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PERFORMANCE OF SMALL RESERVOIR IRRIGATION SCHEMES IN THE UPPER EAST REGION

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Master of Science Thesis

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PEFORMANCE OF SMALL RESERVOIR IRRIGATION SCHEMES IN THE UPPER EAST REGION

by

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Certification

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Dedication

To Mum and Dad. You always believe that I can do it.

Abstract

The development of small reservoirs has been found to be a key contribution to reducing agricultural and water scarcity problems in semi-arid environments. It is therefore important that the performance of these small reservoir irrigation schemes be evaluated to keep track of whether or not the objectives are being achieved. In order to evaluate the performance of the small reservoir irrigation schemes, land utilisation, physical land productivity, relative water supply, water productivity (i.e. physical, kg/m^3 and the economic, GH¢/m^3), efficiency of water fee collection and financial self-sufficiency were the indicators used. Focus Group Discussions, interviews and physical measurements were conducted at nine (9) schemes selected for the study. The results show full capacity use of irrigable area at eight (8) of the study schemes namely; Baare, Sumburungu, Dorongo, Doba, Telania, Bongo Central, Nyangania and Anateem which was indicated by an land utilisation to be greater than or equal to 100%, except the McClean scheme which had 83.33%. The relative water supply of the Baare, Sumbrungu, Nyangania and Anateem schemes were greater than 1 and in the range 1.1 – 1.5 which is indicative of average water use efficiency; whereas the Dorongo, Doba, Telania, Bongo Central and McClean schemes had good water use efficiency indicated by relative water supply values less than 1. From the results of the study, productivity of land per hectare was seen to be in the range 5.5 – 17.3 tonnes at the seven (7) study schemes except for Nyangania and McClean where land productivities were found to be 1.3 t/ha and 2.9 t/ha, respectively. Water productivity was found to be in the ranges 0.7 – 2.6 kg/m^3 and 0.5 – 2.0 GH¢/m^3 for the physical and economic, respectively, except Nyangania which recorded low water productivity values of 0.2 kg/m^3 and 0.1 GH¢/m^3 for physical and economic, respectively. The efficiency of water fee collection was found to be 100% for all the schemes. Using financial self-sufficiency as indicator, all nine (9) schemes studied were financially sustainable with financial self-sufficiency values of greater than 1. From results obtained, there was full capacity use of irrigable area. Four of the schemes had average land productivity while five had low land productivity. Five of the schemes have high water productivity while three have average when a comparison was made with MOFA ranges. Based on the indicators used for evaluation, all the schemes were found to be performing well except the Nyangania scheme.

Key words: Small reservoirs, performance, performance indicators, productivity, Water Users Association

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List of Abbreviations and Acronyms

CBOs	Community Based Organsations
DMC	Dam-site Management Committee
DOC	Department of Cooperation
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FASDEP	Food and Agricultural Sector Development Policy
FGD	Focus Group Discussion
FSL	Full Supply Level
GCM	General Circulation Model
GIDA	Ghana Irrigation Development Authority
GoG	Government of Ghana
GPS	Global Positioning System
ICOUR	Irrigation Company of Upper East Region
IFAD	International Fund for Agriculture Development
IMT	Irrigation Management Transfer
LACOSREP	Land Conservation and Smallholder Rehabilitation Project
MOFA	Ministry of Food and Agriculture
NGO	Non-Governmental Organisation
PIM	Participatory Irrigation Management
UER	Upper East Region
UNDP	United Nations Development Programme
WRC	Water Resources Commission
WRDC	Water Resources Development Component
WUA	Water Users' Association
WVR	White Volta River
ZOVFA	Zurich Organic Vegetable Farmers Association

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CHAPTER ONE

1 INTRODUCTION

1.1 Background

Development of water resources is crucial to maintain food security in the world (Dorsan *et al*., 2004). In semi-arid environments in Africa, especially, where uni-modal rainfall pattern exists, it is very necessary to develop intensive water resources management strategies to store enough water during rainy seasons to mitigate drought. Against this backdrop, it is glaringly factual that unless measures are put in place to make potable water available for the citizenry of a country and water for other purposes such as irrigation, sanitation, livestock watering etc., it will be really impossible to eschew poverty. It is, thus, imperative to develop reservoirs, especially in rural areas in semi-arid environments, to store water in periods of rainfall for use in the dry season since people who live in such places rely mostly on the water stored in small reservoirs for the sustenance of their livelihoods (Liebe *et al.*, 2005; Poolman, 2005; Balazs, 2006).

The development of small reservoirs has been found to be a key contribution to reducing agricultural and water scarcity problems throughout the world. In the semi-arid regions of Ghana, the government has collaborated with donor agencies such as NGOs, World Bank and Catholic Missions in the construction of many small earth dams to facilitate dry season farming. Most of these small reservoirs serve multiple purposes, such as drinking water supply, fishing and watering of animals, and are very well adapted to the environment (Poolman, 2005).

The Government of Ghana (GoG) being keen on guaranteeing food security, especially in ensuring that the nation produces enough to meet the entire requirement of food crop production has sought funds from donor agencies for the construction of small reservoirs in the Upper East Region (UER), which is one of the poorest regions in the country (Andreini *et al.*, 2005). For instance, the International Fund for Agricultural Development (IFAD) in collaboration with the Water Resources Development Component (WRDC) of the Land Conservation and Smallholder Rehabilitation Project (LACOSREP) phases I & II from 1992 to 2006 has been involved in the rehabilitation and construction of small reservoirs in the region aiming at creating opportunity for an all-year-round cultivation. There are a number of them which were also constructed by NGOs and the Catholic Missions (Abaka-Yankson, 2009) all totalling over 200 (GIDA, 2007).

Agriculture is the main occupation of the region and employs over 80% of the population of the region (Birner *et al.*, 2005). The region experiences a uni-modal rainfall pattern with 6 – 7 months of dry season (EPA, 2003). It is also estimated by Mdemu (2008) that, the annual potential evapotranspiration is about twice the annual precipitation mostly in the dry periods of the year with potential evapotranspiration being less than precipitation only during the wet seasons of the year. This phenomenon results in perennial drought in most parts of the region.

The long dry season often results in the drying up of most natural sources of water in the area, so that years of little rain or prolonged drought in the rainy season have great implications for an all-year-round water availability for domestic use, livestock consumption and dry season gardening, which constitute the major uses of water in rural communities in the Upper East Region of Ghana as was indicated by Gyasi and Schiffer (2005).

From the foregoing it is, thus, significant that more of these reservoirs be constructed in the region so as to store enough water during the period of rainfall (5 – 6 months) which is usually drained by the White Volta River (WVR).

Lately, governments and international donors have shifted the focus of irrigation development policy from area expansion by construction to efficient management of already constructed systems due to the poor performance of irrigation systems and increased financial burdens on governments for operating and maintaining irrigations systems. And hence, to bridge the economic gap between the southern and northern parts of the country, which is an objective of the Ghanaian government, focus has not only been on the construction of new small reservoirs in the region but also on the rehabilitation, maintenance, upgrading of infrastructure and management of existing irrigation systems (Martin, 2005) since the livelihoods derived from small reservoirs contribute enormously to the socio-economic development of rural communities (Twikirize, 2005) and their environment.

The management of irrigation projects and policy formulation used to be solely by the government (top-down) which resulted in under performance of some of the projects and collapse of the others since farmers and other stakeholders did not feel responsible (MOFA/IFAD, 1998). But with the adoption of Irrigation Management Transfer (IMT) and Participatory Irrigation Management (PIM) in the management of irrigation projects, very good results have been experienced (MOFA/IFAD, 1998).

