: World Bank.

- Kamara, A., van Koppen B. and Magingxa L., 2001. *Economic viability of small-scale irrigation systems in the context of state withdrawal: the Arabie Scheme in the Northern Province of South Africa*. Presented at the 2nd WARFSA/Waternet Symposium: Integrated Water Resources Management: Theory, Practice, Cases; Cape Town, 30-31 October 2001.
- Kasanga, K. and Kotey N. A., 2001. *Land Management in Ghana: Building on Tradition and Modernity*. Land Tenure and Resource Access in West Africa. International Institute for Environment and Development, London. Russell Press, Nottingham, UK.
- Kay, M., 2001. *Smallholder Irrigation Technology: Prospects for sub-Saharan Africa*. International Programme for Technology and Research in Irrigation and Drainage, Knowledge Synthesis Report No. 3. IPTRID Secretariat, Food and Agriculture Organisation of the United Nations, Rome.
- Keiser J., De Castro, M. C., Maltese M. F., Bos R. And Tanner M., 2005. Effect of Irrigation and Large Dams on the burden of malaria on a global and regional scale. *The American Journal for Tropical Medicine and Hygiene* 72(4), 2005, pp. 392-406
- Kelly, V. A. 2005. *Farmers' Demand for Fertilizer in Sub-Saharan Africa*. Agriculture and Rural Development Discussion Paper. Washington, DC: The World Bank.
- Kikuchi, M., Barker, R., Weligamage, P. and Samad, M., 2002. *Irrigation Sector in Sri-Lanka: Recent Investment Trends and the Development Path Ahead*. IWMI Research Report 62. IWMI, Colombo.
- Kortatsi, B., 1997. *Geology and Groundwater; Volta Basin System*. Information Building Block Ghana Water Resources Management Study, WRRI, Accra.
- Konings, P., 1986. *The State and Rural Class Formation in Ghana, a comparative analysis*. Routledge and Kegan Paul, London.
- Lahiff, E., 1999. *Land tenure on the Arabie-Olifants scheme*. South Africa Working Paper 2. International Water Management Institute and Nkuzi Development Association, Colombo.
- Lankford, B.A. and Beale, T., 2007. Equilibrium and non-equilibrium theories of sustainable water resources management: Dynamic river basin and irrigation behaviour in Tanzania. *Global Environmental Change* 17 (2007) 168-180.
- Laube, W., Awo, M., Schraven, B., 2008. *Erratic Rains and Erratic Markets: Environmental change, economic globalisation, and the expansion of shallow groundwater irrigation in West Africa*. GLOWA Project, Working Paper Series 30. Center for Development Research Department of Political and Cultural Change, ZEF Bonn.
- Lautze, J., Barry, B. and Youkhana, E., 2008. Changing paradigms in Volta basin water management: customary, national and transboundary. *Water Policy* 10 (2008), 577-594.

- Leemhuis, C., Jung, G., Kasei, R. and Liebe, J., 2009. The Volta Basin water allocation system: assessing the impact of small-scale reservoir development on the water resources of the Volta Basin, West Africa. *Advances in Geosciences*, 21: 57-62
- Lentz, C., 2006. Land rights and the politics of belonging in Africa: an introduction. In Kuba, R. & Lentz, C. (eds), *Land and the Politics of Belongings in West Africa..* Brill, Leiden/Boston.
- Lele, U., and A. Subramanian. 1990. *Sectoral strategy for irrigation development in Sub-Saharan Africa: Some lessons from experience.* In *Irrigation in Sub-Saharan Africa: The development of public and private systems.* World Bank Technical Paper Number 123, pp. 60-65. Washington, D. C.: World Bank.
- Liebe, J., 2002. *Estimation of water storage capacity and evaporation losses of small reservoirs in the Upper East Region of Ghana.* Geographische Institute der Rheinischen Friedrich-Wilhelms-Universität Bonn, Bonn.
- Liebe, J., van de Giesen, N., Andreini, M., 2005. Estimation of Small Reservoir Storage Capacities in a semi-arid environment. A case study in the Upper East Region of Ghana. *Physics and Chemistry of the Earth*, 30: 448–454
- Lipton, M., J. Litchfield, and Jean-Marc Faurès, 2003. The Effects of Irrigation on Poverty: A framework for Analysis. *Water Policy* 5(5-6): 413-27
- Lund, Jay R., 1989. The value and depreciation of existing facilities: The case of reservoirs. *The Engineering Economist* 35(1): 1-24.
- Martin, N. and van de Giesen, N., 2005. Spatial Distribution of groundwater production and development potential in the Volta River basin of Ghana and Burkina Faso. International Water Resources Association, *Water International*, Vol 30, No. 2, pp 239-249.
- Martin, N., 2006. Development of Water balance for the Atankwidi Catchment, West Africa- A case study of groundwater recharge in semi-arid climate. *Ecology and Development Series No 41.* MSc Thesis. Delft: Delft University of Technology.
- MAHRH (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques). 2003. *Action Plan for Integrated Resources Management of Burkina Faso.* DGIRH, Ouagadougou, Burkina Faso.
- Markwick, G., 2007. Water Requirements for sheep and cattle. Primefacts 326. Accessed on 12th July, 2010. Available at: http://www.dpi.nsw.gov.au/___data/assets/pdf_file/0009/96273/water-requirements-for-sheep-and-cattle.pdf
- Makombe, G., Meizen-Dick, R., Davies, S.P. and Sampath, R.K., 2001. An Evaluation of Bani (Dambo) Systems as a Smallholder Irrigation Development Strategy in Zimbabwe. *Canadian Journal of Agricultural Economics* 49 (2001) 203–216
- Manzungu, E., Bolding, A., Zawe, C., 1999. *Quarter and half measures and beyond: The case of irrigation management reform in Zimbabwe.* Paper presented at

- the International Researchers' Conference on Irrigation Reform, Hyderabad, India 11-14 December.
- Massa, M. Y.; and Madiega, G. 1995. *La Haute-volta coloniale témoignages, recherches, regards*; ed Karthala Paris. Cited in Opoku-Ankomah, Y., Dembélé, Y., Ampomah, B. Y., Somé, L., 2006. *Hydro-political assessment of water governance from the top-down and review of literature on local level institutions and practices in the Volta Basin*. IWMI, Colombo.
- Mati, B. M. 2002. Use of Geographic Information Systems for planning and management of smallholder irrigation and drainage. In *The changing face of irrigation in Kenya: Opportunities for anticipating change in eastern and southern Africa*, 75-91. ed. Blank, H.G.; Mutero, C.M.; Murray-Rust, H. IWMI, Colombo.
- Mati, B.M., and Penning de Vries, F.W.T., 2005. *Bright Spots on Technology-Driven Change in Smallholder Irrigation: Case Studies from Kenya*. In Penning de Vries F.W.T. (Ed). *Bright Spots Demonstrate Community Successes in African Agriculture*. Working Paper 102. IWMI, Colombo.
- Mbaye, A.; Moustier, P. 2000. *Market-oriented urban agricultural production in Dakar*. In *Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda*, ed. N. Bakker, M. Dubbeling, S. Gündel, U. Sabel-Koschella and H. de Zeeuw. Deutsche Stiftung für Internationale Entwicklung (DSE). Feldafing, Germany: Zentralstelle für Ernährung und Landwirtschaft. pp. 235-256.
- Mdemu, M., 2008. *Water productivity in medium and small reservoirs in the Upper East Region of Ghana*. Phd Dissertation. Bonn: Rheinischen Friedrich-Wilhelms-Universität zu Bonn.
- Meinzen-Dick, R., 1997. Farmer participation in Irrigation: 20 years of experience and lessons for the future. *Irrigation and Drainage Systems* 11: 103-118. Kluwer Academic Publishers.
- MEA (Millennium Ecosystem Assessment), 2005. *Ecosystem and Human Well-being: Wetlands and Water Synthesis*. Washington D.C.: World Resources Institute.
- Merrey D. J., 1997. *Expanding the Frontiers of Irrigation Management Research: Results of Research and Development at the International Irrigation Management Institute 1984-1995*. IWMI, Colombo.
- Merrey, D. J, de Lange, M., Gichuki, F., van Koppen, B., Inocencio, A., Kamara, A. B., Crosby, C., Levite, H., and Sally, H. 2002. *Agricultural water use and improving rural livelihoods in sub-Saharan Africa: Current status, future directions, and the role of the International Programme for Technology and Research in Irrigation and Drainage (IPTRID)*. Keynote Paper: International Congress for Irrigation and Drainage (ICID). 23rd July 2002, Montreal, Canada.
- Merrey, D. J., Meinzen-Dick, R., Mollinga, P. P., and Karar, E., 2007. *Policy and Institutional reform: the art of the possible*. Chapter 5 in D. Molden (ed.),

- Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. IWMI, London: Earthscan and Colombo. pp. 193-231
- Ministère de L'Environnement et de L'Eau. 2001. Etat des lieux des ressources en eau du Burkina Faso et de leur cadre de gestion, Burkina Faso. Cited in Opoku-Ankomah, Y., Dembélé, Y., Ampomah, B. Y., Somé, L., 2006. *Hydro-political assessment of water governance from the top-down and review of literature on local level institutions and practices in the Volta Basin*. IWMI, Colombo.
- Ministère de L'Agriculture de L'Hydraulique et des Ressources Halieutiques. 2004. Organigramme et missions du Ministère en charge de l'eau. Cited in Opoku-Ankomah, Y., Dembélé, Y., Ampomah, B. Y., Somé, L., 2006. *Hydro-political assessment of water governance from the top-down and review of literature on local level institutions and practices in the Volta Basin*. IWMI, Colombo.
- Ministry of Lands and Forestry (2003): *Emerging Land Tenure Issues*. Unpublished report. Ministry of Lands and Forestry, Accra, Ghana.
- Ministry of Works and Housing (MoWH), 1998. *Ghana's water resources: management challenges and opportunities*. Unpublished report. Ministry of Works and Housing, Accra,
- Molden, D., Murray-Rust H, Sakthivadivel R and Makin I (2003) *A water-productivity framework for understanding and action*. In: Kijne W, Barker R and Molden D (eds) *Water productivity in agriculture: Limits and opportunities for improvements*. CAB International, Wallingford, UK
- Molden, D. J., Sakthivadivel, R., Perry, C. J., de Fraiture, C., and Kloezen, W. H., 1998. *Indicators for comparing performance of irrigated agricultural systems*. Research Report 20. IWMI, Colombo.
- Molden, D., Murray-Rust H, Sakthivadivel R and Makin I, 2003. A water-productivity framework for understanding and action. In: Kijne W, Barker R and Molden D (eds) *Water productivity in agriculture: Limits and opportunities for improvements*. CAB International, Wallingford, UK
- Molden, D., Frenken, K., Barker, R., de Fraiture, C., Mati, B., Svendsen, M., Sadoff C. and Finlayson, M., 2007. *Trends in water and agricultural development*. Chapter 2 in D. Molden (ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. International Water Management Institute; London: Earthscan and Colombo: pp. 57-89
- Molden, D., Oweis, T. Y., Steduto, P., Kijne W., Hanjra M. A. and Bindraban, P. S., 2007. *Pathways for agricultural water productivity*. Chapter 7 in D. Molden (ed) *Water for Food, Water for life: A comprehensive Assessment of Water Management in Agriculture*. London: Earthscan and Colombo: International Water Management Institute; pp. 279-310.

- Molle, F. and Berkoff, J., 2006. *Cities versus Agriculture: Revisiting Intersectoral Water Transfers, Potential Gains and Conflicts. Comprehensive Assessment of Water Management in Agriculture Research*. Report 10. International Water Management Institute, Colombo.
- Moris, J. R. and Thom D. J., 1990. *Irrigation development in Africa: lessons of experience*. Boulder, CO: Westview Press.
- Morris, M., Kelly, V.A., Kopicki, R.J. and Byelee D., 2007. *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. The World Bank, Washington D. C.
- Mul, M. L., Kemerink, J. S., Vyagusa, N. F., Mshana, M. J., van der Zaag, P., Makurira, H., 2010. Water allocation practices among smallholder farmers in the South Pare Mountains, Tanzania: The issue of scale. *Agricultural Water Management*, article in press.
- Munguambe, P., Chilundo, M., Cláudio Julaia, C., 2010. Water entitlements and use in Chókwè Irrigation Scheme: the case of AREDONZE, the Associação dos Regantes do Distribuidor 11". Chapter 7 in: Van der Zaag, P. (ed.) , 2010. What role of law in promoting and protecting the productive uses of water by smallholder farmers in Mozambique? Unpublished report of the Water rights in informal economies project (CP66). Challenge Programme for Water and Food, IWMI; pp. .
- Namara, R. E., Horowitz, L., Kolavalli, S., Kranjac-Berisavljevic, G., Dawuni, B. N., Barry, B. and Giordano, M. 2010. *Typology of irrigation systems in Ghana*. Colombo, Sri Lanka: International Water Management Institute. 35p. (IWMI Working Paper 142). doi: 10.5337/2011.200
- Namara, R. E., Horowitz, L., Nyamadi, B. and Barry, B., 2010. *Irrigation Development in Ghana: Past experiences, emerging opportunities and future directions*. Ghana Strategy Support Program, (GSSP Working Paper 0027). International Food Policy Research Institute (IFPRI), Washington.
- National Irrigation Board, Kenya, 2007. Official website of the National Irrigation Board of Kenya, http://www.nib.or.ke/index.php?option=com_content&task=view&id=32&Itemid=45 [accessed 13th May, 2010]
- National Population Census, 2000. Ghana
- Niemeijer, R., Geuns, M., Kliet, T., Ogonda V., and Hoorweg, J., 1985. *Nutritional aspects of rice cultivation in Nyanza province, Kenya*. Leiden: African Studies Centre, Research Report No. 14.
- Nkhoma B. G. and Mulwafu W. O., 2004. The experience of irrigation in management transfer in two irrigation schemes in Malawi, 1960s-2002. *Physics and Chemistry of the Earth* 29 (2004) 1327-1333.

- Nyanteng, V.K. and Dapaah, S.K., 1997. *Agricultural Development: Policies and Options*. In V.K. Nyanteng, editor, *Policies and Options for Ghanaian Economic Development*. ISSER, Accra, Ghana. 140-183.
- Obeng-Asiedu P., 2004. *Allocating Water Resources for Agricultural and Economic Development in the Volta River Basin*. Doctoral thesis. Bonn: University of Bonn.
- Obeng, D. M. and Fiagbe, Y.A.K., 2005. Modelling of Hydropower Systems of Ghana at low level conditions of Akosombo Dam. *Journal of Science and Technology* Vol 25, No. 2, pp 131-138.
- Ofori J.K., Abban E.K., Asante S.K., Kwafo-Apegya and Alhassan A.L., 2006. *Enhancing Fish Production of Community Dugouts in the Northern Ghana*. Paper presented at CPWF Forum on Multiple Use Water Services, 13-17 Nov 2006. Vientiane, Laos.
- Ofori, E. A., van der Zaag, P., van de Giesen, N. and Odai S. N., 2010. 'Productivity of Irrigation Technologies in the White Volta basin'. *Physics and Chemistry of the Earth*. 35: 706-716.
- Omar S., and Yonis M., 2005. *Community Empowerment; The Experience of the Northwestern Integrated Community Development in Somaliland*. In Penning de Vries, F. W. T. (Ed.), 2005. *Bright spots demonstrate community successes in African agriculture*. Working Paper 102. IWMI, Colombo.
- Opoku-Agyemang, M., 2001. *Shifting paradigms: Towards the integration of customary practices into the environmental law and policy in Ghana*. Proceedings from Securing the Future International Conference on Mining and the Environment, Skelleftea, Sweden.
- Opoku-Agyemang, M., 2004. *Transboundary Water Resources Management: International Law Perspectives*. Ghana School of Law, Accra.
- Opoku-Ankomah, Y. and Amisigo, B.A., 1997. *Surface Water Resources; Volta Basin system*, Information Building Block: Ghana Water Resources Management Study. WRRRI, Accra
- Opoku-Ankomah, Y., Dembélé, Y., Ampomah, B. Y., Somé, L., 2006. *Hydro-political assessment of water governance from the top-down and review of literature on local level institutions and practices in the Volta Basin*. IWMI Working Paper 111. Colombo, Sri Lanka: International Water Management Institute.
- Palmer Jones, R.W. and M.A.S. Mandal 1987. *Irrigation Groups in Bangladesh*. Irrigation Management Network Paper 87/2c. Overseas Development Institute, London.
- Penning de Vries, F. W. T., Mati B., Khisa G., Omar S., and Yonis M., 2005. *Lessons learned from Community Successes: A Course for Optimism*. In Penning de Vries, F. W. T. (Ed.), 2005. *Bright spots demonstrate community successes in African agriculture*. Working Paper 102. IWMI, Colombo.

