RE-THINKING WATER STORAGE FOR CLIMATE CHANGE ADAPTATION IN SUB-SAHARAN AFRICA

FINAL REPORT (March 2012)

1. **Implemented by International Water Management Institute (IWMI), Sri Lanka**

2. **Project Title (Long):** Re-thinking Water Storage for Climate Change Adaptation in Sub-Saharan Africa
   Project Title (Short): Water Storage for Climate Adaptation

3. **GTZ Contract Number:** 81102456
   GTZ Project Number: 07.7860.5-001.00

4. **Reporting Period:** 01st March 2008 – 31st March 2012

5. **Project Coordinator and Project Scientists**

5.1 Project Leader

Dr. M.P. McCartney,
International Water Management Institute (IWMI)
PO Box 4199
Vientiane
Laos PDR
Phone: +856-(0)21 770076
Fax: +856-(0)21 770076
Email: m.mccartney@cgiar.org
Web: http://www.iwmi.org

5.2 Leading Scientists -International Water Management Institute (IWMI)

Dr. V. Smakhtin (Eco-Hydrology), Sri Lanka.
Dr. S. Seyoum (Climate modeler), Ethiopia
Dr. S. Xenarios (Economist), Ethiopia
Dr. A. Sood (Hydrological modeler), Sri Lanka

6. **Collaborating NARS Institutions and Staff (Ghana and Ethiopia)**

6.1 Implementing Partners, Ethiopia:

Dr. Assefa Admassie (Economics), EEA -Ethiopian Economic Association / Ethiopian Economic Policy Research Institute, Addis Ababa, Ethiopia.
Dr. Berhanu Adenew EEA -Ethiopian Economic Association
Dr. Kassa Tadele, AMU- Arba Minch University/ Institute of Water Technology, Ethiopia.

6.2 Implementing Partners, Ghana:

Dr. Barnabas A. Amisigo, Water Research Institute (WRI), Accra, Ghana.
Dr. Felix Asante, Institute of Statistical, Social and Economic Research (ISSER). University of Ghana.

6.3 Partners Participating in Workshops, Meetings, and Discussions

NBI-Nile Basin Initiative /Water Resources Planning and Management Unit, Ethiopia.

ENTRO- Eastern Nile Technical Regional Organization, Ethiopia.

EPA - Environmental Protection Agency, Accra, Ghana.

VBA- Volta Basin Authority, Ouagadougou, Burkina Faso.

WRC- Water Resources Commission, Accra, Ghana.

6.4 German Participating Institutions and Staff

6.4.1 Centre for Development Research (ZEF)

Dr. Wolfram Laube.

Dr. Irit Eguavoen.

6.4.2 Potsdam Institute for Climate Impact Research (PIK).

Dr. Zbigniew Kundzewicz.

Dr. Holger Hoff.

Dr. Fred Hatterman.

7. Project Description

In Sub-Saharan Africa (SSA) appropriate water storage can make an important contribution to reducing peoples' climate vulnerability by increasing water and food security as well as adaptive capacity (Figure 1). However, ill-conceived water storage is a waste of scarce financial resources and, rather than mitigate, may worsen the unpleasant impacts of climate change. Hence, this study sought to determine how climate change (CC) could be better built into the planning and management of water storage in SSA. The study was carried out in Ghana (the Volta Basin) and Ethiopia (the Blue Nile Basin). It comprised analytical work at the basin scale as well as site level analsyes. The basin scale analyses focused on evaluation of CC impacts on existing and planned storage within each basin. The site level analyses focused on understanding economic and socio-political aspects of water storage at three "sites" within each basin. Findings were integrated to provide comprehensive insights. Significant effort was devoted to the development of computer simulations of the potential consequences of CC for hydrology in both basins and what this means for different storage options. An approach to evaluate the *need* for storage as well *effectiveness* and *suitability* of different storage types and water storage systems was developed. This attempted to integrate both biophysical and socio-economic aspects of storage within a single framework and provides a basis for evaluating the possible consequences of CC on individual storage types as well as water resource systems. Outputs were disseminated through established regional networks, peer-reviewed papers, on-line sources and policy round tables. Capacity was strengthened formally through the training of 15 post graduate students as well as less formally through experience gained "on the job" by researchers. Findings were disseminated through a range of national and international fora, including end of project round tables in both Ethiopia and Ghana.

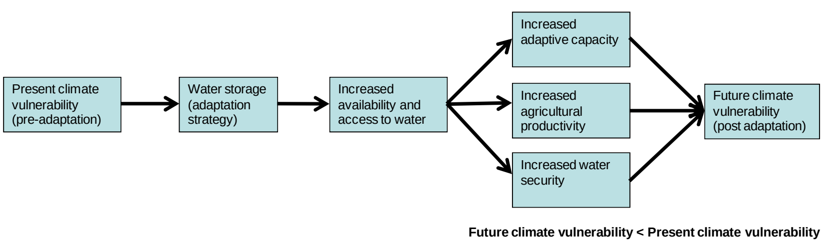


Figure 1. *Water storage as an adaptation strategy to reduce climate vulnerability*

8. Major Research Findings

The major research findings have been grouped as per the project objectives identified in the project proposal:

Output 1: *Assessment of social, economic, biophysical, health and environmental impacts of a range of water storage options in Ghana-Volta and Ethiopia-Blue Nile*

Water storage continuum

The project developed the concept of a *water storage continuum* (Figure 2). Each storage option has an important role to play and, under the right circumstances, can contribute to food security and poverty reduction. For each option, the way the water is accessed and who can access it varies. Some options are highly technical requiring modern tools and methods for construction, whilst others are technically simpler and have been around for millennia. Modes of management also vary considerably. In some cases, decision making and responsibility lies directly with farmers whilst in others relatively complex institutional arrangements are required. Hence, in any given situation, each type of storage has its own niche in terms of technical feasibility, socioeconomic sustainability and institutional requirements, as well as impact on public health and the environment. Furthermore, in any given location the impact of different types of storage on poverty can vary significantly with some options being much more effective in reducing poverty than others.

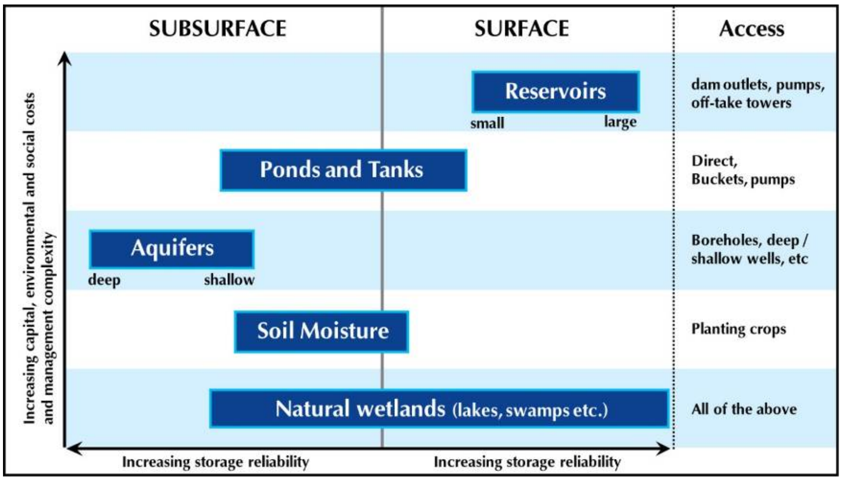


Figure 2. *Conceptualization of the physical water storage continuum.*

Inventory of water storage types in the Blue Nile and Volta River Basins

Our review and inventory of water storage in the Ethiopian Nile and Ghanaian Volta basins (Johnston and McCartney 2010) was the first attempt ever to draw together information on the full spectrum of storage types into a single document. From this exercise we found that water storage, in a variety of forms, is vital for the wellbeing and livelihoods of the people that live in both basins. Simultaneously, the development of water storage is central to the economic development of Ghana and Ethiopia respectively. However, despite its recognized importance, there is a considerable lack of knowledge and information on both existing and planned storage. For both basins, basic understanding (e.g. on groundwater availability and recharge) is insufficient or simply lacking. In both cases data and information for a range of storage types are unavailable or dispersed and difficult to access. With the exception of large dams, past storage development has occurred in a piece-meal fashion, largely through local initiatives and with minimal planning. It is generally characterized by absent or poor data management, insufficient communication with local stakeholders and water resource authorities, and lack of any integrated planning. In some cases (e.g. where reservoirs have silted, wells are dry and ponds have aggravated negative health impacts) it is clear that the lack of information and planning has resulted in less than optimal investments.