IMT is defined as a process of shifting a number of irrigation management functions from a public agency to a private sector, entity, a non-governmental organisation (NGO), a local government, or to a local-level organisation with farmers at its base whereas PIM usually refers to the level, mode, or intensity of user participation that would increase farmer responsibility and authority in the management process (Svendsen *et al*., 2002).

1.2 Problem statement

Small reservoirs have long been identified as a promising way of developing irrigation and enhancing the productivity of agricultural systems, notably in Northern Ghana (Upper East) and thus, have attracted a lot of attention.

The responsibility of management, operation and maintenance of these small reservoirs for irrigation and the other uses which used to be the Government's have, since the year 1999, been transferred to the Water Users Association. However, despite a largely shared agreement on the potential of such intervention, since construction of the small reservoirs for dry season irrigation in the region, there has not been any evaluation of the performance of the schemes to actually know whether targets are being met or not.

1.3 Justification

The purpose of the small reservoir irrigation schemes which is to salvage poor regions and promote good standards of living among settlers (Birner *et al.*, 2005), is very crucial to meet. It is therefore important that the performance of these irrigation schemes be evaluated to keep track of whether or not the objectives are being achieved. This will, thus, enable effective planning so that in case of any discovery of under-performance at some sites, improvement strategies could be quickly put in place.

1.4 Objective of the study

The main objective of the project is to evaluate the performance of small reservoir irrigation schemes in the Upper East Region.

The specific objectives are;

- to determine the productivity of land
- to determine the productivity of water
- to determine the economic performance of the Water Users Association

1.5 Organisation of report

The report has six (6) chapters. The first chapter introduces the topic and brings into light a background to the study, problem statement, justification of the project and the objectives of the study. Chapter 2 reviews literature on performance evaluation of small reservoirs. Chapter 3 describes the study area whereas the forth chapter discusses the methods employed in the study. The fifth chapter gives the results and discussions. The last chapter concludes on the study and makes recommendations.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Performance of small reservoirs worldwide

The need for effective management and development of water resources for sustainable use by all water users has been the focus of many researchers, hydrologists, irrigation engineers, water managers etc. in recent times since water is vital for human survival, health and dignity, and a fundamental resource for human development. With global rise in temperature, local rainfall patterns are changing giving rise to droughts and floods in certain parts of the earth (UNDP, 2007). Many international agencies, donors and NGOs have, thus, been challenged in this regard and have been involved in funding projects such as the development of small reservoirs for irrigation and other beneficial uses in semi-arid areas in most developing countries in Sub-Saharan Africa (Ghana, Burkina Faso, Ethiopia, Tanzania, Zambia) and India (West Bengal, Madhya Pradesh). For instance, to improve the natural conditions in the UER and thereby ensuring all year round farming, the Ghanaian government with support from foreign donors, developed irrigation schemes from the mid 1960s to the 1970s (Gyasi, 2005).

Notwithstanding the benefits reaped from these projects, most of them are underperforming lately due to erratic rainfall patterns, high evaporation rates, poor management, lack of funds for maintenance and disregard of stakeholder participation during the planning stage (Sawunyama, 2005). According to Hatcho and Tsutsui (1998), it is indicated that, with the rising needs of food production by population growth, particularly since World War II, there have been the development of irrigation schemes by governments and international donors. But because much attention has not been paid to the issues of system management or the social and institutional background of the targeted system, it resulted in their under-performance (Hatcho and Tsutsui, 1998).

Ferguson (1989) argues that because the human elements of irrigation have received less attention in the past, the social and institutional aspects of water management are still poorly understood. Thus, instead of engineers and agronomists jostling for supremacy on projects (Kyei-Baffour, 1994) and some professionals seeing themselves as indispensable in irrigation development and management (Wiafe and Nyaledzigbor, 1994), functions must be unambiguously defined to complement one another.

In the Upper East Region, for instance, there have been numerous complaints by the users of these reservoirs that they are not being well maintained resulting in the occasional collapse of some (Abaka-Yankson, 2009).

Also from an annual report of the Small Reservoir Project (2005), it is indicated that, although small reservoirs tend to function better than the larger irrigation schemes found in Ghana, they often malfunction due to lack of simple maintenance such as repair of broken down valves, main and lateral canals, dam wall protection etc., which in turn lead to spillway erosion, dam wall failures, canal and lateral deterioration, and reservoir siltation.

2.2 Performance of irrigation schemes

Performance in the context of this study is defined as how well or badly small reservoir irrigation schemes operate and are managed. In order to assess or actually evaluate the performance of irrigation schemes, there is the need for performance indicators. Evaluation is very essential for effective planning and management (Dorsan *et al.*, 2004). In the study "Performance evaluation of transferred irrigation schemes of Lower Gediz Basin", Dorsan *et al.*, (2004) evaluated some physical, economic and institutional performance criteria for pre and post-transfer periods. For the physical performance criteria, irrigation rate and sustainability of the irrigable area were considered to know whether the irrigable area has been sustainable in the post-transfer periods. Efficiency of water fee collection and financial self-sufficiency under the economic performance criteria were also evaluated. Here, a study was carried out to find out whether the Water Users Association (WUA) was able to carry out successfully the management, operation and maintenance responsibilities with its income generated from water levy collection. That is, financial self-sufficiency value greater than 1 indicated financial sustainability. And among many irrigation schemes under analysis, the higher the financial self-sufficiency, the more the irrigation scheme is financially sustainable. And finally, for the institutional performance criteria, irrigation staff intensity which is a ratio of irrigable area (ha) and irrigation management staff or a ratio of irrigation canal (km) and irrigation management staff was evaluated. For this criterion, intensities of 333 ha per staff (Bekisoglu, 1994) or 13 km per staff (Frazoa and Perreira, 1993) were accepted as ideal figures for the irrigation schemes. According to the evaluation Dorsan *et al.*,

(2004) undertook, the most concrete and positive change occurred in the collection of irrigation fee.

In a related development, Behailu *et al*., (1996) in the study "Performance evaluation of community based irrigation management in the Tekeze basin" with a case study on three small-scale irrigation schemes, adopted the IWMI's performance indicators for evaluation since there were no comprehensive performance evaluation criteria, per se, for the basin. Below are the features of the IWMI's performance indicators;

(a) The indicators are based on relative comparison of absolute values, rather than being referenced to standards or target.
(b) Data collection procedures are not too complicated or expensive.
(c) The indicators relate the phenomena that are common to irrigation and irrigated agricultural systems.
(d) These set of indicators are designed to show gross relationship and trends and should be useful in indicating where more detailed study should take place, for example where a project has done extremely well, or where dramatic changes take place.

The following are the indicators used for evaluation;

Output per cropped area (US$/ha) = $\frac{Revenue}{Irrigated\ crop\ area}$

This indicator shows the productivity of land. That is, the revenue obtained from crop yield was divided by the area of land cultivated.

Output per unit irrigation supply (US$/m^3) = $\frac{Revenue}{Diverted\ irrigation\ supply}$

This is used to describe the return on volume of irrigation water supplied including losses.

Output per unit water consumed (US$/m^3) = $\frac{Revenue}{Volume\ of\ water\ consumed\ by\ ET}$

This shows the revenue per meter cube of irrigation water that is actually consumed by crops to satisfy the evapotranspiration requirement during the entire growth period.