- Perry, C. J., 1995. Determinants of Function and Dysfunction in Irrigation Performance and Implications for Performance Improvement. *International Journal of Water Resources Development* 11 (1): 25-38
- Perry, E., 1997. Low-cost irrigation technologies for food security in sub-Saharan Africa, In: *Irrigation Technology Transfer in Support of Food Security. Proceedings of a subregional workshop, Harare, Zimbabwe, 14-17 April 1997.* Water Reports - 14. FAO, Rome; also available on <http://www.fao.org/docrep/W7314E/w7314e00.htm> Washington D.C., USA
- Poolman, M. I., 2005. *Developing small reservoirs: A participatory approach can help.* Unpublished paper. Small Reservoirs Project. Delft University of Technology, Delft.
- Plusquellec, H., 2002. *How design, management and policy affect the performance of irrigation projects. Emerging modernization procedures and design standards.* FAO, Bangkok, Thailand.
- Quiggin, J. and Horowitz J.K., 1999. The impact of Global Warming on Agriculture: A Ricardian Analysis: Comment. *American Economic Review* 89 (4): 1044-45.
- Ramatou, T. (2002). La Place du savoir traditionnel dans la gestion des ressources en eau dans le bassin du Nakambé. From Forum technique et de communication sur les comités de gestion des points d'eau en milieu et semi-urbain dans le bassin du Nakambé au Burkina Faso. International Development and Research Center, Ottawa. Referenced in Lautze, J., Barry, B. and Youkhana, E., 2008. Changing paradigms in Volta basin water management: customary, national and transboundary. *Water Policy* 10 (2008), 577-594
- Ray, Susanta K., Hanumantha C. H. Rao, and K. Subbarao, 1988. *Unstable Agriculture and Droughts: Implications for Policy*, Studies in economic development and planning, 47. General Editor: T N Madan. New Delhi: Institute of Economic Growth.
- Reardon, T., E. Crawford, R. Bernstein, C. Eicher, T. Jayne, J. Oehmke, and K. Savadogo. 1993. Challenges for creating and sustaining a Green Revolution in Africa. Paper presented at the July 30-31, 1993 American Agricultural Economics Association preconference workshop on Post-Green Revolution Agricultural Development Strategies in the Third World: What Next? Orlando, Fla., U.S.
- Reardon, T., Crawford, E., and Kelly. V., 1994. Links Between Nonfarm Income and Farm Investment in African Households: Adding the Capital Market Perspective. *American Journal Agricultural Economics*. 76:1172-1176.
- Renault, D. and Wallender, W.W., 2000. Nutritional Water Productivity and Diets. *Agricultural Water Management* 45 (3): 275-96
- Rodgers C., van de Giesen N., Laube W., Vlek P. L. G., Youkhana E., 2007. The GLOWA Volta Project: A framework for water resources decision-making and

- scientific capacity building in a transnational West African basin. *Water Resource Management* 21: 295–313.
- Rogers, P. and Hall, A. W., 2003. *Effective Water Governance*, TEC Background Papers no 7, Global Water Partnership, Stockholm.
- Rosegrant M. W., Svendsen M., 1993. Asian Food Production in the 1990s: Irrigation Investment and Management Policy. *Food Policy* 18 (2): 13-32.
- Rosegrant M. W. and N. D. Perez, 1997. *Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials and Strategies for the Future*. Environment and Production Technology Division, Discussion Paper No. 28. International Food Policy Research Institute, Washington D.C.
- Rosegrant, M. W., Paisner, M. S., Meijer, S. and Witcover, J., 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. Washington D.C.: International Food Research Institute.
- Rosenberg, D. M., McCully, P., and Pringle, C. M., 2000. Global-scale Environmental Effects of Hydrological Alterations: Introduction. *Bioscience* 50 (9) 746-751.
- SADCC (Southern African Development Coordination Conference) and Australian International Development Assistance Bureau. 1992. Vol. II: Southern African Development Coordination Conference (Food Security Project) – Regional Irrigation Development Strategy, Final Report. Harare (August).
- Sally, H., 1997. *Améliorer les performances des Périmètres Irrigués: les Actes du Séminaire Régional du Projet Management de Irrigation au Burkina Faso*. IIMI, Colombo,
- Samad, M. and Merrey D. J., 2005. *Water to Thirsty Fields: How Social Research Can Contribute*. In M. Cernea and A. Kassam, eds., *Researching the Culture in Agriculture: Social Research for International Development*. Wallingford, UK: CABI Publishing.
- Savenije, H.H.G., 1995. Spreadsheets: Flexible tools for integrated management of water resources in river basins. In: Modelling and Management of sustainable Basin-scale Water Resources Systems. IAHS Publications no. 231; pp. 207-215.
- Savenije H.H.G., 2000, Water Resources management: concepts and tools. Lecture note. IHE, Delft.
- Savenije H. H. G., van der Zaag, P., 2000. Conceptual framework for the management of shared river basins; with special reference to the SADC and EU. *Water Policy* 2 (2000) pp. 9-45
- Schrieder, G. and Knerr B., 2000. "Labour Migration as a social security mechanism for smallholder households in sub-Saharan Africa: The Case of Cameroon." *Oxford Development Studies*. 28:223-236.
- Seckler, D., Molden, D., Amarasinghe, U. and de Fraiture, C., 2000a. *Water issues for 2025.: A Research Perspective*. International Water Management Institute, Colombo.

- Seckler, D.; Amarasinghe, U.; Molden, D.; de Fraiture, C. 2000b. World water supply and demand, 1995 to 2025. International Water Management Institute Special Report prepared as a contribution to the World Water Vision of the World Water Commission. IWMI, Colombo.
- Seini, A. W. *Agricultural Growth and Competitiveness under Policy Reforms in Ghana*. 61. 2002. Accra, Ghana, ISSER, University of Ghana, Legon. Technical Publication.
- Shah, T., 1993. *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*. Mumbai: Oxford University Press.
- Shah, T., van Koppen, B., Merrey, D., de Lange, M. and Samad, M., 2002. *Institutional alternatives in African smallholder irrigation: Lessons from international experience with irrigation management transfer*. Research Report 60. IWMI, Colombo.
- Shah, T., 2003. Governing the Groundwater Economy: Comparative Analysis of National Institutions and Policies in South Asia, China and Mexico. *Water Perspectives* 1 (1):2-27.
- Shiklomanov, I.A. and Rodda, J., 2003. *World Water Resources at the beginning of the 21st Century*. Paris: United Nations Educational, Scientific and Cultural Organisation.
- Siebert, S.; Döll, P. and Hoogeveen, J. 2002. *Global irrigated area map version 2.1*. Center for Environmental Systems Research, University of Kassel, Germany, and FAO, Rome, Italy. Online documentation and download of 5 min map of irrigated area version 2.1.
- Sijbrandij, P., van der Zaag, P., 1993. Canal maintenance: a key to restructuring irrigation management; a case of farmer participation and turnover from Mexico. *Irrigation and Drainage Systems* 7: 189-204.
- Smith, L., 2004. Assessment of the Contribution of Irrigation to Poverty Reduction and Sustainable Livelihoods. *Water Resources Development*, 20(2): 243-257
- Svendsen, M. ed., 2005. *Irrigation and River Basin Management: Options for governance and institutions*. Wallingford, UK: CABI Publishing.
- Svendsen, S., Ewing, M. and Msangi, S., 2009. *Measuring irrigation performance in Africa*. IFPRI Discussion Paper 894. Washington, D.C.: International Food Policy Research Institute.
- Tate & Lyle Technical Services Limited, 1982. *Irrigation Company Upper Region: The farming system and recommendations for project implementation volume 2*. Enterprise House, England.
- Van de Giesen, N., Andreini, M. van Edig, A. & Vlek, P., 2001. *Competition for Water Resources of the Volta Basin, Regional Management of Water Resources*. Proceedings of a symposium held during the Sixth IAHS Scientific assembly at Maastricht, The Netherlands, July 2001. IAHS Pub. No. 268, 199-205.