Future population growth, in conjunction with CC, will increase the importance of water storage in both basins. However, as water resources are increasingly utilized and climate variability increases, planning will become ever more difficult. Without much more systematic planning, it is probable that many water storage investments will fail to deliver intended benefits. In some cases they may even worsen the negative impacts of CC. To ensure successful future water storage development within both basins requires much greater integrated planning than in the past. To this end the development of basin water storage development strategis, that are consistent with any basin master plan and clearly identify objectives and priorities for investment in all water storage options, not just large dams would be beneficial.

Health impacts of water storage

A study of the health impacts of water storage conducted for this project (Boelee et al., 2011) found that popular options for addressing CC such as rainwater harvesting and water storage may lead to increased transmission of water-related diseases. In the rush to develop water harvesting and storage for CC adaptation care must be taken not to increase the health burden of already vulnerable people. Poorly planned and managed water storage will have adverse implications for public health that can undermine the sustainability of the interventions. It is very hard to assess the impact of climate variability and CC, as well as other global changes associated with increased population pressure, on disease transmission because of the many human factors and other uncertainties. However, it is clear that some adaptation measures, such as increased rainwater harvesting and water storage, may aggravate existing health hazards by expanding the open water surface in susceptible areas with vulnerable populations. Participatory Health Impact Assessment (PHIA), even if only partially applied, can help to address health risks. Also, by considering a wider range of options in planning, design and management of water storage, health risks could probably be addressed to a large extent. Unfortunately, currently too little thought is given to the possible public health implications of different options. If adverse impacts are to be avoided in future much greater consideration must be given to the full range of potential health impacts and possible mitigation measures under the altered conditions that will result from CC.

Output 2: *Analysis of resilience of storage options under specified CC scenarios*

Ethnographic studies

Ethnographic studies – mostly conducted in Ethiopia, but also some in Ghana - covered a range of issues including: acquisition of storage; rules and regulations; land and water rights; management bodies, resettlement and compensation; livelihood change and gender issues. This work involved a range of methods including participatory rural appraisals and interviews. The studies provided a wealth of information on local level implications and the political-ecology of water storage for agriculture, which is difficult to summarize. However, a few of the key study findings were:

- most farmers are very aware of CC and many perceive it to already be occurring with increasing risk for their own livelihoods and well-being;
- farmers priorities are not all about water but mostly they recognize the value of irrigation and the need for water storage to facilitate this;
- in some places farmers are taking the initiative to create small-scale storage and irrigation but in many places they lack the wherewithal and resources to do this effectively without assistance from government or NGOs;

- even where biophysical, economic, socio-political and administrative conditions are the same water storage facilities are acquired, used and managed differently by different communities (e.g. on the Fogera plains in Ethiopia);
- new government initiated large scale schemes provide opportunities for some but also create additional risks for farmers, at least initially;
- large scale schemes require new institutional arrangements for management (e.g. water user associations) but the legal status of such institutions is often unclear and they may not have the capacity to properly fulfil their mandate;
- irrigated agriculture can substantially increase the workload on farmers (particularly in the dry season) requiring them to make difficult livelihood choices (e.g. abandonment of livestock) and sometimes leading to conflict with religious authorities (e.g. in relation to holidays and religious duties);
- there is a risk that irrigated agriculture can increase and intensify conflicts within communities;
- there are significant risks of impoverishment associated with the relocation of communities caused by the construction of large scale surface water storage and irrigation schemes;
- if farmers are consulted and informed early enough in the process they will often be pro-active in organizing measures to mitigate the adverse impacts on them (e.g. organizing temporary land exchange arrangements with their kin and others);
- a key risk of relocation is loss of social cohesion within communities but, at least initially, many relocated farmers attempt to maintain former social support networks;
- if given the opportunity farmers are proactive in reconstructing their livelihoods;
- there are significant gender implications associated with water storage and if not managed carefully women tend to realise fewer of the benefits and be disproportionately burdened by negative impacts (e.g. of relocation).

All the studies were written up in student theses and many have been published and presented at workshops and conferences.

Evidence for a drying climate in Ghana

Patterns of rainfall change in Ghana over the last half century have remained poorly understood as most previous research efforts focused on the West African region above 10° N. Moreover, past studies predominantly investigated changes only in annual rainfall amount. Previously temporal changes in agriculturally-relevant rainfall characteristics have only been studied at the local level. In several past studies, data were seemingly not corrected for serial correlation prior to trend analyses, thereby reducing confidence in the validity of the trends observed. Against this background, as part of this project, we investigated the presence of trends (using the Mann – Kendall test) over the period 1960-2005 in 28 rainfall characteristics including indicators of cumulative rainfall depth, rainfall frequency and intensity, and occurrence of the wet season, using daily effectively pre-whitened rainfall time series from rain gauges located from latitudes 4°52 N to 10°54 N in Ghana.

At the country level, the study found an insignificant declining regional trend in annual rainfall. However, several significant regional trends, at the 95% confidence level, were observed: i) a reduction of light rainfall ($<20 mm.day^{-1}$), ii) a delay in the onset of the wet season (about 0.5 $day.year^{-1}$), and iii) a lengthening of rainless periods during the wet season (about 0.1 $day.year^{-1}$). 95%-significant declining trends in light rainfall were observed at individual stations between latitudes 6° N and 9.5° N. These changes may have been deleterious for rainfed crops and, if they continue, may have implications for water resources and storage in the country. The cause of the observed trends is unclear and it is not yet possible to conclude that they are definitely a consequence of CC and will continue.

It is interesting to note that trends in several variables, such as the length of the longest rainless period during the wet season, although insignificant at a majority of rainfall stations, were found to be regionally significant at the country level. Hence, the study highlighted – what is believed to be an innovative methodological finding - the need for investigation of regional trends rather than trends at individual stations only. The results were written up in a paper that has been accepted for publication and is currently in press (Lacombe, et al., in press).

CC scenario modelling

In this project, in addition to statistical downscaling, and for the detailed analyses of CC impacts we used a dynamic regional climate model (RCM) to determine future climate projections in both the Volta and Blue Nile basins. The model used was the COSMO-CLM (CCLM) model with initial and boundary conditions for the IPCC SRES A1B scenario taken from the ECHAM5 Re-Analysis (ERA40). Simulated temperature and precipitation were bias corrected using CRU data as reference and comparing against the simulated data on a monthly time step for a 30 year reference period 1971-2000. Further details of the modelling approach are available in Hatterman (2011) and Kreienkamp et al. (2010). A regional climate model (RegCM3) from the International Centre for Theoretical Physics was also used for experimental dynamic downscaling in the Upper Nile Basin. The ECHAM5 GCM outputs and the European Re-analysis (ERA40) were used for initial and boundary conditions for the RegCM3 downscaling experiments. Details of this work are currently being written up in two journal articles (Demissie, et al., in prep.)

Figure 2 and Table 1 summarize changes in key meteorological time series (i.e. temperature, basin average rainfall, potential and actual evapotranspiration) on an annual time-step over the period 1983 to 2100 as derived from the CCLM model for the A1B scenario for both the Nile and Volta basins. For the Volta, the A1B scenario anticipates a basin-wide increase in annual average temperature of up to 3.6^{o}C and a decrease in annual average rainfall of approximately 20% by the end of the 21st century. As a consequence of the rise in temperature, basin wide annual potential evapotranspiration increases by approximately 22%. However, because of the reduction in rainfall, basin wide actual evapotranspiration decreases by approximately 15%. For the Nile, the A1B scenario anticipates a basin-wide increase in annual average temperature of up to 4^{o}C and a decrease in annual average rainfall of approximately 15% by the end of the 21st century. For the same reasons as in the Volta the basin wide annual potential evapotranspiration increases by approximately 13% but basin wide actual evapotranspiration decreases by approximately 3%.