Relative water supply (RWS) = $\frac{Total\ water\ supply}{Crop\ demand}$

This depicts whether there is enough irrigation water supply or not. RWS values equal to 1 indicate that sufficient water was supplied for irrigation, values less than 1 and greater than 1 indicate insufficient and excessive water supplies, respectively (Beyribey, 1997 as cited by Çakmak *et al.*, 2009).

Water delivery capacity = $\frac{Canal\ capacity\ at\ the\ system\ head}{Peak\ consumptive\ demand}$

The water delivery capacity of the irrigation scheme shows the capacity of the main canal to convey the maximum peak consumptive demand i.e. the ratio of canal capacity at system head to maximum consumptive demand.

Gross return on investment (%) = $\frac{Revenue}{Cost\ of\ infrastructure}$

This indicator considers the production and the total cost of infrastructure for each scheme.

$$\text{Financial self-sufficiency (\%)} = \frac{\text{Revenue from irrigation}}{\text{Total O \& M expenditure}}$$

This depicts the financial sustainability of the schemes.

2.3 Management of small irrigation schemes

Efficient and sustainable use of the water resource is requested of the agricultural sector, and management issues have become paramount to achieving the goal. In view of this, different approaches such as Irrigation Management Transfer (IMT) and Participatory Irrigation Management (PIM) have been adopted and practiced in many countries, all over the world, including Mexico, Turkey, the Philippines, Japan, Pakistan, USA, Morocco, France and India to improve the management of irrigation systems since the decades of expansion and construction of irrigation systems in the 1960s and 1970s (Hatcho and Tsutsui, 1998). Also in the Upper East Region of Ghana, these approaches were adopted under the LACOSREP I with formation of Water Users Association at forty-four (44) dam-sites (MOFA/IFAD, 1998).

Hatcho and Tsutsui (1998) again spelt out the objective of IMT and PIM as being "to shift the level of user management to the higher side by enhancing user participation and promoting management transfer wherever the management capacity of users has been established." And thus, depending on the condition of each country, full transfer or partial transfer can be possible.

Small reservoirs which have been constructed for the purpose of storing water in rainy seasons and using it during dry periods have variable uses such as irrigation, potable water, livestock watering, aquaculture, bathing, and laundry and therefore proper management to ensure sustainability is crucial (Poolman, 2005 and Mdemu, 2008). Governments are giving increased responsibility to Community Based Organizations (CBOs) to manage irrigation schemes. In general, devolution in irrigation management aims at promoting active involvement of local people and it often involves the formation of organisations of formal user groups known as Water Users Associations (Gyasi, 2002).

In Ghana (particularly the Northern regions), management, operation and maintenance of irrigation projects were the responsibility of the government through its line agencies without much involvement of the beneficiary communities (MOFA/IFAD, 1998). The Ghana Irrigation Development Authority (GIDA) under the auspices of MOFA, through Technical Officers and Technical Assistants were responsible for the management and operations of small irrigation schemes. They controlled and regulated the delivery of irrigation water to farmers, partitioning and allocation of land and even, dictated the type of crop to be planted. GIDA did the planning and execution of maintenance activities at these schemes, therefore employing paid labour to do field work (MOFA/IFAD, 1998).

This management structure (top-down approach) was observed to be ineffective and unsustainable hence was modified to the decentralised structure where the schemes were managed by the beneficiaries. It resulted in a deterioration of the dam embankment, canals and laterals since Technical Officers occasionally shirked responsibilities such as ensuring routine maintenance of the dam infrastructure and catchment area protection. There was also a problem of untimely delivery of funds for operation and maintenance being the sole responsibility of the Government of Ghana (GoG) because farmers paid no levies which could have been used to support operation and maintenance (MOFA/IFAD, 1998).

Currently, in Ghana (UER), small reservoir projects are managed by the users of the facilities namely, Water Users Association (WUA) ensuing government's policy of decentralization, diversification and privatization of the economy (Gyasi, 2005). For effective management and utilization of the facilities, under LACOSREP I and II, management and ownership of the rehabilitated dams were transferred to the beneficiaries and that the formation or prior existence of a functional WUA was in fact a prerequisite for a given community to have its dam rehabilitated (MOFA/IFAD, 1998).

The advent of the WUA which is an eclectic organisation of user groups made up of gardeners, fishermen and livestock owners who have stakes in the dam infrastructure and services has yielded good results in terms of management, operation and maintenance (Abaka-Yankson, 2009). The association collects a fixed sum (levy) from every participating farmer and uses it for repairs and maintenance of irrigation canals, dam walls, valves and spillways. Decisions on water distribution arrangements as well as the amount to levy for irrigation water for a particular season are jointly taken at a general meeting of the WUA (MOFA/IFAD, 1998).

In the management of the small reservoirs, when there is the need for assistance, the Ghana Irrigation Development Authority (GIDA) provides technical personnel to support the WUAs (Mdemu, 2008). Elected representatives of the user groups constitute the Dam-site Management Committee (DMC), which is responsible for the management of the system (MOFA/IFAD, 1998).

With the management functions of the WUAs, Abaka-Yankson (2009) outlined them as follows;

(1) Maintenance of the irrigation system (control structures, canals, laterals).

(2) Maintenance of dam infrastructure (dam wall, spill way, and reservoir).

(3) Grassing of dam embankment and bunds against erosion.

(4) Protection of the catchment area (grassing, tree planting) to control erosion.

(5) Protect crops from grazing animals.

They are also responsible for land allocation and water distribution, collection of water levies and funds mobilization, record keeping, formulation and enforcement of bye-laws and conflict resolution.

2.4 Impact of management on performance

The management of small irrigation schemes which was the sole responsibility of the Government of Ghana (GoG) through MOFA and GIDA had several bottlenecks, some of which are lack of funds for periodic maintenance of the system, lack of proper management strategies to suit the environment and non-involvement of stakeholders in decision-making. But with the adoption of decentralisation and subsidiarity where responsibilities are entrusted to the beneficiaries (WUAs), considerable positive impacts in aspects of financial mobilisation, periodic maintenance of the system and catchment area protection, irrigable area control and plot allocation, and conflict management and resolution have been measured (Abaka-Yankson, 2009) including other benefits such as growth of participatory culture, formulation and enforcement of bye-laws by the WUAs.

2.5 Determination of surface area of small reservoirs through remote sensing

Remote sensing is a powerful technique for the collection of multi-temporal data sets used to track the hydrological impact of regional reservoir storage volumes and the effects of their further development (Sawunyama, 2005).

In order to manage the water effectively for competing uses, the water level or storage capacity of these reservoirs need to be correctly estimated. Recent attempts to delineate these reservoirs using remote sensing with Landsat imagery have been quite successful especially in the Upper East region (Sawunyama, 2005). This was done to determine the number; spatial distribution and storage volumes of reservoirs for effective water management and reservoir planning.

A study by Liebe (2002) on the use of remote sensing data to estimate reservoir storage capacities for small reservoirs indicates that there exist relationships between areas, depth and volume for the small reservoirs. In the study a relationship ($C = 0.00857 * Area^{1.4367}$) was established to estimate small reservoir capacities using remotely sensed surface areas and storage volumes in semi-arid environments. The constants may differ from place to place due to changes in study area and climatic conditions. In order to determine the maximum dimensions of reservoirs by means of remotely sensed data, which are represented by their largest surface area extent, the time of acquisition has to be as close as possible to the end of the rainy season, when reservoirs are filled to their full supply capacity and losses (draft, seepage, evaporation) are still negligible (Liebe, 2002).