- Van de Giesen, N., 2006. *Research on Ensembles of small reservoirs in Ghana*, West Africa. Ecole Polytechnique, Fédérale De Lausanne.
- Van de Giesen, N., Liebe, J., Andah, W. and Andreini, M., 2008. *Assessing the hydrological impact of ensembles of small reservoirs*. Presented at the 2nd International Forum on Water and Food, Addis Ababa, Ethiopia. November 10-14, 2008.
- Van den Bossche J. P., and Bernacsek, G. M., 1990. *Source book for inland fishery resources of Africa Volume 2*. CIFA Technical Paper. Available at <http://www.fao.org/docrep/005/t0360e/T0360E03.htm>. [Accessed 28/07/2010]
- Van der Zaag, P., and Savenije, H.G., 2005. *Principles of Integrated Water Resources Management*. Unpublished lecture note. UNESCO-IHE, Delft.
- Van der Zaag, P., 2007. Asymmetry and equity in water resources management; critical governance issues for Southern Africa. *Water Resources Management*. DOI:10.1007/s11269-006-9124-1
- Van der Zaag, P. (ed.), 2010. What role of law in promoting and protecting the productive uses of water by smallholder farmers in Mozambique? Unpublished report of the Water rights in informal economies project (CP66). Challenge Programme for Water and Food, IWMI.
- Van Koppen, B., 1998, *Gendered Water And Land Rights in Construction: Rice Valley Improvement in Burkina Faso*. Paper presented at the 8th biennial conference of the International Association for the Study of Common Property (IASCP), Bloomington Indiana (USA), 31 May-4 June.
- Vishnudas, S., Savenije H.H.G., van der Zaag P., Kumar C.E.A. and Anil K.R., 2007. Sustainability analysis of two participatory watershed projects in Kerala. *Physics and Chemistry of the Earth*, 33 (2008) 1-12.
- Wallace, T., 1979. *Rural Development through Irrigation: Studies in a Town on the Kono River Project*. Centre for Social and Economic Research, Ahmadu Bello University, Zaria, Nigeria. Paper No. 3.
- WEAP, 2009. *Water Evaluation and Planning System*. Tutorial. Stockholm Environment Institute.
- Wester, P., Scott, C. A., Burton, M., 2005. *River basin closure and institutional change in Mexico's Lerma-Chapala Basin*. In Mark Svendsen (ed.) *Irrigation and River Basin Management: Options for Governance and Institutions*. Wallingford: CABI Publishing, pp. 125-144.
- Whitlow, R. 1984. A survey of dambos in Zimbabwe. *Zimbabwe Agricultural Journal* 81(40): 129-38.
- Wiafe Kwabena, 1997. *Irrigation, Information Building Block*. Ghana Water Resources Management Study. Accra: WRRI.
- Williams, G., 1988. The World Bank in rural Nigeria, revisited: a review of the World Bank's Nigeria: agricultural sector review 1987. *Review of African Political Economy*, 15: 43, 42-67

- World Bank, 2000. *World Development Report 2000-1: Attacking Poverty*. Washington DC: The World Bank.
- World Bank, 2001. *World Development Indicators*. Washington DC: The World Bank.
- World Bank-AFTS2 (Environmental, Rural and Social Development, Eastern Africa Sector). 2004. *River Basin Management and Smallholder Irrigation Improvement Project*. Implementation Completion Report. Washington, D.C.: World Bank.
- WRI (Water Research Institute) (2005). *Assessment of Groundwater Resources of the Upper-East Region of Ghana*. A CSIR-Water Research Institute Technical Report. WRI/TR No. 24
- W.R.R.I., 1975. *Catchment Areas and River Lengths of River Basins in Ghana*. W.R.R.I., (CSIR) Accra.
- Yanggen, D., V. Kelly, T. Reardon, and A. Naseem., 1998. *Incentives for Fertilizer Use in Sub-Saharan Africa: A Review of Empirical Evidence on Fertilizer Yield Response and Profitability*. MSU International Development Working Paper No. 70. East Lansing: Michigan State University.
- Yilma, T., Berg, E. and Berger, T., 2004. *Prospects and challenges of Agricultural Technology-Market Linkage under Liberalisation in Ghana: Evidence from a micro-data*. African Development and Poverty Reduction: The Micro-Linkage. Forum Paper 2004.
- You, L., Ringler, C., Nelson. G., Wood-Sichra, U., Robertson, R., Wood, S., Guo, Z., Zhu, T., Sun, Y., 2010. *What is the Irrigation Potential of Africa? A combined Biophysical and Socioeconomic approach*. IFPRI Discussion Paper 00993. Washington D. C.: International Food Policy Research Institute.
- Zone, S. (2002). *Customary Law and Traditional Water Management-Case study concerning the Yatenga Province, Burkina Faso*. Background Paper for the workshop, 'Water as a Basic Right', by Green Cross Burkina Faso. 2nd World Water Forum, Stockholm.