Table 1. *Basin averaged climatic/hydrological variables for the Nile and Volta basins for three periods 1983-2012, 2021-2050 & 2071-2100 derived for the A1B scenario using the CCLM model.*

	Temperature (^{o}C)	**Rainfall (mm)**		**Potential Evapotranspiration (mm)**	**Actual Evapotranspiration (mm)**
		Mean	CV		
Volta					
1983-2012	30.3	835	0.12	2729	717
2021-2050	31.3	757	0.11	2813	668
2071-2100	33.9	666	0.15	3323	606
Blue Nile					
1983-2012	20.9	1,310	0.12	1,363	539
2021-2050	21.9	1,290	0.13	1,405	522
2071-2100	24.9	1,110	0.15	1,535	525

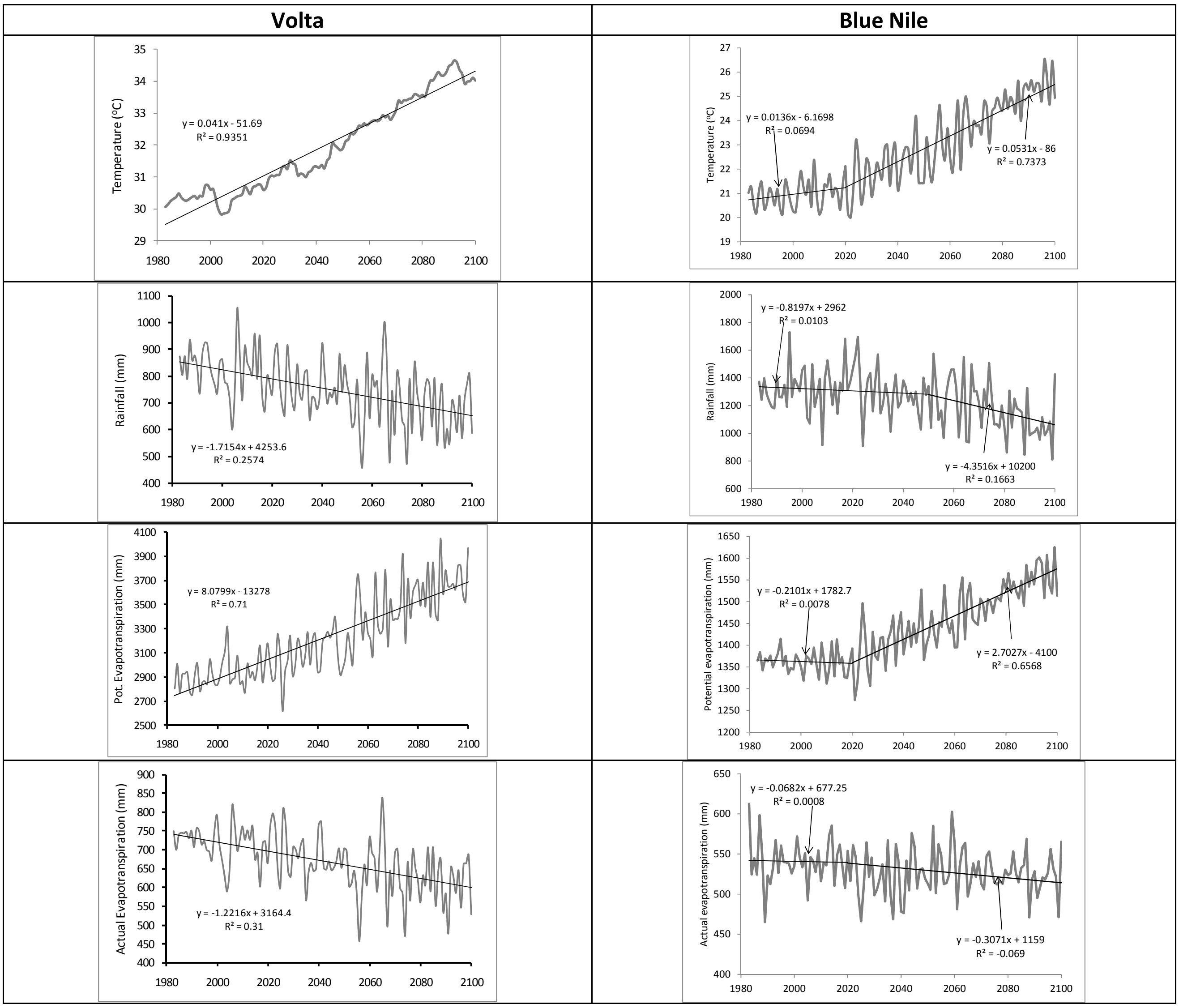


Figure 3. *Basin average annual climate variables for both the Blue Nile and Volta basins (1983-2100): a) temperature, b) rainfall; c) potential evapotranspiration and d) actual evapotranspiration derived from the CCLM model for the A1B scenario.*

For both basins the results exhibited significant spatial variability (Figure 4a). This has implications for different forms of water storage. For example, groundwater recharge, essential for groundwater storage shows significant but variable declines in the Volta basin (Figure 4b).

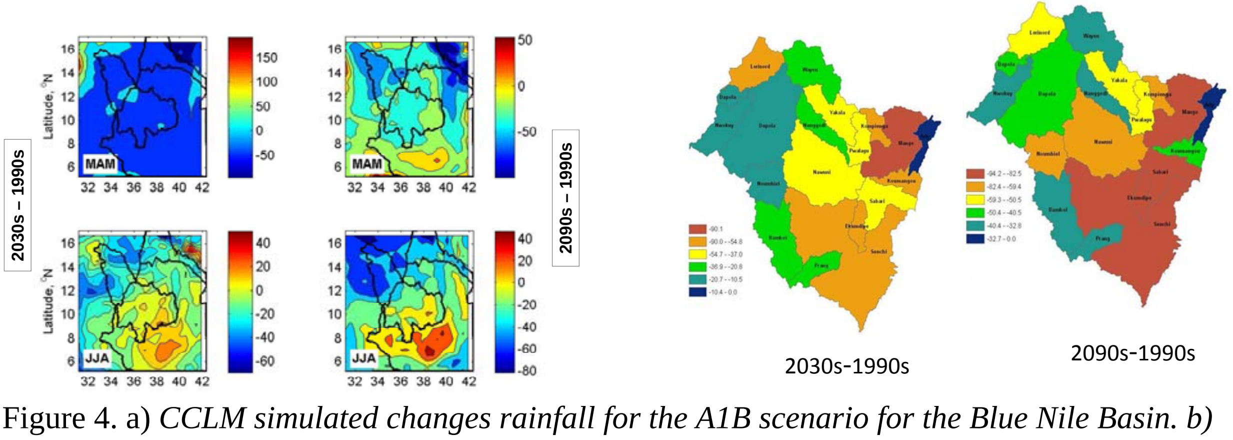


Figure 4. a) *CCLM simulated changes rainfall for the A1B scenario for the Blue Nile Basin. b) SWAT simulated changes in groundwater recharge arising as a consequence of CC in the A1B scenario in the Volta Basin.*

Evaluation of resilience of dams in the Blue Nile

The aim of this component of the study was to evaluate the possible impacts of CC on the technical performance of reservoirs in the Blue Nile basin of Ethiopia. Two reservoirs were selected as a trial. The Koga dam, located approximately 35km southwest of Bahir Dar, is a new dam built to irrigate 7000 ha and provide water for electricity generation. The Gomit dam is a community dam built to irrigate 90 ha with no hydropower capability. For both dams computer model simulations were used to determine the performance of the reservoirs, evaluated in terms of Reliability, Resilience and Vulnerability (RRV) criteria, where:

- Reliability is a measure of the frequency of the reservoir to fail to supply water for all demands
- Resilience is a measure of the speed of recovery of the reservoir from failure
- Vulnerability is a measure of the cumulative maximum extent of failure

In each case the RRV criteria were evaluated under both existing and hypothetical future climate conditions. The study found that although there are sometimes trade-offs in RRV terms (e.g. a reservoir that is highly resilient maybe less reliable), the results indicate that under all conditions, the larger Koga reservoir is more resilient and reliable and less vulnerable than the smaller Gomit reservoir. As would be expected, higher rainfall in the future will increase resilience and reliability and decrease the vulnerability of both reservoirs but if there is reduced rainfall in the future this will decrease resilience and reliability and increase vulnerability of both reservoirs. Furthermore, the magnitude of the impact of possible changes in rainfall on the RRV terms is greater for the smaller reservoir than the larger. This research was written up and presented at the Tropentag conference in 2010.

Making appropriate choices from the range of storage options available is the key to planning and management of future water storage. In any given situation this requires an understanding of the possible implications of CC on the technical performance of different storage options. The RRV criteria are a useful tool for determining how the technical performance of reservoirs may alter as a consequence of CC. They provide a starting point for building CC into dam planning and management and, as well as single reservoirs, they can be used to assess the technical performance of reservoirs linked in systems. A key contribution of this project was extending the approach to other storage types (e.g. groundwater and small ponds and tanks) as well as storage systems comprising more than one storage type (see below).

Output 3: *Analysis of investment scenarios and associated risks – basin perspective*

Results from the CCLM modelling (i.e. rainfall, temperature and potential evapotranspiration) were used in two models used in combination to assess the implications of the A1B CC scenario on the water resources and storage in both the Volta and Blue Nile basins. The outputs generated from CCLM were used as input to a hydrological model (SWAT) which was setup, calibrated and validated with observed climate and hydrological data. Then results from the SWAT model (i.e. projections in river flow and groundwater recharge) in conjunction with existing and projected water demands were used as input to the Water Evaluation and Planning (WEAP) model to evaluate possible consequences for existing and planned water demand and hence storage in both basins (Figure 5). Because the exact trajectory of development is unknown, a number of development scenarios were simulated in both basins (Table 2).