2.6 Stakeholders' involvement in the project

Stakeholder participation has been discovered as the surest way to ensure sustainability of projects in beneficiary communities and thus in UER there has been an appreciable involvement of stakeholders in the small reservoir development project.

To expand and improve the efficiency of irrigation in order to support agricultural development and growth, principles of sustainability in operation and maintenance, use of natural resources, equitable access by women to benefits of irrigation, and the rights to participate in irrigation management must be pursued holistically (MOFA, 2007).

According to Abaka-Yankson (2009) the following are the stakeholders involved; primary users (WUA), government institutions (MOFA, GIDA, and WRC), development agencies (IFAD, World Bank), NGOs (such as Action Aid, the Red Cross Organisation, and Catholic Missions), the local chiefs and other important personalities. Below is a compendium of the various stakeholders and their respective roles;

Table 2.1: Role of stakeholders in management and provision of small reservoirs

Stakeholder	Role(s)
Water Resources Commission (WRC)	Ensures sustainability of water resources and offer assistance to collaborating agencies to modify their policies towards WRM.
MOFA/UER	Extension education on irrigation management and water conservation
IFAD (LACOSREP I and II)	Rehabilitation and construction of dams and dugout for dry season gardening and livestock watering.
GIDA	Design and supervise the construction of irrigation infrastructure (dams, canals, etc).
Department of Cooperatives and Community Development	Organizing WUAs into cooperative societies; training in group dynamics, financial management
Catholic Secretariat / Missions	Fund construction of community dams.
WUAs	Management and maintenance of the reservoirs

(Source: Abbaka-Yankson, 2009)

2.7 Effects of small reservoir development on the environment

Notwithstanding the socio-economic multiple uses of small dams, there are several positive and concomitant negative effects on the environment.

One such positive use that has gone unnoticed is the ability of small reservoirs to act as silt traps for large reservoirs downstream like the Akosombo dam in the Volta basin (IFAD, 1999). This function has been compromised, though, as more catchments are opened up to agricultural activities (Senzanje and Chimbari, 2002). This is because agricultural run-off may carry sediment, salts, nutrients, organic loads, pesticides and pathogens to the receiving reservoir. In effect the multiple uses of small dams is threatened by this change in water quality.

Recharging of aquifers is another use and in view of that small reservoirs in some countries (e.g., India) are referred to as 'percolation tanks', i.e. they lose water through seepage which will then find its way to ground water reservoirs (Keller *et al.*, undated). This function of small reservoirs is seen to be very beneficial in the Upper East Region since most villages and small towns in the region rely solely on groundwater for drinking purposes (Annor, 2007).

Small reservoirs can also provide control against floods as the floodwater escaping downstream is delayed (in temporal storage) so as to be compatible with the flood carrying capacity of the river channel downstream (Nelson, 1985 and Poolman, 2005).

In spite of the above mentioned positive impacts, some negative impacts of small reservoirs include being a source of water borne diseases such as malaria, bilharzia (schistosomiasis), cholera, dysentery and diarrhoea (Chavula, 2000). That is, since water in small reservoirs do not relatively flow, pathogens find that environment conducive for growth and development hence causing diseases.

2.8 Land tenure rights and irrigation

FAO (2002) defines land tenure rights as the relationship, whether legally or customarily defined between people (as individuals or groups) with respect to land. Its institution is the principal mechanism for the allocation of land resource. The substance of such rights and the manner in which they are allocated have major implications for the use and management of the land resource as well as for the social and economic development of many communities, in which both social status and power depend on the size and structure of land holdings (Vogelsang, 1998), and the townspeople, with particular impacts on the livelihoods of the poor.

According to Gyasi (2005), it is indicated that customary land tenure system is practiced in the UER. Land is entrusted to the '*tendana*' (tendamba-plural), literally meaning the owner of the land who is the custodian and responsible to grant usufruct customary rights to community members for free. The '*tendana*' is normally the patrilineal descendant of the first family to settle in the area. Since succession is patrilineal, land is inherited by a man's sons, with the eldest son inheriting a larger share.

A similar land tenure system is applied for irrigated lands but in this case two types of arrangements for land ownership exist: (1) a secure tenure wherein users of irrigation facilities have total control over the command area, and (2) seasonal tenureship, common in most small reservoir schemes managed by WUA, whereby land is returned to the original landowning families in the rainy season (Gyasi, 2005).

2.9 Impacts of climate change on irrigation water use UER

Climate change is defined as changes in the long-term averages of precipitation and temperature (Döll, 2002) which could occur due to natural variability (such as changes in emission of solar radiation, volcanism, and greenhouse emissions) or anthropogenic conditions (excessive burning, release of smoke by industries into the atmosphere). It involves the interactions of many systems such as the atmosphere, hydrosphere, biosphere, as well as the human system (Asante, 2009).

In an anticipation to track the impacts of climate change on irrigation water use, Döll and Siebert (2001) worked on global modelling of irrigation requirements in which they developed a global irrigation model by integrating simplified agro-ecological and hydrological approaches. Again, Döll (2002) investigated global impacts of climate change and variability on agricultural water irrigation demand by comparing the impacts of current and future climate on irrigated cropland using the framework developed in 2001. Results by Döll (2002) show that changes in precipitation, coupled with increases in evaporative demands, increase the need for irrigation worldwide, with small relative changes in total, about +5 to 8% by 2070 – depending on the general circulation model (GCM) projection – and larger impacts, about +15%, in Southeast Asia and the Indian subcontinent.

2.10 Productivity of stored water in small reservoirs in UER

The many small reservoirs in the Upper East Region which were, primarily, constructed for the purpose of irrigation have got several other uses such as livestock watering, domestic use (cooking, drinking, and sanitation), recreation, fish production, block-making, and building (Rusere, 2005).

By virtue of the multi-usage of small reservoirs, together with their role in sustaining the socio-economic well-being of the beneficiaries, it is very significant to determine the water productivity for each varied use, Yamoah-Antwi (2009) argued. This will enable the suggestion of appropriate water productivity improvement strategies to ensure that stored water is allocated and used efficiently to yield good impacts on the socio-economic well-being of the beneficiaries especially during the dry periods of the year (Yamoah-Antwi, 2009).

Against this backdrop, Yamoah-Antwi (2009), studied the productivity of nine (9) small reservoirs in the Upper East Region, where livestock were discovered to have the highest productivity among the various uses of the stored water in the small reservoirs.

To enhance productivity in all the various uses, he spelt out four (4) strategies in his report which are; Provision of standard for furrow formation by MOFA, Water conservation mechanisms (e.g. mulching), Training of WUA executives and farmers, Prevention of stored water from pollution.

Productivity of water being an indicator of performance (Faulkner, 2006) must, thus, be correctly calculated to enhance the evaluation of performance of small reservoir irrigation schemes. In this research work, physical water productivity (kg/m^3) and economic water productivity (GH¢/m^3) are calculated, including other performance indicators to enable the evaluation of the performance of some selected small reservoir irrigation schemes.

CHAPTER THREE

3 STUDY AREA

3.1 Location and population

The Upper East Region of Ghana is the north-easternmost part of Ghana. It is located between latitudes 10° 15' and 11° 10' north and longitudes 0° and 1° west. Its gross area is 8842km^2 (IFAD, 1991). The UER shares boundaries, internationally, with Burkina Faso on the north and Togo on the east and regionally with the Upper West and Northern Regions at the west and south, respectively. There are nine administrative districts: Bolga, Bongo, Builsa, Kassena-Nankana East, Kassena-Nankana West, Talensi Nandam, Bawku west, Bawku East and Garu Tempani shown in Figure 3.1. It should be noted that, the map shown in Figure 3.1 was the map of the region before the Kassena-Nankana district was divided into east and west. According to the population and housing census of 2000 (GSS, 2005) the region has a population of 920,089, made up of 442,492 males and 477,597 females. The Upper East Region has a comparatively high population density of 104.1 persons per square km compared to the national average of 79.3 persons per square km which can be attributed to the comparatively favourable soil conditions in parts of the region. The population of the Upper East Region is ethnically diverse, comprising different ethnic groups that speak different languages (Birner *et al.*, 2005).