APPENDIX A – DATA FOR CROPWAT

Monthly Summary of Maximum Daily Temperatures of Navrongo

Mean Daily Maximum Temperature (°C)												
Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	35.0	36.1	38.3	37.2	36.7	32.1	30.2	29.6	30.2	34.9	36.5	34.9
1962	34.8	37.2	39.3	37.1	35.8	31.7	30.8	29.6	30.6	33.0	34.9	35.1
1963	36.9	38.1	36.9	37.1	34.4	33.3	31.3	30.3	31.2	32.5	35.2	35.6
1964	34.8	37.5	38.8	38.6	35.4	32.1	31.3	29.4	29.9	33.7	35.6	34.7
1965	34.7	37.9	39.4	37.3	35.8	33.2	31.2	29.9	31.2	34.1	36.6	34.6
1966	36.2	37.1	39.3	37.5	36.3	32.1	31.7	29.9	30.8	33.3	36.7	35.9
1967	34.6	37.3	38.1	38.1	35.7	33.4	31.1	29.2	30.2	34.2	36.1	34.6
1968	34.6	36.6	36.9	35.9	35.3	31.6	30.7	31.4	31.2	34.4	35.8	36.6
1969	36.2	39.3	40.4	37.5	36.7	34.2	31.4	30.4	31.2	32.9	35.3	37.1
1970	37.2	38.1	39.9	38.6	35.7	35.3	31.1	29.6	30.8	34.7	36.2	34.6
1971	34.8	37.8	38.2	38.1	36.2	32.9	30.3	29.4	30.6	33.6	36.3	33.6
1972	35.2	37.6	38.8	35.6	35.1	31.9	31.8	30.4	31.2	33.7	35.9	35.0
1973	35.8	38.7	39.3	38.7	36.2	32.6	32.1	30.0	31.2	35.2	36.4	35.5
1974	33.6	36.8	38.5	38.4	35.6	34.6	30.1	30.2	30.2	33.7	35.9	34.4
1975	33.6	37.3	38.7	38.2	34.8	33.9	30.1	30.3	30.3	34.0	36.5	35.3
1976	34.2	36.8	38.6	38.3	34.7	31.7	31.8	30.3	31.9	32.0	34.7	35.5
1977	36.0	37.3	38.1	38.8	36.2	33.5	31.5	30.2	31.3	34.1	36.9	34.8
1978	36.2	38.9	38.1	35.6	34.4	32.1	30.2	31.2	31.8	34.3	36.3	36.4
1979	37.0	38.1	39.5	39.7	34.9	31.5	30.6	30.8	31.3	34.1	36.2	34.3
1980	36.9	38.0	39.9	39.4	36.1	33.6	31.9	30.6	32.3	34.2	36.2	33.9
1981	34.7	38.0	39.3	38.9	35.7	34.1	30.8	30.7	32.0	36.3	37.1	36.9
1982	35.0	36.9	37.6	37.5	35.2	33.2	32.4	30.4	32.2	34.0	35.6	34.8
1983	32.1	38.2	41.7	40.6	36.1	32.5	32.0	31.6	32.2	36.6	37.6	35.7
1984	34.8	36.9	39.3	37.8	34.8	32.8	32.3	32.0	31.2	34.5	32.1	34.1
1985	36.3	36.4	39.3	38.9	37.4	33.2	30.8	30.2	30.7	35.2	37.4	33.6
1986	34.8	38.6	39.0	39.5	36.7	33.4	30.5	30.8	31.0	34.0	35.5	34.2
1987	36.5	39.2	38.5	40.2	39.0	33.1	31.8	31.3	32.1	34.3	37.6	35.5
1988	34.8	38.3	40.1	38.1	37.6	32.8	30.4	30.1	31.2	35.7	36.9	33.8
1989	33.8	35.9	38.3	39.7	38.7	33.7	31.1	30.2	31.5	33.9	37.3	35.1
1990	34.7	36.9	39.5	38.7	36.4	33.7	31.2	31.5	31.9	36.1	38.1	36.2
1991	36.1	39.0	39.4	37.9	33.0	32.9	31.2	30.4	32.6	33.5	36.1	34.8
1992	33.4	37.5	39.6	38.2	34.3	32.2	30.4	30.0	31.9	34.7	35.5	36.2

1993	33.9	37.8	39.1	39.2	38.4	35.4	30.9	31.0	31.2	34.8	37.7	35.6
1994	35.0	27.8	39.8	39.6	36.1	32.6	31.8	30.0	31.2	32.7	35.6	34.5
1995	34.0	36.8	40.1	39.1	37.1	34.3	31.7	30.0	32.2	34.4	37.4	36.7
1996	37.8	39.1	39.9	39.0	36.7	32.0	31.5	30.8	31.0	33.3	36.4	36.8
1997	37.0	36.3	38.4	37.7	35.6	31.8	31.6	31.7	32.6	34.5	37.2	36.3
1998	35.7	38.9	39.9	40.0	36.7	33.4	32.0	30.6	30.7	34.1	37.5	36.1
1999	36.4	36.7	40.7	39.2	37.1	34.1	31.4	30.2	30.9	33.6	37.3	35.6
2000	36.7	35.6	39.5	40.3	37.1	33.2	31.2	31.0	32.0	34.6	37.9	35.7
2001	36.1	36.9	40.4	39.8	36.7	33.4	31.9	30.8	31.8	36.6	38.2	37.9
2002	34.8	37.8	40.9	39.4	37.3	33.9	32.6	30.7	32.2	34.0	37.0	36.1
2003	36.1	39.2	40.0	39.4	37.6	32.3	31.3	31.0	31.9	34.9	37.3	36.3
2004	36.4	38.0	38.5	37.0	34.2	32.6	30.9	30.9	31.6	36.1	37.6	38.1
2005	34.5	39.7	41.1	40.3	37.6	32.9	31.1	30.8	32.2	35.0	38.1	37.2
avg	35.3	37.4	39.2	38.5	36.1	33.0	31.2	30.5	31.4	34.3	36.5	35.5

Monthly Summary of Minimum Daily Temperatures of Navrongo

Mean Daily Minimum Temperature (°C)												
Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	19.8	20.4	23.8	25.7	25.3	23.2	22.6	22.2	21.6	21.9	19.4	17.5
1962	17.8	21.1	24.6	25.3	24.3	22.8	22.4	22.0	22.0	22.1	22.3	18.6
1963	18.4	23.3	23.9	25.2	24.6	23.4	22.7	22.2	22.4	22.3	19.1	17.6
1964	19.3	20.3	25.1	25.4	25.1	22.6	22.2	22.1	21.6	22.0	20.4	20.2
1965	19.6	21.7	23.6	24.9	24.6	23.4	22.7	22.2	21.9	22.4	18.6	16.9
1966	17.9	19.9	24.2	25.3	25.3	22.8	22.7	22.2	21.9	21.8	20.2	18.6
1967	18.4	22.2	24.7	25.7	24.4	23.3	22.4	21.8	21.7	21.8	19.9	19.6
1968	18.3	21.6	23.6	24.4	24.0	22.5	22.3	22.1	21.9	21.9	20.3	19.6
1969	18.9	22.6	26.0	25.9	25.1	24.4	22.8	22.2	22.3	22.5	19.4	18.5
1970	19.2	21.7	25.1	26.6	24.8	24.2	22.7	22.1	21.7	22.5	19.7	18.9
1971	18.0	22.3	25.4	25.8	25.4	23.2	22.2	22.0	21.9	21.4	19.4	19.6
1972	19.0	22.8	25.8	25.1	25.2	22.9	22.5	22.4	21.9	22.2	19.4	19.8
1973	20.4	23.1	25.8	26.1	24.4	22.9	22.9	21.9	22.2	22.2	19.4	19.3
1974	19.7	21.3	25.1	25.8	24.5	23.7	21.9	22.4	21.4	21.8	19.3	18.2
1975	18.3	20.0	24.5	25.7	24.1	23.4	22.0	21.8	21.7	21.7	19.7	19.4
1976	19.4	22.4	24.0	25.3	24.5	22.4	22.6	21.9	22.2	22.0	20.9	17.9
1977	20.6	21.5	24.3	27.1	25.5	23.9	23.0	22.3	22.3	21.8	19.5	18.8
1978	20.0	22.7	25.2	25.3	24.2	22.9	22.3	22.4	22.1	22.6	20.6	19.5
1979	20.6	21.3	26.3	27.0	24.8	23.2	22.4	22.7	22.3	22.8	21.0	19.8
1980	21.1	23.5	25.0	26.5	25.7	24.1	23.5	22.6	22.7	23.0	21.1	18.3
1981	19.3	22.8	25.6	26.7	25.2	24.0	22.9	22.6	22.2	22.4	20.2	18.6
1982	19.0	23.0	24.9	26.3	24.8	22.3	22.9	22.4	22.7	22.4	19.6	19.1
1983	19.5	23.8	26.1	27.7	25.4	23.5	22.9	22.9	22.5	21.7	19.9	20.2
1984	20.3	22.0	25.7	26.6	24.6	23.5	23.2	22.7	22.1	22.5	21.4	19.1
1985	21.4	22.5	27.3	27.1	26.3	23.4	22.2	22.6	22.4	21.9	20.1	18.8
1986	18.9	23.3	25.3	27.2	25.9	23.4	22.4	22.4	22.0	22.3	19.4	18.3
1987	20.4	22.5	24.5	26.8	27.3	24.1	23.2	22.7	22.9	23.0	20.1	19.8
1988	20.6	22.5	26.8	26.9	26.2	23.6	22.7	22.7	22.6	22.2	20.3	19.3
1989	18.9	21.5	23.7	26.7	26.1	23.2	22.9	22.5	22.1	21.7	19.8	19.6
1990	20.8	21.7	24.5	26.5	25.2	23.9	22.8	22.4	22.1	22.7	22.5	21.1
1991	21.4	24.3	26.0	26.2	24.3	24.3	23.1	22.9	23.2	22.2	20.2	19.6
1992	19.8	22.8	26.3	26.3	24.7	23.2	22.5	22.5	22.1	22.5	20.5	19.2
1993	19.1	23.1	25.5	26.9	26.0	24.7	22.7	22.8	22.3	22.8	22.9	20.5
1994	20.6	22.7	25.7	27.2	25.3	23.7	23.1	22.9	23.1	22.7	19.2	19.5
1995	18.6	21.1	26.2	27.0	25.9	24.5	23.2	22.5	23.0	22.7	20.5	20.1