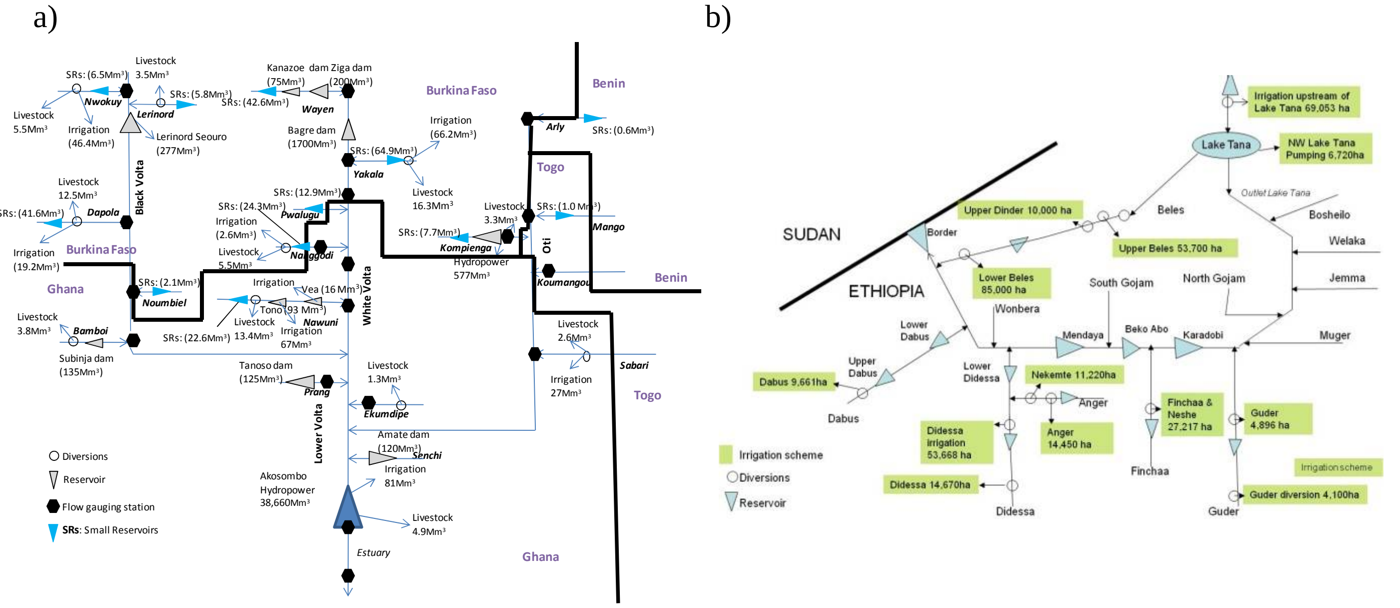


Figure 5.*WEAP model configuration showing all existing and planned water resource development and large-scale storage for a) the Volta, b) the Ethiopian Blue Nile*

Table 2. *Water resource development scenarios*

Scenario	Description	Total reservoir storage (Mm^3)	Irrigated Area (ha)	Hydroelectricity generating capacity (MW)
Natural	No water resource development. Provided a baseline to enable the impact of just CC to be assessed			
Current development	The present water resource development (i.e., irrigation and hydropower schemes) and existing water storage	153,124 (V)	30,468 (V)	1,044 (V)
		11,578 (BN)	15,345 (BN)	218 (BN)
Intermediate development	Planned water resource development, including new storage, that it is anticipated will occur in the near to medium term future (i.e. before approximately 2025).	180,124 (V)	63,253 (V)	1,547 (V)
		70,244 (BN)	272,018 (BN)	2,194 (BN)
Full development	All planned water resource development that is likely to occur in the future (i.e. possibly before 2050).	203,437 (V)	65,207 (V)	1,940 (V)
		167,079 (BN)	364,355 (BN)	10,276 (BN)

V = Volta BN = Blue Nile

Results from this study indicate that changes in climate will affect the hydrology and water demands of both basins. For example, irrigation demand increases in both basins not only because irrigated areas increase but also because CC results in greater evaporative demand. Tables 3 and 4 summarize the results in relation to irrigation demand and hydropower generated in both basins.

Table 3. *Anticipated changes in hydroelectricity generated and percentage of the total potential in each of three development scenarios under the A1B CC scenario*

	Current Development		Intermediate Development		Full Development	
	Hydroelectricity generated ($GWhy^{-1}$)	% of total potential	Hydroelectricity generated ($GWhy^{-1}$)	% of total potential	Hydroelectricity generated ($GWhy^{-1}$)	% of total potential
Volta						
1983-2012	4,678	77	6,975	80	8,378	79
2021-2050	3,159	48	4,779	53	5,684	53
2071-2100	1,569	24	2,599	30	2,946	29
Ethiopian Blue Nile						
1983-2012	1,397	100	12,814	98	40,803	91
2021-2050	1,390	100	12,962	99	44,245	98
2071-2100	1,138	82	8,422	64	28,449	63

Table 4. *Anticipated changes in irrigation water demand and percentage of the total delivered in each of three development scenarios under the A1B CC scenario*

	Catchment average irrigation demand (m^3ha^{-1})	Current Development		Intermediate Development		Full Development	
		Water Demand[1] (Mm^3)	% demand delivered	Water Demand [1] (Mm^3)	% demand delivered	Water Demand[1] (Mm^3)	% demand delivered
Volta							
1983-2012	14234	356	86	786	92	824	94
2021-2050	14527	376	70	817	74	856	83
2071-2100	15328	394	42	855	40	896	44
Ethiopian Blue Nile							
1983-2012	8,244	128	100	2,012	89	2,787	87
2021-2050	8,491	133	99	2,214	88	2,928	91
2071-2100	9,726	153	64	2,618	36	3,394	40

The results indicate that in both the Volta and the Ethiopian Blue Nile basins, the changes in climate, predicted for the A1B scenario, will have significant impacts on both hydropower generation and irrigation. The model simulations indicate that in the Blue Nile approximately 90% of irrigation demand will be met and the hydropower generated will broadly match the potential until the middle of the 21st century. However, in the latter part of the century, in the Intermediate and Full Development scenarios, significant reductions occur in both the proportion of irrigation water demand met and the proportion of potential hydropower generated. In contrast in the Volta the impact is felt much earlier with significant reductions in both hydropower and irrigation before 2050. It is clear that increased water storage increases the area of land that can be irrigated and the amount of electricity that can be generated. However, it is also apparent that, if an A1B type scenario comes to pass, the performance of that development will be curtailed as a consequence of CC.

Effective water resources management is critical for successful adaptation to CC. Although there remains great uncertainty about how CC will impact the water resources of the basins it is clear that even with massively increased water storage, under a mid-range scenario, the performance of planned irrigation and hydropower schemes is likely to be severely constrained by the end of the 21st century. Obviously, the consequences of harsher CC - which is equally, and based on current emissions trends perhaps more, likely - would be even more severe.

These findings highlight the fact that prospects for development and economic growth in the Volta and the Ethiopian Blue Nile will be hindered by CC. Adaptation to CC and development are clearly linked and need to be considered together. CC necessitates a fundamental rethinking of the way water resources and particularly water storage options are planned and managed. In comparison to the past, planning needs to be much more systematic with much greater consideration of the potential implications of CC. As highlighted in this study, modelling has an important role to play in evaluating the possible impacts of different development options and scenarios.

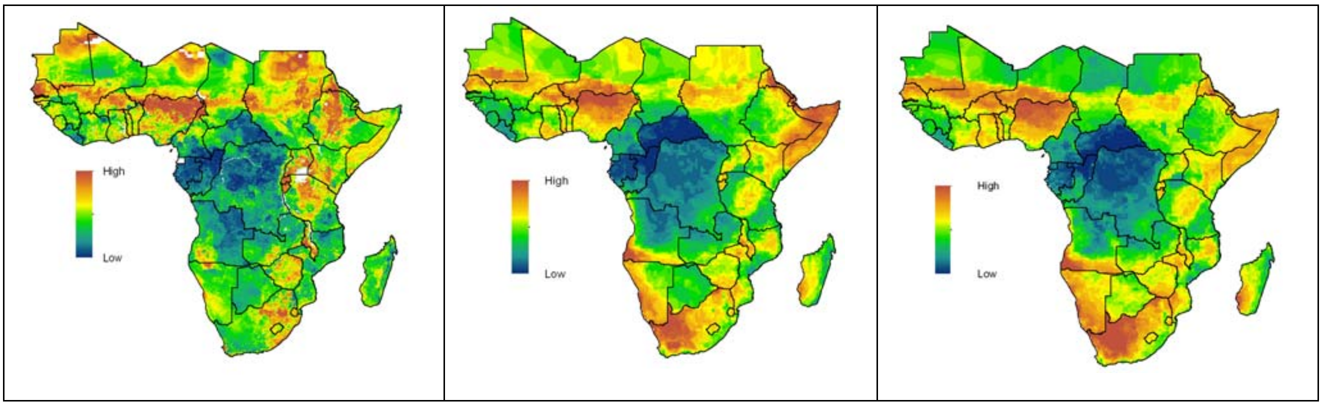
This work was written up and published in papers presented at the 3rd Ghana Water Forum (2011), the Symposium on Sustainable Water Resources Development at Arba Minch (2011) and the International Conference on Ecosystem Conservation and Sustainable Development at Ambo University (2011). It is also being published in peer reviewed journal articles and an IWMI Research Report that is currently in preparation.