3.2 Climate

The region falls within the Inter-tropical Convergence Zone whose climatic boundary oscillates annually between the south coast of Ghana and 20° north. As the boundary moves north and south it draws with it the associated weather zones. The effect of this on the region provides a uni-modal rainfall regime lasting from 5–6months which is characterized by low and erratic rainfall and a dry period of 6–7 months. Considerable variations exist between successive rainy seasons with respect to time of onset, duration and amount of rainfall received (Walker, 1962). With an average of 28.6°C, temperatures are consistently high. Monthly averages range from 26.4°C at the peak of the rainy season in August to a maximum of 32.1°C in April (Liebe, 2002). Average annual relative humidity is 55%. Relative humidity is highest during the rainy season with values of 65% and may drop to a minimum of less than 10% during the Harmattan period in December and January. With this high variability in temperature and relative humidity, evapotranspiration as expected is high and that may affect drying of reservoirs.

3.3 Relief and drainage

The relief of the area is generally flat to gently undulating with slopes ranging from 1–5% except in a few uplands where slopes may be 10% (Adwubi, 2008). These plains are broken in some places by hills or ranges formed from either outcrops of Birimian rocks or granite intrusions. The granite areas are generally low to gently rolling (122 – 255m above sea level) except the inselberg outcrops near Bongo which rises to about 326m (Adu, 1969). The White Volta is its largest river, which finally assimilates the runoff from all rivers that drain the Upper East Region. Its major tributaries are the Red Volta, the Sisili and the Tono River, all flowing into Ghana from Burkina Faso.

Figure 3.1: Map of the Upper East Region showing the various districts

3.4 Vegetation

The vegetation is Sudan savanna consisting of short drought and fire resistant deciduous trees interspersed with open savanna grassland. Grass is very sparse and in most areas the land is bare and severely eroded. Needham (1993) who investigated the natural resources and livelihood systems in the region stated that it is no more possible to find examples of natural vegetation due to the over-exploitation of the natural resource base for several hundred years. The natural vegetation has been much modified by human activities, particularly agriculture which is almost entirely in the hands of smallholder cultivators, who combine bush farm cultivation of distant fields with permanent cultivation of nearby compound farms. Overgrazing is evident in some areas particularly near ponds and dams, since the region has the highest density of cattle (IFAD, 1991). Common grasses include *Andropogon gayanus* in the less eroded areas and *Hyperrhenia* *spp., Aristida spp.* and *Heteropogon spp.* in the severely eroded areas. Common trees include *Anogeissus spp., Acacia spp.* and *Triplochiton spp.*

3.5 Soils

Soils in the area are generally formed by weathering of the bedrock although some drift of soil transported by wind and water is also found. They belong to Luvisols, Cambisols, Gleysols, Regosols, Vertisols, Plinthosols and Fluvisols developed from granites, Birimian rocks and alluvia of mixed origin. The soils have predominantly light textured surface horizons with heavy textured soils confined to valley bottoms. There are extensive areas of shallow concretionary and rocky soils which have low water holding capacities and limited suitability for agriculture (Quansah, 2005).

3.6 Geology

A large part of the area (82%) is underlain by metamorphic and igneous complexes with gneiss and granodiorite predominating; where hills rise above the soil surface they consist of greenstone and schist. In the south-eastern boundary of the region a substantial band of sandstone, grit and conglomerate parallels the boundary and the course of the White Volta. There are small areas of intrusive diorite in the north-west of the region. Laterite has been formed by fluvial processes in the flat lands adjacent to present and past water courses and occurs over large areas. Sand occurs as local deposits and along most of the major river courses.

3.7 Indigenous animals

Livestock production is an integral part of the agricultural production system in the UER. Common livestock include cattle, goats, sheep, donkeys and horses; and domestic birds such as *Gallus domesticus*, and ducks. Other animals like crocodiles are dominant in the region and are mainly used for tourism (e.g. Paga Crocodile Sanctuary).

CHAPTER FOUR

4 METHODOLOGY

The methods used in carrying out the various tasks for the achievement of the objective of the study are spelt out in this chapter.

4.1 Desk study/ Literature Review

A desk study was done during which review of literature including journals, articles, thesis and reports on small reservoirs worldwide as well as work done on small reservoirs in the UER of Ghana was carriedout. Documents on small reservoirs in the region were also collected from MOFA and GIDA and reviewed accordingly.

With the selection of the small reservoir irrigation schemes to be evaluated, the following selection criteria were adopted; Site must be accessible, Availability of water in the reservoir, Availability of compiled agronomic and infrastructural data, Height of dam wall must be less than 15 m (as defined by the World Bank in Table 4.1 below) and the Existence of an effective Water User Association (WUA) (Behailu *et al.*, 1996).

Table 4.1: Definitions of small reservoirs

Organization / Country	Height (m)	Capacity (m^3)
World Bank	< 15	N/A
World commission on Reservoirs	< 15	50000 – 1 x10^6
United State of America (USA)	≤ 6	0.123 x 10^6

(Source: Senzanje and Chimbari, 2002)

Based on the above selection criteria nine irrigation schemes were selected for this research work.

4.2 Field work

The following are the various activities undertaken during the field work;

4.2.1 Reconnaissance visit

The field work commenced with a reconnaissance visit to the sites so that the physical conditions of the facilities would be known and then potential sites identified. During the visit, the offices of WRC, MOFA and GIDA were visited for briefing on the small reservoir irrigation schemes in the region and also to inquire whether there were data available on the irrigation schemes to be evaluated. Included in the activities during the visit were taking of relevant pictures and also a physical inspection of the facilities.

4.2.2 Data collection

Various data on the small irrigation schemes were collected by conducting Focus Group Discussions, key informant interviews, physical measurements and also from reports and relevant documents collected from the offices of WRC, MOFA and GIDA.

4.2.3 Focus Group Discussions (FGDs) and interviews

Focus Group Discussions were organised for dry season farmers at all the sites to get first hand information on the types of crops cultivated, crop yield, water levy, size of plot and their infrastructural maintenance culture. This information was used to validate the data collected from the WUA executives. There were six (6) interviews organised with key informants about activities of the WUA and the performance of the irrigation infrastructure. Below are pictures showing one of the FGDs organised and an interview with a Key Informant in the Ghana Irrigation Development Authority (GIDA);

Plate 4.1: A session of a FGD at Dorongo and a key informant interview at Bolga

4.2.4 Physical Measurements

Physical measurements were carried out on the field because of the anticipated difficulty in capturing some data types through questionnaires, interviews and FGDs as well as to ascertain some of the data collected.