1996	19.9	23.6	26.1	26.5	25.7	23.2	22.8	22.6	22.5	22.1	17.6	18.1
1997	20.2	22.2	25.6	25.7	25.1	23.6	23.1	23.0	23.3	23.3	21.1	19.3
1998	20.1	23.3	25.4	28.1	26.5	24.5	23.6	23.1	22.9	23.1	20.5	19.9
1999	21.4	21.8	25.9	26.1	25.3	23.9	23.0	22.7	22.3	22.4	20.5	18.7
2000	21.8	21.0	24.3	27.2	25.5	23.5	22.5	22.4	21.9	22.3	19.6	18.4
2001	18.6	21.3	24.4	26.0	25.8	23.4	23.0	22.4	22.4	22.5	20.6	20.1
2002	20.9	22.1	26.5	27.4	26.1	24.2	23.7	22.9	22.5	22.4	20.3	19.6
2003	20.8	23.6	24.9	26.6	26.2	23.6	23.2	23.0	22.7	23.6	21.3	19.1
2004	20.7	22.6	24.2	25.6	24.2	23.2	22.7	22.8	22.7	23.0	21.7	20.7
2005	20.4	25.7	27.5	28.3	26.1	24.1	22.9	22.8	23.1	22.4	20.9	20.7
avg	19.7	22.3	25.2	26.3	25.2	23.5	22.8	22.5	22.3	22.3	20.2	19.2

Monthly Total Rainfall of Navrongo

Monthly Total Rainfall (mm)												
Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	0.0	0.0	0.3	20.3	49.8	157.2	152.9	199.1	234.7	3.1	0.0	0.0
1962	0.0	0.0	0.3	51.6	49.0	178.6	120.7	328.7	158.2	82.8	41.7	0.0
1963	0.0	70.6	0.0	99.1	101.9	82.0	288.0	354.6	133.1	87.4	26.7	0.0
1964	0.0	0.0	12.9	11.7	105.7	106.4	168.9	144.3	322.8	36.1	8.9	5.1
1965	25.7	0.0	0.0	66.8	69.3	91.4	260.6	229.9	185.4	32.3	0.0	0.0
1966	0.0	0.0	10.4	90.9	32.0	146.3	211.6	296.4	120.1	67.8	0.0	0.0
1967	0.0	10.2	15.5	37.9	87.6	67.6	88.4	319.3	221.5	12.9	2.3	4.3
1968	0.0	19.6	104.7	100.8	67.3	129.5	303.0	175.8	121.2	49.0	10.4	0.0
1969	0.0	0.0	0.0	73.9	66.3	114.3	158.2	315.7	256.5	91.7	2.5	0.0
1970	0.0	0.0	0.5	58.7	71.1	95.5	185.4	319.3	168.4	31.0	0.0	0.0
1971	0.0	0.8	32.8	42.9	96.5	188.5	165.6	339.3	221.0	57.9	0.0	26.9
1972	0.0	0.0	3.1	125.0	73.9	142.8	218.2	189.0	121.2	40.9	0.0	0.0
1973	0.0	0.0	3.6	82.0	207.8	142.8	330.2	325.9	126.5	53.6	0.0	0.0
1974	0.0	0.0	62.2	59.7	82.5	145.3	167.1	269.2	141.5	49.0	0.0	0.0
1975	0.0	0.0	0.3	20.6	97.0	82.8	259.1	268.2	149.4	10.4	0.0	0.0
1976	4.6	8.9	4.8	59.7	131.8	75.2	202.3	178.5	137.0	207.7	0.0	0.0
1977	0.0	0.0	38.7	13.4	57.1	41.9	204.3	176.0	90.1	49.0	0.0	0.0
1978	0.0	0.0	36.9	89.4	231.2	90.1	182.4	344.4	131.7	111.5	0.0	0.0
1979	0.0	0.0	0.0	114.8	168.3	139.4	261.8	220.7	160.4	56.2	4.6	0.0
1980	0.0	0.0	0.3	74.5	95.9	64.7	176.9	308.8	149.4	69.2	0.0	0.3
1981	0.0	0.0	2.0	42.7	62.7	198.1	166.5	258.4	84.4	3.9	0.0	0.0
1982	0.0	0.0	79.6	36.5	161.1	81.5	130.7	243.1	236.2	51.5	1.0	0.0
1983	0.0	0.0	0.0	20.5	98.2	139.7	119.9	261.1	78.6	1.0	0.0	0.0
1984	0.0	0.0	8.7	97.5	188.2	84.5	98.0	222.0	116.2	36.7	0.5	0.0
1985	0.0	0.0	0.0	2.6	64.4	164.6	231.0	306.0	181.9	14.0	0.0	0.0
1986	0.0	0.0	9.4	37.8	113.1	179.2	248.8	142.4	447.7	41.0	5.8	0.0
1987	0.0	0.0	85.5	9.3	31.8	274.3	176.6	413.0	96.5	46.1	0.0	0.0
1988	0.0	0.0	26.6	130.2	31.9	141.6	123.2	246.9	187.4	0.7	26.0	0.0
1989	0.0	0.0	11.2	32.3	41.3	162.1	184.1	354.0	297.8	47.2	0.0	31.8
1990	0.0	0.0	0.0	19.7	136.1	48.9	233.0	249.7	126.1	9.9	13.7	33.6
1991	0.0	0.0	34.0	43.1	148.0	64.7	164.7	357.4	83.5	81.1	0.0	0.0
1992	0.0	0.0	0.0	58.8	153.4	152.7	243.7	211.5	154.1	58.6	0.0	0.0
1993	0.0	0.0	TR	46.5	75.2	137.0	172.5	170.4	173.5	12.5	1.6	0.0
1994	0.0	0.0	32.3	12.7	115.8	62.4	164.3	428.2	100.8	84.7	0.0	0.0
1995	0.0	TR	5.7	41.6	44.6	141.5	94.0	231.1	55.7	72.5	0.0	0.9

1996	0.0	0.0	1.1	47.4	194.6	207.2	108.2	300.5	206.6	38.4	0.0	0.0
1997	0.0	0.0	7.5	34.8	155.5	204.0	91.3	194.7	178.9	73.3	0.0	0.0
1998	0.0	19.7	0.0	20.8	134.8	77.0	127.5	281.9	146.0	47.9	0.0	0.0
1999	0.0	4.1	1.5	29.6	117.9	108.1	312.6	455.5	258.1	77.9	0.0	0.0
2000	1.0	0.0	0.0	2.8	53.7	228.7	237.9	282.2	158.2	22.6	0.0	0.0
2001	0.0	0.0	0.0	30.3	125.1	131.1	176.9	336.2	155.9	4.2	0.0	0.0
2002	0.0	0.0	0.0	65.1	105.3	94.0	192.9	211.2	122.2	85.3	20.2	0.0
2003	0.0	1.8	0.9	22.3	95.8	207.2	182.8	284.4	238.6	100.1	6.1	0.0
2004	0.0	0.0	28.0	176.6	74.3	139.8	259.9	210.4	118.5	34.7	2.2	0.0
2005	0.0	4.5	tr	20.7	13.7	226.1	179.0	189.3	88.3	28.7	0.0	0.0
avg	0.7	3.2	15.4	52.8	99.5	132.0	189.5	269.9	165.4	50.5	3.9	2.3