Output 4: *Guidelines for i) evaluation of the socio-political and institutional conditions under which various storage options should or should not be implemented; ii) which storage options or their combinations to adopt iii) investments in water storage aimed at improving resilience and risk reduction for farming communities; iv) implementation process*

Evaluation of storage options

There is a re-emerging interest from donors to invest in water storage and irrigation infrastructure development. Key issues for consideration when planning water storage as a development option and a strategic adaptation measure to mitigate CC were summarized in the IWMI Blue Paper: *Water storage in an era of climate change.* This was published as a key output from this project and was released at the Stockholm Water Week in August 2010. This emphasized the necessity of considering three key aspects in planning and managing water storage: need, effectiveness and suitability. These elements have been expanded on in an IWMI Research Report that is currently under preparation and that will be published by the end of 2012*: Agricultural water storage in an era of climate change: assessing need, effectiveness and suitability.* This develops a framework for evaluation that links biophysical, social and economic aspects of storage and provides a basis for assessment within the context of CC.

Storage need is defined in relation to i) Landuse (agriculture and livestock); ii) rural population density; iii) rainfall availability (Total rainfall per person) and iv) rainfall variability. Using scenarios for population rise and CC storage need can be mapped for countries or regions both under existing and CC conditions (Figure 6). Such maps can be used to better target and plan future interventions.



2010 2050 2100

Figure 6. *Maps of existing and future water storage need in Sub-Saharan Africa assuming an A1B CC scenario*

Effectiveness (i.e. the technical performance) of water storage systems will be altered by CC. In the past a number of risk-based indicators have been used to evaluate the *technical performance* of water resource systems and storage. These determine the *reliability, resilience* and *vulnerability* of storage under given climatic conditions (see above). As such they can be used to evaluate performance under possible future climates. However, in the past these have been used almost exclusively for large reservoirs. In the current study an approach was developed to enable these to be applied to other water storage options and combinations of water storage types. Thus the effectiveness of a storage system (comprising a number of different storage types) is determined as a function of the systems:

- Engineering reliability (i.e. measure of frequency of failure of the system to deliver water for all demands)
- Engineering resilience (i.e. measure of speed of recovery from failure of the system to deliver water for all demands)
- Engineering vulnerability (i.e. cumulative maximum extent of failure of the system to deliver water for all demands)

Suitability (i.e. socioeconomic aspects) of different storage options were also assessed. In the past, indicators have been developed to assess the potential socioeconomic impacts of CC on water resource systems but as with effectiveness the primary focus has been large dams. A few studies have been conducted to determine where rainwater harvesting could be successfully applied. Whilst most have focused on biophysical conditions one has also incorporated socio-economic factors to produce "suitability" maps. However, there is no consideration of storage *per se* and no possibility of comparison with other water storage options. In this project an approach was developed that determines suitability as a function of three components: i) Economic viability, ii) Social suitability and iii) Environmental sustainability.

Economic analyses (development of an outranking methodology)

In the past the selection of a storage option, its design and operation have largely been undertaken in an *ad-hoc* manner often without any form of economic analyses. This is particularly true of small-scale, local storage development. For larger scale developments (e.g. large dams and well fields) evaluations have, until recently, focused almost exclusively on financial considerations, usually assessed through Cost Benefit Analysis (CBA).

CBA is widely acknowledged as the most appropriate approach for choosing between water storage options due to the straightforward valuation of marketed goods and services. In the absence of policy distortions and market failures, market prices are assumed to portray both individual and relative social values. However, significant problems can arise when prices are not adjusted to market conditions or differing values are placed on various aspects of a scheme by diverse stakeholders. As part of this study we addressed the need for reorientation of the assessment process for the selection of appropriate water storage options in SSA. With this aim, a multi-criteria outranking-based approach was developed as an alternative/addition to standard CBA.

The method developed assesses representative water storage options by combining quantitative and qualitative criteria (not just monetary factors), thereby minimizing information loss but still conforming to best economic practice. The approach which is based largely on data derived from household surveys as well as information gleaned from relevant literature and local experts was developed and tested though application to the case study sites in both Ghana and Ethiopia. The approach proposed avoids some of the major limitations of CBA and places greater emphasis on socioeconomic and environmental criteria. As such we believe it provides for a more equitable distribution of benefits to be gained from different storage options. Further details are provided in Xenarios et al. (2011) and Xenarios et al. (in press).

9. Assessment of Research Findings

The research conducted has varied implications for a range of stakeholders. Key messages from the research are summarized below.

Existing situation

- Inability to manage rainfall variability is a key constraint to agricultural production and economic growth in many places in Sub Saharan Africa. CC will exacerbate this.
- Historically there has been little systematic planning of water storage– particularly small-scale storage. As a result many schemes are not fit for purpose, a waste of scarce financial resources and in some cases harmful.
- To combat CC much better planning is necessary in future. In comparison to the past planning of water storage needs to be much more systematic and integrated across a range of levels and scales. This needs to include planning of public health implications of different water storage options using tools such as PHIA.
- Farmers already perceive changes in climate and very often believe it is having a negative impact on their livelihoods.
- Despite large spatial variability, trend analyses, including regional analyses, provides a way of evaluating past changes in agriculturally relevant aspects of climate.
- There are a variety of physical water storage options which can contribute to improved management of water resources and contribute to the resilience of rural communities and their ability to cope with CC. Each has a specific niche in relation to technical feasibility and social suitability.
- In some places farmers can take the initiative to plan and develop new water storage infrastructure but often they require assistance from government and NGOs. All new options present potential livelihood risks (at least initially) as well as benefits. The risks need to be mitigated through careful planning and management.

CC simulation

- There remains great uncertainty about how CC will impact the water resources of SSA. However, it seems probable that prospects for development and economic growth in SSA will in many places be hindered rather than enhanced by CC.
- Adaptation to CC and development are clearly linked and need to be considered together.
- Climate modelling has a key role to play in evaluating the possible implications of CC and enabling robust responses to be determined.
- Climate scenarios across SSA exhibit great spatial variability. Therefore, climate adaptation practices must address spatial variability. This requires spatially explicit planning.
- Uncertainties in climate projections could be improved through better understanding of the regional climate system and by employing robust downscaling methods. This calls for greater investment by governments and donors in meteorological data collection and more analyses and research.
- Future climate scenario development must consider both global and local climate drivers that vary with season, altitude and location.
- Climate modeling requires good computing facilities, internet connectivity and expertise. There should be sustained investment by governments and donors to build capacity throughout SSA.

Involving communities

- Understanding the adaptive capacity of local communities and how this might change as a consequence of different water storage types is a pre-requisite for choosing appropriate options from the range of possible interventions.
- Farmers will if given the opportunity often take some initiative in developing storage facilities and/or minimizing the risks (e.g. of greater impoverishment) arising from the installation of storage.
- Initiatives can be enhanced by earlier communication with affected communities, by training and agricultural extension and by better administrative support.

- For any particularly intervention, there are some knowledge gaps which occur frequently and regularly hinder successful implementation of storage projects (e.g. underestimating the time required to establish a successful and sustainable system, poor communication with households that have to be relocated, poor evaluation of off-farm employment opportunities and markets).
- Generally better communication to farmers and local authorities is a pre-condition for community support and "buy-in" to initiatives. This requires greater focus from project implementers and additional funding from donors.

Economic evaluation

- Past planning of storage has primarily primarily focused on cost-benefit analysis (CBA)
- Although straightforward, CBA is focused on financial aspects of a scheme and may lead to reductionism, information loss and sub-optimal, non-sustaianable intereventions.
- An outanking approach is proposed for the preservation of knowledge encompassed in different storage related factors. This still aims at fulfilling the principle of economic efficiency but is based on more diversified criteria, threshold values and weights.
- The application of such an approach is believed to result in more equitable results and better highlights, within any given context, the advantages and problems of different water storage options, thereby improving decision-making.