4.2.4.1 Measurement of surface areas of the reservoirs

The Full Supply Level (FSL) surface area was determined for each of the study reservoirs, which was necessary to enable the computation of the current storage capacity of the reservoirs. To do this, four (4) GPS coordinates were taken on the dam wall of the small reservoir with a hand held Garmin GPS 76 instrument and six (6) coordinates round the tail end. The number of coordinates round the small reservoir was enough to represent its periphery so that a good approximate surface area can be determined. During navigation round the reservoir, one direction (i.e. clockwise or anti-clockwise) was kept. And again, a clear sky was ensured to prevail to enable the Garmin GPS 76 acquire a good number of satellites (>3), not forgetting other precautions. The data stored on the GPS was imported into GPS Trackmaker 13. This was used to convert the GPS data into text formats so it could be read by ArcCatolog. The coordinates were then plotted with ArcGIS and connected together to form polygons. The surface areas were then calculated. Below are pictures of the GPS navigation round two of the study reservoirs;

Plate 4.2: GPS 76 navigation at dam wall and tail end of a small reservoir at Baare

4.2.4.2 The measurement of flow velocity and canal dimensions

The float method of measurement of flow velocity in open channels was adopted in this study since there was no hydraulic flow metering structures constructed in the canals.

Expanded polystyrene (a packaging material), which is usually the float used in such measurements, was used. The weight of the expanded polystyrene is negligible and, thus, had no effect on the measured surface velocity. Flow velocities of water delivered at the intake in the main canals and that delivered to the field in the lateral canals were measured. The canals were found to be trapezoidal and the dimensions were measured. Other measured parameters include the length of travel of float (*l*) and the time of travel of float (*t*). To enable the conversion of surface velocity of flow to mean velocity, a factor of 0.8 (JICA, 2004) was used. That is, mean flow velocity is given by;

Mean flow velocity, v (m/s) = $0.8 * \frac{l\ (m)}{t\ (s)}$

The canal dimensions measured were used for calculating the cross-sectional area of flow. That is, cross-sectional area of flow is given by;

$A = (\frac{a+b}{2}) * h$

Where,

A = cross-sectional area of flow (m^2)

a = width of water surface for depth h (m), b = bottom width (m) and h = depth of water in canal (m).

Finally, discharge (Q) was calculated using the continuity equation. That is,

Discharge, Q (m^3/s) = v (m/s) * A (m^2)

Below are some pictures indicating the use of the float method to measure the flow velocity of water in the canals.

Plate 4.3: Measurement of canal dimensions and flow velocity

4.3 Calculating Crop Water Requirement

CROPWAT model by Food and Agriculture Organization (FAO) was used to estimate the crop water requirements (CWR), which is defined as the depth of water to meet evapotranspiration of a disease free crop growing in large fields without restricting conditions on soil profile, soil moisture and fertility thus achieving full production protential. The CROPWAT model uses the equation below to compute CWR.

$$CWR = k_c \times ET_o$$

Where,

CWR = Crop water requirement [mm/day]

k_c = Crop coefficient [dimensionless]

ET_o = potential evapotranspiration [mm/day]

Crop coefficient, kc is a function of the crop type and the day of the growing season.

Potential evapotranspiration, ET_o is calculated using FAO Penman-Monteith equation (Allen et al., 1998) below with parameters of temperature, relative humidity, sunshine hours, and wind speed.

$$ET_o = \frac{\Delta \frac{(R_n - G)}{\lambda_w} + \rho_a C_p \frac{(e_s - e_a)}{\lambda_w}}{\Delta + \gamma_a \left(1 + \frac{r_c}{r_a}\right)}$$

Where,

ET_o = potential evapotransipiration [$mmday^{-1}$]

R_n = the net radiation [$MJm^{-2}day^{-1}$]

G = soil heat flux [$MJm^{-2}d^{-1}$]

(e_s-e_a) = the vapour pressure deficit of the air [kPa]

ρ_a = the mean air density at constant pressure [kgm^{-3}]

c_p = the specific heat of the air [$MJkg^{-1}\,°C^{-1}$]

Δ = the slope of the saturation vapour pressure-temperature relationship [$kPa°C^{-1}$]

λ_w = the latent heat of vaporization [$MJkg^{-1}$]

γ_a = psychrometric constant [$kPa°C^{-1}$]

r_c = crop resistance [sm^{-1}]

r_a = aerodynamic resistance [sm^{-1}].

The CROPWAT model requires the following input data to compute CWR.

- Climatic data – mean monthly maximum and minimum temperatures (°C), monthly rainfall (mm), relative humidity (%), sunshine duration (hours) and wind speed (m/s)

- Crop data – the crop type and planting dates

Relevant offices such as GIDA, MOFA, WRC were contacted for the collection of secondary data such as climatic data, types of crops cultivated, crop yield, initial surface area of the small reservoirs, actual irrigable area, design irrigable area, number of members of the WUA, irrigation fee (WUA levy) per member, irrigation fee collected in a farming season, WUA's income, cost of repairing broken structures (i.e. canals, dam walls, valves etc.) and the MOFA standard for land productivity.

4.4 Performance indicators

For the evaluation of the performance of the small reservoir irrigation schemes, the following performance indicators were used;

4.4.1 Land productivity criteria

4.4.1.1 Land utilisation

The Designed irrigable areas and Actual irrigable areas obtained from the GIDA were verified with field measurements at all the schemes studied and were used for the computation of the land utilisation. According to Bekisoglu (1994), land utilisation is, therefore, given by

$$\text{Land utilisation (\%)} = \frac{\text{Actual Irrrigated Area}}{\text{Designed Irrigable Area}} * 100\ \%$$

4.4.1.2 Physical Land productivity

Interviews and FGDs were conducted with irrigators at all the dam-sites to obtain data for the computation of the land productivity. The data collected included the main type of crops grown, the principal crop cultivated, the length of the growing season, crop yield per hectare per season and the cultivated area. It was discovered from the interviews conducted that bowls were used to harvest the crops and are finally packaged in crates. That is, four (4) bowls of tomatoes fill one crate.

Thus to enable determination of the total mass of yield, a conversion rate was obtained from the MOFA. That is 1 crate of tomatoes is equivalent to 52 kg. The total number of crates was multiplied by 52 kg to get the total mass (kg) of yield and finally converted into tonnes (t).

Physical land productivity was calculated using the equation below;

$$\text{Physical land productivity (t/ha)} = \frac{\text{Crop yield (t)}}{\text{Total area cultivated (ha)}}$$ (Behailu *et al.*, 1996)

4.4.2 Water productivity criteria

Under this, Relative water supply, physical water productivity (kg/m^3) and economic water productivity (GH¢/m^3) were calculated.

4.4.2.1 Relative water supply

Relative water supply is given by the equation below.

$$\text{Relative water supply} = \frac{\text{Total water supply}}{\text{Crop water requirement}}$$ (Behailu *et al.*, 1996)

The discharge calculated (as explained above) was used to determine the total volume of water supplied from the reservoir. That is;

$V (m^3) = Q (m^3/s) * T(s)$

Where,

V = Total volume of water supplied, Q = discharge, and T = duration of dry season irrigation, given by

$T = t * D$

Where, average length of time for irrigation in a day, t = 8 hours

Irrigation days, D = 70 days

The determination of the irrigation days was done by counting the total number of days on which irrigation occurred for the entire growth period of the crop under study. The irrigation interval was taken into consideration in this determination.

4.4.2.2 Physical water productivity

The physical water productivity was calculated using the equation below;

$$\text{Physical water productivity } (kg/m^3) = \frac{\text{Crop yield}}{\text{Total water supplied}}$$ (Lemoalle, 2006)

4.4.2.3 Economic water productivity

For the monetary value of yield, the current price of a crate of tomato was found from the central market in the city of Bolgatanga where tomatoes are normally sold on a large scale. The number of crates was then multiplied with the price of 1 crate of tomatoes to calculate the monetary value of the total yield. Thus, according to Lemoalle (2006), for computation of the economic water productivity, the equation below was used.

$$\text{Economic water productivity (GH¢ /m}^3) = \frac{\text{Revenue obtained from crop yield}}{\text{Total water supplied}}$$

4.4.3 Economic performance criteria

Efficiency of water fee collection and the financial self-sufficiency of the WUA were calculated as explained below based on data available.