Mean Daily Relative Humidity (%) at 1500 hours of Navrongo

Mean Daily Relative Humidity at 1500hrs (%)												
Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	14	12	16	34	40	56	68	71	67	43	23	14
1962	11	11	15	33	42	60	65	71	66	54	39	17
1963	16	27	23	37	53	55	64	70	66	56	24	12
1964	11	9	24	25	44	60	60	70	67	47	25	23
1965	18	13	14	26	42	51	63	71	65	48	16	17
1966	12	11	20	37	41	58	61	70	66	52	24	14
1967	13	13	21	33	43	50	59	70	69	46	24	20
1968	13	19	28	42	45	62	63	63	64	46	28	17
1969	12	15	23	36	41	54	62	67	65	57	27	14
1970	13	11	19	29	44	46	65	77	69	46	27	25
1971	13	11	27	29	45	53	64	73	65	45	21	25
1972	19	20	23	45	49	59	64	66	64	52	23	25
1973	19	23	18	30	44	57	59	69	64	44	21	17
1974	19	12	26	32	40	46	66	68	67	51	25	18
1975	21	19	26	33	49	48	66	66	68	45	20	14
1976	17	18	19	28	48	57	56	65	60	62	32	14
1977	15	11	13	27	42	51	61	65	67	47	25	14
1978	14	15	27	41	49	57	63	65	63	49	25	28
1979	24	16	19	29	50	67	70	73	68	52	31	21
1980	19	17	18	31	51	58	62	71	64	56	31	17
1981	17	18	28	34	48	53	67	71	64	40	17	13
1982	13	18	27	37	51	59	58	71	65	54	23	14
1983	12	14	15	28	47	62	62	68	61	34	20	24
1984	16	10	20	36	49	57	50	58	60	47	25	16
1985	19	14	20	30	41	56	64	70	67	41	25	23
1986	22	17	26	35	43	55	68	68	68	52	29	19
1987	17	19	27	25	39	63	68	70	67	53	25	22
1988	17	13	22	41	42	59	67	72	69	43	29	21
1989	26	20	28	29	37	57	69	74	65	47	28	31
1990	21	20	15	41	48	53	69	67	65	43	28	25
1991	23	25	32	38	60	61	67	69	60	52		23
1992	20	20	20	39	56	64	68	71	66	48	28	17
1993	18	16	24	33	41	52	70	69	64	50	28	18
1994	14	14	21	28	48	56	61	73	68	62	26	15

1995	13	11	20	35	41	51	65	73	63	50	20	17
1996	12	16	19	35	46	65	63	69	69	53	17	16
1997	14	15	20	38	44	66	65	68	64	53	30	14
1998	17	17	13	33	47	59	64	71	71	55	25	19
1999	16	19	20	33	44	54	67	73	69	55	27	17
2000	22	14	16	29	42	57	66	69	65	51	24	26
2001	18	12	17	30	42	57	63	70	63	38	21	15
2002	14	12	18	34	43	55	62	69	63	54	26	19
2003	14	21	20	35	40	61	66	68	63	54	29	17
2004	16	14	20	42	55	58	64	69	65	46	26	20
2005	18	19	25	35	42	59	68	71	64	47	23	18
avg	16.5	15.8	21.2	33.6	45.3	56.8	64.0	69.4	65.4	49.3	25.2	18.8

Mean Daily Wind Speed of Navrongo

Mean Daily Wind Speed (knots)												
Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	1.8	3.7	3.2	2.3	2.6	3.0	2.4	2.0	1.4	1.3	1.1	1.7
1962	2.3	3.2	2.1	2.8	2.5	2.8	2.7	1.9	2.1	1.7	1.3	1.8
1963	1.6	2.2	2.3	3.1	2.3	2.5	2.1	2.0	1.4	1.4	1.2	1.2
1964	2.1	2.1	2.7	2.2	2.8	2.2	2.5	2.6	1.7	1.5	1.5	1.5
1965	2.6	1.8	2.3	2.9	3.2	3.1	2.1	2.0	1.6	2.5	1.7	2.0
1966	2.1	2.6	2.5	3.6	3.3	2.6	2.7	2.3	1.6	1.5	1.6	1.6
1967	2.8	2.8	2.8	3.8	3.4	3.6	3.0	2.7	1.7	1.4	1.4	1.5
1968	1.9	1.7	2.1	2.9	2.7	2.2	2.5	2.0	1.5	1.0	0.6	0.7
1969	1.5	1.4	2.0	1.9	2.4	2.7	1.8	1.8	1.5	1.2	1.1	1.2
1970	1.5	1.4	1.3	1.8	2.0	1.6	1.4	1.2	13.0	13.0	1.3	1.5
1971	1.7	1.8	2.2	2.3	2.3	1.9	1.5	1.2	1.2	1.1	1.2	1.1
1972	1.2	1.8	2.4	2.4	2.4	1.8	1.6	1.5	1.4	1.4	1.2	1.3
1973	1.5	1.6	1.9	1.6	1.9	1.6	2.0	1.1	1.4	1.2	1.3	1.4
1974	1.7	1.8	1.6	1.7	1.9	1.8	1.5	1.4	1.2	1.2	1.1	1.3
1975	1.6	1.2	1.7	2.6	2.2	2.1	1.5	1.5	1.0	1.0	0.9	1.1
1976	1.3	1.3	1.4	2.0	1.5	1.3	1.6	1.0	0.8	0.8	0.8	0.9
1977	0.9	1.0	1.4	1.5	1.8	1.5	1.0	1.1	0.8	0.7	1.2	1.2
1978	1.1	1.1	1.8	2.3	1.9	1.6	1.7	1.0	1.0	1.3	1.4	1.5
1979	1.8	2.4	3.1	2.9	2.5	1.4	1.2	1.5	1.2	1.1	1.4	1.8
1980	2.0	3.0	2.4	3.0	3.1	2.4	2.6	1.4	1.3	1.4	0.7	2.1
1981	2.9	3.0	3.0	2.2	3.2	3.3	2.0	1.7	1.7	2.3	2.1	1.9
1982	3.2	2.9	2.4	2.9	2.8	2.4	2.0	1.6	1.4	1.7	1.4	2.1
1983	2.6	3.7										
1984												
1985												
1986	1.6	1.5	1.5	2.9	2.0	0.8	1.4	0.8	0.8	0.9	1.0	1.9
1987	1.1	1.4	1.6	1.7	2.6	1.9	1.2	0.9	0.8	0.6	0.8	1.2
1988	1.7	1.9	1.2	2.0	2.0	1.3	1.3	1.1	0.7	1.2	1.0	1.6
1989	2.7	2.6	4.0	2.2	1.8	1.8	1.3	1.5	1.2	1.2	1.3	1.9
1990	2.4	2.8	3.1	2.6	3.0	3.0	2.0	1.4	1.4	1.7	1.8	2.0
1991	2.8	2.5	2.3	3.3	1.7	1.3	1.8	1.3	1.2	1.3		2.8
1992	4.2	3.5	3.1	2.8	1.9	2.0	1.1	1.2	1.2	1.5	2.4	2.3
1993	3.9	3.0	2.9	2.9	2.6	1.7	1.0	0.8	0.6	1.1	0.9	2.3
1994	3.2	2.3	2.0	2.9	2.0	1.6	1.6	1.1	0.6	0.7	1.0	2.7
1995	2.4	2.3	2.0	1.7	1.9	1.9	1.3	0.9	0.9	1.4	1.6	1.8