10. Know-How Transfer

A wide range of activities were undertaken to ensure that research findings are used and will be developed further. Considerable effort was made (and is ongoing) to publicise the full range of project findings to a range of stakeholders. This has included publication of research findings not just in peer reviewed journals but also in more readily accessible formats including:

- The IWMI Blue Paper entitled: *Water Storage in an era of climate change: addressing the challenge of increasing rainfall variability*. This was linked to an IWMI initiated media campaign at World Water Week in 2010 which resulted in significant publicity for the project and the ideas being generated by it. Subsequently IWMI has received many requests to duplicate figures produced in the Blue Paper including the water storage continuum and the water storage as an adaptation strategy (Figures 1 and 2 above) – most recently in a UNEP publication entitled *Releasing the pressure*. The work was also cited in a UK parliamentary briefing document on water adaptation in Africa climate (April 2011 - http://www.parliament.uk/documents/post/postpn_373-Water-Adapatation-in-Africa.pdf).
- Shorter widely read pieces, such as:
    - Science and Development Network which provides news and analysis of science relevant to the developing world http://www.scidev.net/en/agriculture-and-environment/water-security-climate-change/opinions/water-storage-requires-evidence-based-approach-1.html
    - IMAWESA a knowledge management network for promoting agricultural water management in eastern, central and southern Africa http://imawesa.info/2011/10/19/water-storage-critical-to-increased-food-security-in-africa/#more-1325.
    - IWMIs feature e-alert which is sent out to a mailing list maintained by IWMI.
- The publication of two ZEF working papers, one IWMI working paper and a ZEF policy brief. In addition two IWMI research reports will be published this year. These publications are freely available for downloading from the internet.

In addition, a project website was established and has been regularly updated (http://africastorage-cc.iwmi.org/home.aspx). This provides background information for the project and is also a repository of key project outputs, including presentations, reports and other publications. ZEF also developed a webpage on their website dedicated to the project and where publications can be downloaded (http://www.zef.de/1393.html).

Presentations of research findings have been made at a range of international and national fora in Ethiopia, Ghana and elsewhere (Table 5). These have enabled key results to be widely promoted both to co-researchers but also, in some cases, to local and regional politicians and planners.

Table 5. *Forums at which project results from this project were presented*

2010 Tropentag Conference on Agricultural Research for Development Zurich, Switzerland Reflektionen aus einem Entwicklungsforschungsprojekt. Tagung "Wasser in Afrika - Lebensgrundlage, Entwicklungspotential, Handelsgut. Siegen, Germany Colloquium of the Institute for Social Anthropology, Gologne Germany VAD Conference (German Association for African Studies), Mainz, Germany. The global dimensions of change in River Basins. Bonn, Germany GWSP Conference of the Global Catchment Initiative (GCI), Bonn, Germany Symposium on Sustainable Water Resources Development, Arba Minch, Ethiopia
2011 International Conference on Ecosystem Conservation and Sustainable Development, Ambo, Ethiopia 3rd Ghana Water Forum, Accra, Ghana International Congress: water 2011 – Integrated water resources management in tropical and subtropical drylands, Mekelle, Ethiopia International Conference on Climate Change and Development, Addis Ababa, Ethiopia Nile Basin Development Forum, Kigali, Rwanda International conference on Management of water in a changing world: lessons learnt and innovative perspectives. Dresden, German American Anthropological Association Meeting, Montreal, Canada
2012 Bonn Comparative Water Studies Workshop, Bonn, Germany

Final project seminars and roundtables were conducted in both Ethiopia and Ghana (in August and September 2011) to which a wide range of stakeholders (government, NGOs, donors and other researchers) were invited. These enabled us to present key project findings and provided a forum, in each country, for discussion of the findings and the implications for future water storage planning and management in Ethiopia and Ghana.

11. Training

Formal training:

- Following training in Germany by Dr. Laube and Dr. Eguavoen, five MA students (Constance Abwoyo, Seidu Billa, Sina Marx, Ben Otto, Susanne Remmel) and one BA student (Weyni Tesfai) from Cologne University, conducted ethnographic fieldwork at the 3 Ethiopian research sites, between February and April 2010.
- One diploma student (Ursula Baumgärtner) conducted field research at Vea in Ghana from October to November 2010.
- One MSc student from the University of Accra (Etorno Agbeko) has conducted research into the impact of CC on fisheries in reservoirs in the Volta Basin.
- One MSc student (Tom Eickhof) from the University of Berlin, Germany conducted research and wrote up a thesis on issues of water storage in the Vea catchment, Ghana.

- Seven MSc students from Arba Minch University (Yakob Mohamed, Fuad Yassin, Habtom Bekele, Gashaw Muluneh, Hadush Kidane, Hailay Tedla and Mulugeta Gerba) completed research studies. These studies investigated: rainfall variability and implications for rain fed agriculture; upstream-downstream interactions and the impacts of CC; potential impact of CC on reservoirs in the Blue Nile; possible impact of CC on groundwater-surface water interactions
- One PhD student (Michael Menker Girma) of the Freie University of Berlin who conducted research and wrote a thesis on the potential impact of climate and landuse change on the water resources of the upper Blue Nile.

Several of the Arba Minch University students now work in Ethiopia in jobs related directly to the research they conducted though this project. Michael Girma is now employed by the African Climate Policy Centre (ACPC), which is a unit of the United Nations Economic Commission for Africa (UNECA), based in Addis Ababa. There is no doubt that he and the MSc students obtained these jobs primarily because of the experience gained in this project.

Informal training

The capacity of all the researchers involved in this project was increased through experience gained on-the-job. This included the learning of new analytical techniques, learning to use models not previously used by them, supervision of young researchers and students, increased experience in making presentations (not just to other researchers but also other stakeholders) and, of course report and paper writing. Many of the researchers from the national partners already had considerable experience of working on internationally funded projects but for some of them it was the first time and this project provided the opportunity to interact with scientists of multiple disciplines from different countries. We believe that the capacity of staff of other stakeholders (e.g. government officials, NGOs and donor organisations) have also been increased as a consequence of exposure to study findings and the discussions initiated as part of the project process.

12. Lessons Learned

This was a highly ambitious project that sought large impacts through integrated biophysical and socio-economic research. In many ways the ambition outstripped what was actually feasible within a relatively short period of time. Hence, although we believe we achieved a great deal and have increased knowledge and capacity, the key objective of the project (i.e. to increase the resilience of the rural poor and vulnerable to CC related risks in sub-Saharan Africa through better water storage mechanisms, improved investment strategies and institutional support) was not entirely realized. Major constraints to the project were as follows:

- The length of time required to do the CC downscaling. This took far longer than was anticipated and significantly delayed the computer modelling and subsequent analyses that depended on it.
- Rapid turnover of staff, both within IWMI (i.e. particularly from the Ghana office where several key project staff left during the period of the project) and from some of the partners (e.g. Arba Minch University and The Ethiopian Economic Association). This resulted in loss of capacity and meant that some tasks had to be reassigned to others.

The request for a no-cost extension to the project was due largely to these two factors. As a result of the no cost extension we were able to successfully complete the computer modelling but are still in the process of writing up and publishing the final results. Because of the long-time needed for publication this will be completed by the end of this year.

Collaboration between partners generally worked well and we believe that the opportunity for Ghanaian and Ethiopian researchers to interact and exchange experiences, between the east and west of the continent, was particularly valuable.

13. Future Research Needs

Future research is required to:

- Improve understanding of regional climate systems across sub-Saharan Africa and the downscaling of CC scenarios to basin levels
- Give greater understanding of the specific socio-economic conditions that cause different storage options to be more or less successful in improving livelihoods and reducing poverty
- Develop standardized approaches for mapping and inventorying water storage in all its forms
- Improve understanding of water resources and storage across SSA including: i) mapping of aquifers; ii) groundwater-surface water interactions; iii) potential CC impacts on water supply and demand; iv) the social and environmental impacts of different storage options and the implications of scaling-up small-scale interventions; v) the reasons for success/failure of past storage schemes.
- Develop of clear environmental and social safeguards that minimize potential adverse impacts for all storage options.
- Develop better understanding of the decision making mechanisms related to the development of different water storage options.
- Evaluate different decision aiding tools, based on economic and technical assumptions, for a better understanding of the pros and cons of alternative approaches.

14. Summary

Farmers already perceive changes in climate and very often believe it is having a negative impact on their livelihoods, often through impacts on water. In some places farmers can take the initiative to plan and develop new water storage and associated irrigation infrastructure but often they have to depend on assistance from government and NGOs. All new options present potential livelihood risks (including health risks) as well as benefits. The risks need to be mitigated through careful planning and management. However, historically there has been very little systematic planning of water storage, particularly small-scale storage. As a result many storage interventions are not fit for purpose, a waste of scarce financial resources and in some cases harmful. If the negative impacts of CC are to be mitigated, future planning of water storage needs to be much more systematic and integrated across a range of levels and scales and should include evaluation of possible public health implications. The development of basin water storage development strategies would assist this process.