4.4.3.1 Efficiency of water fee collection

The total number of members of the WUA was multiplied by the water levy per person per season to compute the expected income of the WUA since the only source of income was from the collection of water levy. The actual income generated from water levies at the end of the season was also calculated from the product of the number of members who paid water levy before the season was over and the water levy per person per season. According to Bekisoglu (1994), Efficiency of water fee collection was then calculated using the equation below.

$$\text{Efficiency of water fee collection (\%)} = \frac{\text{Irrigation Fees Collected}}{\text{Total Irrigation Fees expected}} * 100$$

4.4.3.2 Financial self-sufficiency

To enable calculation of the financial self-sufficiency of the schemes, data such as WUA's levy per person per season, number of WUA members, expenditure on operation and minor maintenance (e.g. repair of broken canals, damaged valves and dam wall) were collected from the WUA executives at all the study site.

It was discovered from interviews and FGDs conducted that, the only source of income for the schemes was from the payment of water levies. The income was, thus, calculated by multiplying the levy per person per season by the total number of WUA members.

From data collected, it was observed that operation and maintenance (O and M) was not done seasonally but was ad hoc. Therefore, to enable measurement of financial sustainability, by calculating the financial self-sufficiency, of the schemes over the years after rehabilitation in 1999, a base year for analysis was chosen (1999). The expenditure on O and M for particular years was discounted to the base year and annuity found using an averaged inflation rate (18.1%) for the period of analysis (i.e. 1999 – 2009).

The financial self-sufficiency was then calculated by using the equation below.

$$\text{Financial self sufficiency} = \frac{\text{Water Users Association Income}}{\text{Total O\&M expenditure}} \qquad \text{(Bekisoglu, 1994)}$$

4.5 Evaluation of overall performance of schemes

Included in the secondary data collected was the range recorded by MOFA for physical land productivity (t/ha), which was then converted to physical water productivity (kg/m^3) and economic water productivity (GH¢/m^3). For most irrigation schemes in Ghana conveyance efficiencies are in the range 40 – 60, thus a conveyance efficiency of 50% (which is the average) was assumed for the calculation of the volume of irrigation water needed to be supplied for such a yield as indicated by the MOFA. That is, in the determination of the total volume of irrigation water needed to be supplied to a hectare of land for this yield, the relation below was used.

$$\text{Total water supplied } (m^3/ha) = \frac{\textit{Crop water requirement}}{50\%}$$

$$= \frac{7030}{50\%}$$

$$= 14060 \text{ } m^3/ha$$

NB: MOFA range for physical land productivity = 10 ~ 20 t/ha

Calculation of the range for physical water productivity (kg/m^3) was, then, done as shown below.

$$\text{Physical water productivity } (kg/m^3) = \frac{\textit{Physical land productivity}}{\textit{Total water supplied}}$$

$$= \frac{10000 \sim 20000}{14060}$$

$$= 0.7 \sim 1.4$$

The monetary value of the yield was then calculated to enable determination of the range for economic water productivity (GH¢/m^3).

NB: 1 crate = 52 kg = GH¢ 40.0 on the Bolga Market

MOFA range for the monetary value of land productivity = 7692 ~ 15384 GH¢/ha

$$\text{Economic water productivity } (GH¢/m^3) = \frac{\textit{Monetary value of land productivity}}{\textit{Total water supplied}}$$

$$= \frac{7692 \sim 15384}{14060}$$

$$= 0.5 \sim 1.1$$

The calculated productivities (i.e. physical land productivity, physical water productivity and economic water productivity) were thus, compared to the MOFA ranges to see whether the schemes were performing well or underperforming.

CHAPTER FIVE

5 RESULTS AND DISCUSSIONS

5.1 Location of study schemes

The nine small reservoir irrigation schemes which were studied are spatially distributed in three (3) districts of the region including Kassena-Nankana East, Bongo and Bolga. Thus for easy location of these schemes, a GPS coordinate picked at the middle of the dam wall was taken at each reservoir site to represent the location of the irrigation scheme. The single GPS coordinates which represent the locations of the nine (9) small reservoirs studied were plotted on maps of the districts and the municipality as shown in Figure 5.1 below.

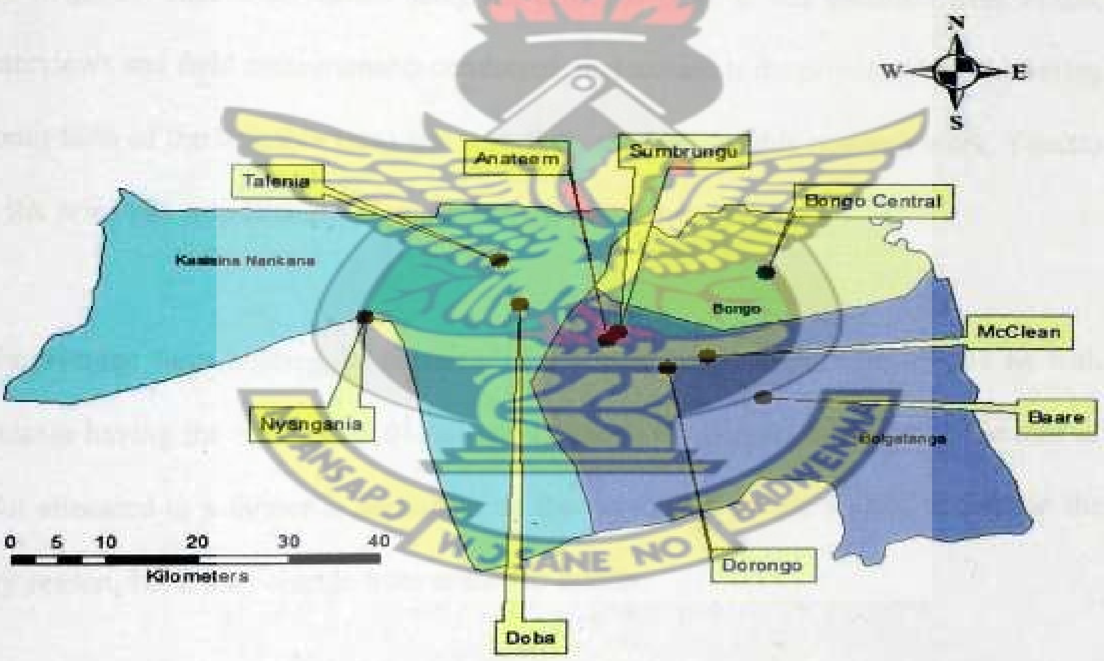

Figure 5.1: Locations of study schemes

5.2 Description of the study schemes

Gleaning from the FGDs organised, physical measurements, made and other data collected from relevant offices, below is a table of the principal characteristics of the study reservoirs.

It is evident from Table 5.1 below that, each irrigation schemes studied have reservoirs with storage capacities ranging from 66000 to 380000 cubic meters, and actual irrigable area varying from 5 to 13 hectares.