1996	1.5	1.5	1.2	1.9	1.8	1.1	1.2	1.0	0.9	1.0	1.6	1.4
1997	2.3	3.2	2.2	1.6	1.7	1.1	1.6	1.3	1.0	1.2	1.0	1.8
1998	2.3	2.5	2.3	1.9	1.8	1.1	1.3	1.1	1.1	1.2	1.2	1.5
1999	2.3	1.9	1.4	1.7	1.5	1.3	1.2	1.7	1.0	1.4	0.9	2.8
2000	2.5	2.7	1.6	1.7	1.7	1.6	1.3	1.8	1.7	1.3	1.7	2.3
2001	2.8	3.9	2.5	3.3	3.2	2.6	2.7	2.4	2.2	2.2	2.2	3.2
2002	4.5	3.8	2.6	3.1	3.5	3.1	2.6	2.4	2.1	2.0	2.3	3.5
2003	3.7	3.1	3.3	3.5	3.4	2.5	2.3	2.2	2.2	1.5	1.8	3.1
2004	3.3	3.6	3.3	2.1	1.9	1.7	1.3	1.3	1.1	1.3	2.9	2.5
2005	5.2	4.9	3.0	4.2	4.0	3.2	2.9	2.8	2.5	2.8	3.2	3.8
avg	2.3	2.4	2.3	2.5	2.4	2.0	1.8	1.6	1.6	1.6	1.4	1.9
Avg (km/day)	103.5	107.9	101.3	110.8	106.6	91.0	80.2	69.3	71.0	73.2	63.0	83.4

Mean Daily Duration of Bright Sunshine of Navrongo

Mean Daily Duration of Bright Sunshine (hours)												
Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	9.2	9.3	8.3	6.3	8.4	7.8	6.0	5.2	6.7	10.4	10.0	10.1
1962	10.2	9.3	9.0	7.3	8.3	7.8	6.6	5.6	6.7	8.9	9.6	9.8
1963	9.9	8.8	7.9	8.0	8.3	8.3	7.5	6.0	6.5	7.4	9.8	9.8
1964	8.0	9.7	8.4	7.8	8.3	8.1	6.6	5.2	5.4	9.6	9.3	7.5
1965	9.6	9.8	9.5	8.0	7.5	8.7	7.6	5.5	7.0	9.6	9.4	9.4
1966	9.5	9.1	8.7	8.1	9.0	6.9			6.9	9.0	10.0	9.4
1967	9.6	8.0	7.4	8.7	9.1	8.6	7.1	5.0	6.1	9.5	9.3	7.8
1968	9.3	8.3	8.1	7.8	9.0	6.9	7.5	7.1	6.9	8.9	8.5	9.6
1969	9.4	9.0	9.0	7.5	9.2	8.2	7.9	6.3	6.9	8.4	8.8	10.2
1970	9.8	8.0	9.1	6.6	8.0	9.7	6.4	4.6	5.9	9.1	9.5	8.5
1971	9.9	8.9	7.8	8.8	8.7	8.6	7.3	5.8	7.3	9.0	9.7	8.6
1972	9.7	9.7	8.8	7.3	7.7	7.8	7.8	6.4	7.0	8.1	8.4	7.7
1973	8.6	8.7	5.9	7.8	9.3	8.1	7.9	6.6	6.9	9.0		
1974			8.0	8.3	7.8				6.0			
1975			7.2	7.4	8.6	8.6	6.0	6.6	6.1	8.6	8.8	
1976	9.1		9.1			7.4	7.5	6.5	8.4	7.7	9.6	9.4
1977	8.3	8.0	5.5	6.8	8.0	7.9	7.5		6.9	8.7	9.6	9.0
1978	9.6	8.9	8.6	7.3	8.1	8.5	5.9	7.3	7.4	8.5	9.1	9.4
1979	8.7	10.0	6.1	8.1	7.3	6.8	7.1	5.9	6.9	8.4	9.0	7.7
1980	8.9	7.2	8.9	8.1	8.6	7.6	7.1	6.2	8.3	7.5	82.0	83.0
1981	9.7	8.5	7.4	7.6	7.1	8.8	6.6	5.9	8.1	9.1	7.7	9.5
1982	9.8	7.1	7.2	7.5	7.5	8.1	6.8	5.2	7.1	5.5	8.2	7.7
1983	7.5	8.0	7.6	7.4	7.7	6.9	7.5	7.1	7.7	8.9	9.4	8.7
1984	7.1	8.1	6.9	6.7	6.9	7.3	7.8	8.0	6.9	6.8	7.1	6.0
1985	7.7	5.2	2.0	5.6	7.7						91.0	67.0
1986	8.7	8.7	7.8	8.4	8.2	8.1	6.1	6.5	7.1	8.4	8.4	7.8
1987	7.3	9.2	7.7	7.6	8.3	8.1	7.3	6.7	7.3	8.2	9.2	7.9
1988	7.3	8.0	7.8	6.9	8.7	5.8	5.4	5.6	6.0	9.0	8.6	8.1
1989	8.6	7.6	7.9	8.9	9.8	8.4	6.7	5.7	7.0	8.1	9.4	8.4
1990	7.5	9.3	7.8	7.6	8.9	7.9	5.9	6.9	7.2	8.6	9.3	9.0
1991	9.3	9.1	7.2	7.5	5.7	7.3	6.5	5.4	7.8	8.0	8.3	8.3
1992	6.5	7.4	6.1	6.8	7.3	8.1	7.0		7.3	8.8	7.5	9.0
1993	8.0		7.5	7.7	9.0	8.2	6.7	6.9	7.1	8.7	8.6	8.5
1994	8.3	7.8	8.2	7.5	8.0	7.8	6.3	4.5	6.3	8.2	9.7	8.8
1995	9.6	9.5	8.4	7.9	8.3	8.8	6.7	4.9	7.2	8.3	9.3	9.0

1996	9.8	8.8	7.4	8.0	8.3	7.4	7.2	6.0	6.3	8.0	9.4	9.4
1997	8.8	6.8	6.5	8.7	7.9	7.6	7.4	7.1	7.0	7.5	9.4	9.1
1998	7.5	8.9	7.6	7.0	7.6	7.9	6.5	5.3	5.6	8.6	9.1	8.5
1999	9.2	8.3	8.8						5.8	8.0	8.5	9.2
2000	8.8	9.1	7.8	8.8	8.0	7.9	6.8	6.7	6.2	5.8	9.4	8.5
2001	9.2	9.0	8.9	8.3	8.5	8.1	6.9	5.6	7.2	8.8	9.1	9.8
2002	8.0	9.2	7.6	8.0	8.7	7.5	7.4	6.1	7.8	8.1	9.4	9.6
2003	8.4	8.7	8.0	8.2	9.0	7.0	7.7	5.3	7.0	9.1	9.2	9.3
2004	8.9	7.1	5.7	7.5	7.5	7.4	6.5	6.2	6.4	9.1	8.9	9.3
2005	7.5	6.7	7.4	7.9	9.0	7.0	5.7	5.9	7.0	8.9	8.8	9.7
avg	8.8	8.5	7.7	7.7	8.2	7.9	6.9	6.0	6.9	8.4	12.6	12.0

Geographical characteristics:

Latitude – (10.9°)

Longitude – (-1.1°)

Altitude – (203m)



Sub-Saharan Africa has an irrigation potential of about 42 million hectares of which only 17% is developed. Despite several investments in irrigation the growth is slow. This study aims at helping to achieve sustainable irrigation in sub-Saharan Africa, through gaining a better understanding of productive irrigation water use and effective management of irrigation development. The study is conducted in the White Volta sub-basin specifically in Northern Ghana and Southern Burkina Faso which have been experiencing rapid irrigation development since the mid 1990s.

The study identified growing markets for irrigated products as an important driving force behind the expansion of irrigation which has given rise to new technologies. The new technologies have spread because they gave farmers direct control over water sources. These new technologies allow relatively small farm sizes which can be adequately managed by the surveyed farmers. As a result high productivities are achieved. The hydrological impact of upscaling irrigation in the sub-basin is sustainable and will maximize the overall benefits derived from water resources in the Volta Basin.