There remains great uncertainty about how CC will impact the water resources of SSA. However, the results of this project confirm that prospects for development and economic growth are likely to be adversely affected in many places. Adaptation to CC and development are clearly linked and need to be considered together. Climate modelling has a key role to play in evaluating the possible implications of CC and enabling robust responses to be determined. In addition to temporal variation, climate scenarios across SSA exhibit great spatial variability which must be addressed in strategies for climate adaptation. For water storage this means spatially explicit planning and reliance on different mixes of storage options in different places. Uncertainties in climate projections could be improved through better understanding of the regional climate system and by employing robust downscaling methods. This calls for greater investment by governments and donors in meteorological data collection and more analyses and research. Climate modeling requires good computing facilities, internet connectivity and expertise. There should be sustained investment by governments and donors to build capacity throughout SSA.

Understanding the adaptive capacity of local communities and how this might change as a consequence of different water storage types is a pre-requisite for choosing appropriate options from the range of possible interventions. Farmers will if given the opportunity often take some initiative in developing storage facilities and/or minimizing the risks (e.g. of enhanced impoverishment) arising from the installation of storage. Initiatives can be enhanced by earlier communication with affected communities, by training and agricultural extension and by better administrative support. For any particularly intervention, there are some knowledge gaps which occur frequently and regularly hinder successful implementation of storage projects (e.g. underestimating the time required to establish a successful and sustainable system, poor communication with households that have to be relocated, poor evaluation of off-farm employment opportunities and markets). Generally better communication to farmers and local authorities is a pre-condition for community support and "buy-in" to initiatives. This requires greater focus from project implementers and additional funding from donors.

Past planning of storage has primarily primarily focused on cost-benefit analysis (CBA). Although straightforward, CBA is focused on financial aspects of a scheme and may lead to reductionism, information loss and sub-optimal, non-sustaianable intereventions. In this project we develeoped an outanking approach that preserved the "knowledge" encompassed in different storage related factors. This still aims at fulfilling the principle of economic efficiency but is based on more diversified criteria, threshold values and weights.The application of such an approach is believed to result in more equitable results and better highlights, within any given context, the advantages and problems of different water storage options, thereby hopefully improving decsion-making.

15. Publications, papers and reports

Many of the publications listed below are available on the project website (http://africastorage-cc.iwmi.org/home.aspx).

Peer reviewed publications

- Boelee, E., Yohannes, M., Poda, J-N., McCartney, M.P. Cecchi, P., Kibret, S., Hagos, F. & Laamrani, H. (in press) Options for water storage and rainwater harvesting to improve health and resilience against climate change in Africa *Regional Environmental Change* DOI 10.1007/s10113-012-0827-4
- Eguavoen, I and zur Heide, F. (in press) Klimawandel und Anpassungsforschung in Äthiopen. *Zeitschrift für Ethnologie*
- Girma, M.M., Schuett, B., Awulachew, S.B & McCartney, M.P. (submitted) Hydrological impact of climate change in the upper Blue Nile basin using regional downscaling. *Physics and Chemistry of the Earth*.
- Lacombe, G., McCartney, M.P. & Forkuor, G. (in press) Drying climate in Ghana over the period 1960-2005: evidence from the resampling-based Mann-Kendall test at local and regional levels. *Hydrological Sciences Journal*.
- McCartney, M.P. (2010) Planning agricultural water storage for climate change in sub-Saharan Africa. *Nature & Faune* (special edition on Climate change implications for agricultural development and natural resources conservation in Africa*)*. FAO publication. 35-40 (http://www.fao.org/docrep/013/am071e/am071e00.pdf)
- McCartney, M.P. & Girma, M.M. (in press) Evaluating the downstream implications of planned water resource development, under current and projected future climate, in the Ethiopian portion of the Blue Nile River. *Water International*.
- Xenarios, S., McCartney, M.P., Polatidis, H. & Asante, F. (submitted) An outranking assessment of water storage for climate change adaptation in sub-Saharan Africa. *Journal of Water and Climate*

In preparation

- Demissie, S.S., McCartney, M.P., & Awulachew, S.B. (in prep). Climate patters and scenarios in the Upper Blue Nile Basin, Ethiopia. *International Journal of Climatology*
- Demissie, S.S., Gebru, B.K., McCartney, M.P. & Awulachew, S.B. (in prep). Evaluating hydrological impacts of climate change using grid-based parameterization of monthly water balance model in the Upper Blue Nile Basin. *Hydrological Processes*
- Forkuor, G., McCartney, M.P., Sood, A., Demissie, S.S. & Hatterman, F. (in prep) The water resource implications of one climate change (A1B) scenario in the Volta River Basin. *IWMI RR*.
- McCartney, M.P., Rebelo, L-M., Xenarios, S., Eugavoen, I. & Smakhtin, V. (in prep) Agricultural water storage in an era of climate change: assessing need, effectiveness and suitability. *IWMI RR*.
- Sood, A., Muthuwatta, L. & McCartney, M.P. (in prep) Using SWAT to evaluate changes in hydrology in the Volta River Basin arising from possible climate change *Water International*

Non-Peer reviewed publications

- Amisigo, B. A. (2010) Report on the field surveys undertaken on the efficiency and performance of water storage in the Volta Basin in Ghana. CSIR- Water Research Institute, Accra, Ghana.
- Akwaka, A.L. & Demisse, S.S. (2010) Assessment of climate change impact on Baro Hydropower projects. Paper presented at the 11th Symposium on Sustainable Water Resources Development, Arba Minch 3-4 December 2010 (http://africastorage-cc.iwmi.org/Data/Sites/25/pdf/ashenafi_and_solomon_hydropower_baro.pdf)
- Asante, F. (2009) Technical, financial and economic performance of water storage systems in the Volta Basin of Ghana. Institute of Statistical, Social and Economic Research, University of Ghana, Accra, Ghana 30 pp.
- Boelee, E. McCartney, M.P., Yohannes, M., Hagos, F., Lautze, J. & Kibret 2010. Climate change, water resource development and malaria in Ethiopia. Paper presented at . Presentation at session

"Water Resources Management" of "Water and Health: Where Science Meets Policy", October 25-26, 2010, The University of North Carolina, USA (http://africastorage-cc.iwmi.org/Data/Sites/25/media/PDF/waterstoragemalariappt.pdf)

- Demissie, S.S., McCartney, M., Awulachew, S.B. & Gebru, B.K. (2010) Climate patterns and hydro-climatic scenarios of the upper Blue Nile Basin. Paper presented at the 11th Symposium on Sustainable Water Resources Development, Arba Minch 3-4 December 2010.
- Demissie, S.S. & McCartney, M.P. (2011) Water storages and multiple-use water services for climate adaptation. Paper presented at 3rd Nile Basin Development Forum, 26-28 October 2011, Kigali, Rwanda
- Eguavoen, I. (2011) Social impact of the Koga dam in Ethiopia. *ZEF News 13*, Bonn 7pp.
- Eguavoen, I. and Tesfai, W. (2011) Rebuilding livelihoods after dam-induced relocation in Koga, Blue Nile basin, Ethiopia. ZEF Working Paper 83. Bonn, Germany. 25pp.
- Eguavoen, I., Derib, S.D., Deneke, T.T., McCartney, M., Otto, A. & Billa, S. (2011) Digging, damming or diverting? Small-scale irrigation in the Blue Nile, Ethiopia. ZEF Working Paper 84. Bonn, Germany. 29pp.
- Eguavoen, I.(2011) Pro-active farmers and supportive municipalities in Ethiopian dam projects. *ZEF Policy Brief 9.* Bonn, Germany
- Eguavoen, I. & Abwoyo, C. (2011) Certificates and contestation. Land tenure security of female farmers in the Blue nile Basin, Ethiopia. Paper presented at the American, Anthropological Association annual meeting, Montreal, Canada.
- Eugavoen, I. & Leidreiter, A. (2010) Diskurse um klimawandel und Anpassungsstrategien am Blauen Nil in Äthiopien. Paper presnted at VAD Tagung, Mainz, Germany.
- Forkuor, G., McCartney, M.P. & Amisigo, B. (2011) Evaluating the implications of future water resources development under current and projected future climate in the Volta Basin. 3rd Ghana Water Forum, 5-7 September 2011, Accra, Ghana.
- Girma, M. M., Schutt, B., Awulachew, S. B., McCartney, M. P., & Demissie, S. S. (2010). Downscaling rainfall in the upper Blue Nile basin for use in hydrological modeling. In *The global dimensions of change in River Basins*. Bonn, Germany 73-82.
- Hattermann, F.F. (2011) Report on generation of regional climate series. Project Report. Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany. 27 pp.
- Johnston, R., McCartney, M.P., Amisigo, B., Asante, F., Behulu, F., Dagalo, S., Fikadu, F., Forkuor, G, Owusu, E.S., Tadele, K. Tadesse, T. & Yazea, W. (2010) Inventory of water storage types in the Blue Nile and Volta River Basins (IWMI Working Paper 140) 48 pp. (http://africastorage-cc.iwmi.org/Data/Sites/25/media/PDF/wp140(web_version).pdf)
- Kreienkamp, F., Spekat, A. & Enke, W. (2010) Adaptation of 50 km Africa runs of CCLM and REMO-Impetus to IDP/ASCII and production of statistical climate scenarios for several SRES-Scenarios and runs of global climate models. Climate and Environment Consulting, Potsdam GmbH, Potsdam, Germany. Project Report.
- Marx, S. (2011) Large scale irrigation in the Blue Nile basin: chances and obstacles in implementing farmer's self-management. A case study of the Koga Irrigation and Watershed Management Project in Amahara Region, Ethiopia. Research Report (ZEF) 52 pp.
- Marx, S. (2010) Chances and Obstacles in Implementing a large-scale irrigation scheme managed by farmers: Koga Irrigation and Watershed Management Project. Field research report. Bonn.
- McCartney, M.P. & Smakhtin, V. (2011) Agricultural water storage in developing countries. Proceedings of the World Water Congress 25-29 September, Recife, Brazil (Pap 004939 CD only). 9 pp.
- McCartney, M.P. (2010) Water storage requires evidence-based approach. Sci dev opinion piece 2 pp.
- McCartney, M.P. & Smatkhin, V. (2010) Water Storage in an era of climate change: addressing the challenge of increasing rainfall variability. Colombo, Sri Lanka: International Water Management Institute. (Blue Paper for World Water Week). 14 pp. (http://africastorage-cc.iwmi.org/Data/Sites/25/media/PDF/blue_paper_2010-final.pdf)
- McCartney, M.P. & Eugavoen, I. (2010) Rethinking water storage for agricultural adaptation to climate change in sub-Saharan Africa. Proceedings of the Tropentag Conference on International

Research on Food Security, Natural Resource Management and Rural Development Zurich, Switzerland 14-16 September 2010 4pp. (http://www.tropentag.de/abstracts/full/663.pdf)

- McCartney, M.P. (2010) Water storage requires evidence-based approach. Sci dev opinion piece 2 pp. http://www.scidev.net/en/opinions/water-storage-requires-evidence-based-approach-1.html?utm_source=link&utm_medium=rss&utm_campaign=en_opinions
- Menker, M., Schuett, B., Awulachew, S.B., McCartney, M.P. & Demissie, S.S. (2010) Downscaling rainfall in the upper Blue Nile basin for use in hydrological modelling. Presented at the GWSP Conference of the Global Catchment Initiative (GCI) on the global dimensions of change in river basins – threats linkages and adaptation (6-8 December 2010, Bonn).
- Tadesse, T., Tadele, K., Behulu, F., Yazea, W., Fetene, F. & Dagalo, S. (2009) Inventory of water storage types and characteristics in the Abbay River basin. Project Report. Arba Minch University, Arba Minch, Ethiopia 88 pp.
- Tadesse, T., Tadele, K., Yazea, W., Dagalo, S.& Fetene, F. (2011) Comprehensive assessment of water stoareg options in the Blue Nile (Abbay) River Basin Project Report. Arba Minch University, Arba Minch, Ethiopia 51 pp.
- Xenarios, S. & McCartney, M.P. (2010) Economic and environmental related aspects of water storage in Sub-Saharan Africa. Paper presented at the 11th Symposium on Sustainable Water Resources Development, Arba Minch 3-4 December 2010 (http://africastorage-cc.iwmi.org/Data/Sites/25/pdf/2a_xenarios_mccartney_cta_23110.pdf)
- Xenarios, S., McCartney, M.P., Polatidis, H and Eguavoen, I (2011) Economic Assessment of water storage for adaptation to climate change. Paper presented at International conference: Management of water in a changing world: lessons learnt and innovative perspectives. Dresden, Germany.
- Xenarios, S., McCartney, M.P. & Adenew, B. (2011) Identifying efficient water storage schemes for climate change adaptation in agriculture: evidence from Indris watershed in Ethiopia. Paper presented at International Conference on Ecosystem Conservation and Sustainable Development, Ambo University, Ethiopia 10-12 February 2011.
- Xenarios, S., Asante, F. & McCartney, M.P. (2011) Economic efficiency of water storage options: an application of the approach to Ghana. 3rd Ghana Water Forum, 5-7 September 2011, Accra, Ghana.
- Xenarios, S., Eguavoen, I. & McCartney, M.P. (2012) A comparative socio-economic analysis of water storage schemes in Sub-Saharan Africa. Paper presented at Bonn Comparative water studies Workshop, 20-21 January 2012.
- Yassin, F.A. & McCartney, M.P. (2010) Evaluating the Technical Performance of the Koga and Gomit Reservoirs in the Blue Nile under Existing Conditions and Possible Climate Change Proceedings of the Tropentag Conference on International Research on Food Security, Natural Resource Management and Rural Development Zurich, Switzerland 14-16 September 2010 4pp. (http://www.tropentag.de/abstracts/full/218.pdf)

Student theses

- Abwoyo, C. (2011) Access to Land and water in Guder Indris Irrigation Scheme: Oromia Region, Ethiopia. MA thesis, University of Cologne, Germany 112 pp.
- Agbeko, E. (2011) Impact of climate change on water storage and quality for reservoir fishery production in the Vea Reservoir. MPhil thesis, University of Ghana 157 pp.
- Baumgärtner, U. (2010) Access to land and water in the Vea Irrigation Scheme in Northern Ghana: an agricultural sociological approach. University of Bonn Research Report 108 pp.
- Bekele, H.M. (2009) Evaluation of climate change impact on the Upper Blue Nile Basin Reservoirs. MSc thesis, Arba Minch University, Ethiopia. 125 pp.
- Billa, S.S. (2011) Gender aspects in the use of land and water resources: the case of Shina Community in Ethiopia. MA thesis, University of Cologne, Germany 75 pp.
- Eichoff, T. (2010) Climate change and water storage: opportunities and limitations for increasing adaptive capacity in the Vea catchment, northern Ghana. MSc thesis Humboldt University 145 pp.
- Gerba, M.A. (2010) Groundwater-surface water interaction and responses to climate change in the Lake Tana Basin, Upper Abay. MSc thesis, Arba Minch University, Ethiopia. 110 pp.

- Michael Menker Girma (2011) Potential impact of climate and landuse change on the water resources of upper Blue Nile basin. PhD thesis. Department of Earth Sciences, Freie University of Berlin.
- Kidane, H. (2010) Analysis of rainfall variability and frequencies and implications for rain fed agriculture development in Abbay Basin, Ethiopia. MSc thesis, Arba Minch University, Ethiopia. 110 pp.
- Marx S. (2011) The political ecology of irrigation management in the Blue Nile Basin: impacts of global environmental policies on local adaptation in the Koga Irrigation Project, Ethiopia. MA thesis, University of Cologne, Germany 101 pp.
- Mohammed, Y. (2009) Climate change impact assessment on soil water avialbility and crop yield in Anjeni watershed, Blue Nile Basin. MSc thesis, Arba Minch University, Ethiopia. 140 pp.
- Muluneh, G.K. (2010) Upstream downstream interactions and impacts of climate change on water storage interventions in the Abbay River Basin, Ethiopia. MSc thesis, Arba Minch University, Ethiopia. 161 pp.
- Otto, B.A. (2011) Access, acquisition and usage of shallow wells and ponds in Kuhar Michael Kebele, Abay River Basin, Ethiopia. MA thesis, University of Cologne, Germany 100pp.
- Remmel. S. (2010) Institutions and control over irrigation water – the case of Birbirsa irrigation scheme, Oramia Regional State. Research Report. University of Bonn 40 pp.
- Tedla, H.Z. (2010) Assessment of potential surface water storage to cope with climate change and variability on selected reservoirs in Abbay River Basin: the case of Tana and Fincha sub-basins. MSc thesis, Arba Minch University, Ethiopia. 146 pp.
- Yassin, F.A. (2009) Investigation and hydrological characterization pf surface water storage options in the Upper Blue Nile: case study of Koga and Gomit dams MSc thesis, Arba Minch University, Ethiopia. 103 pp.