Various crops such as onion, pepper, tomato, kenaf and leafy vegetables are grown at all the irrigation sites with tomato being the principal crop. It was gathered from FGDs, interviews and field measurements conducted, that tomato is the principal crop (covering about 60% of the irrigable area) and was, thus, selected for this research work. Tomato is the principal crop because it usually has the best market price.

The average farm holding, in hectares, of a farmer ranges from 0.01 to 0.07 ha with Telania having the smallest (0.01 ha) and Dorongo the biggest of 0.07 ha. The size of plot allocated to a farmer is dependent on the number of people willing to farm in the dry season, i.e. it may change from season to season.

It is also evident from the table below that, the nine schemes are fed by gravity with the irrigated command located in valleys immediately downstream of the earth dams.

Table 5.1: Principal characteristics (from data collected) of the selected schemes

Characteristic	Reservoir								
	Baare	Sumbrungu	Dorongo	Doba	Anteem	Telania	Bongo Central	Nyangania	McClean
Year of construction	1991	1961	1963	1956	1961	1970	1961	1962	1960
Principal crop	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato
FSL surface area (ha)	14.2	6.5	21	6.2	10	16	11	15	8.8
Storage capacity (m^3)	216408	70420	379676	65798	130762	256886	149951	234138	108823
Design Irrigable Area(ha)	6.4	5	6	7	7	10	13	10	12
Actual Irrigable Area(ha)	6.4	5	11	7	7	10	13	10	10
No. of WUA members	107	24	150	106	26	220	320	369	38
Water levy (GH¢)	4.00	4.00	3.00	4.00	4.00	3.00	0.50	5.00	4.00
Average landholding (ha)	0.04	0.02	0.07	0.03	0.02	0.01	0.02	0.03	0.02
Mode of irrigation	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity

5.3 Performance indicators

5.3.1 Land utilisation

This criterion gives an indication of whether the irrigable areas are used at full capacity or not.

According to data collected from GIDA on the small reservoir irrigation schemes studied and interviews conducted with WUA executives at all the study sites, no variations were observed from the design and actual irrigable areas of seven (7) of the nine (9) schemes studied giving a land utilisation of 100%. The remaining two (2) schemes namely; McClean and Dorongo revealed some variations where the actual irrigable area for Dorongo was found to be almost twice the design irrigable area while for the McClean scheme, the design irrigable area was found to have reduced by 2 ha. The land utilisation for the Dorongo and McClean schemes were, thus calculated to be 183.33% and 83.33% respectively. For the Dorongo irrigation scheme, it was gathered from a FGD that the increase in the actual irrigable area was as a result of an increase in demand for land for dry season farming by the townsfolk. That is, the farmers already in the WUA needed more land to cultivate and also some others got onboard knowing the benefits of dry season farming. The variation seen in the case of the McClean irrigation scheme was as a result of a road construction in the community cutting about 2 ha of the irrigable area, as gathered from an interview with the chairman of the WUA, and thus, making that piece of land not cultivable. That is, the reduction in the irrigable area is neither due to loss of soil fertility nor geological changes but rather due to community development.

In order to sustain the irrigation area, however, the maintenance programmes should be conducted properly, land degradation due to drainage and salinity problems should be prevented and misuses of agricultural lands by urban and industrial developments have to be strictly controlled.

5.3.2 Physical land productivity

According to Figure 5.2 below, Sumbrungu, Anateem and Dorongo show relatively high yield per hectare of cultivated land. This may be due to good farming practices.

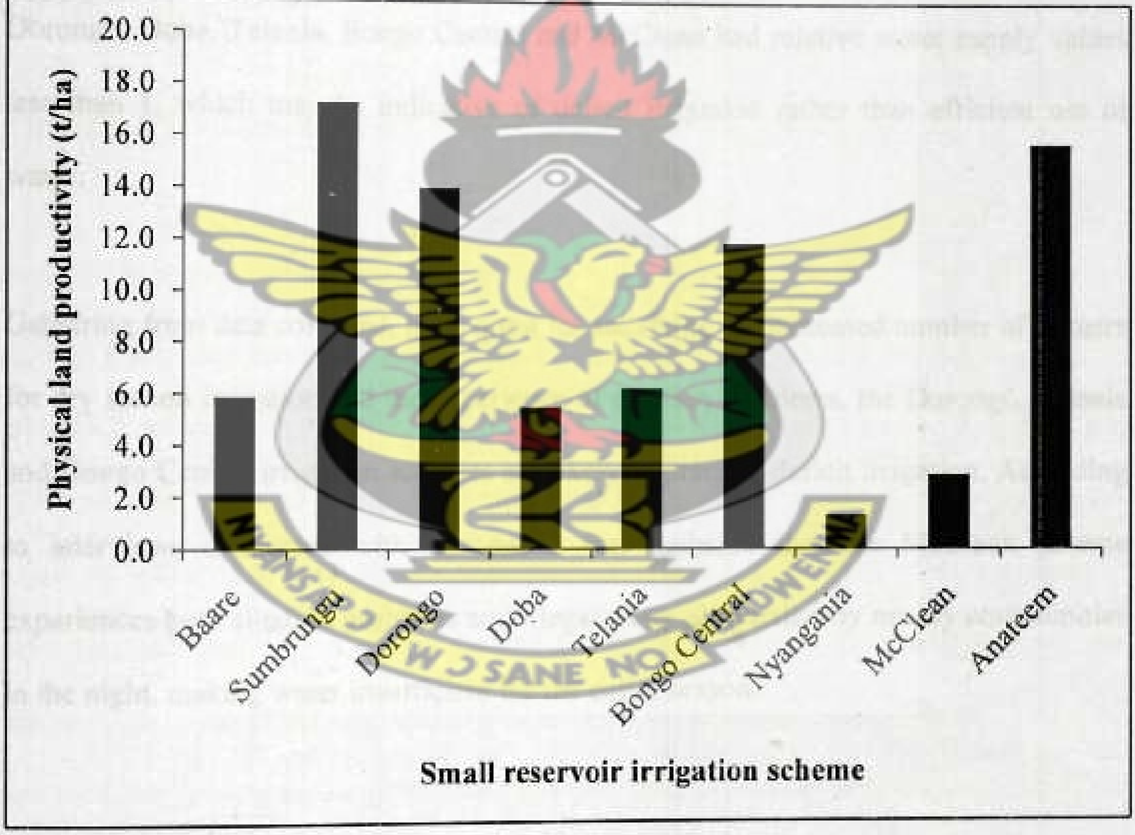

Figure 5.2: Evaluation of performance using physical land productivity

5.3.3 Water productivity criteria

5.3.3.1 Relative water supply (RWS)

This indicator measures the adequacy of water supplied for irrigation and the efficiency of water use. That is, it indicates whether the irrigation water supplied is enough or not or whether it is being wasted. The RWS values as shown in Figure 5.3 below reveal that four of the schemes namely, Baare, Sumbrungu, Nyangania and Anateem have adequate water supply and efficiencies of water use below 100%. This poses no threat because for most irrigation schemes in developing countries, efficiencies of 40 – 60% and RWS values greater than 2.5 are normally common. The remaining five schemes including Dorongo, Doba, Telania, Bongo Central and McClean had relative water supply values less than 1, which may be indicative of deficit irrigation rather than efficient use of water.

Gathering from data collected, in its quest for satisfying the increased number of farmers for dry season irrigation and the experience of siltation problems, the Dorongo, Telania and Bongo Central irrigation schemes are likely to practice deficit irrigation. According to interviews conducted with farmers, it was gathered that the McClean scheme experiences both siltation problems and illegal water abstraction by nearby communities in the night, making water insufficient for the entire season.

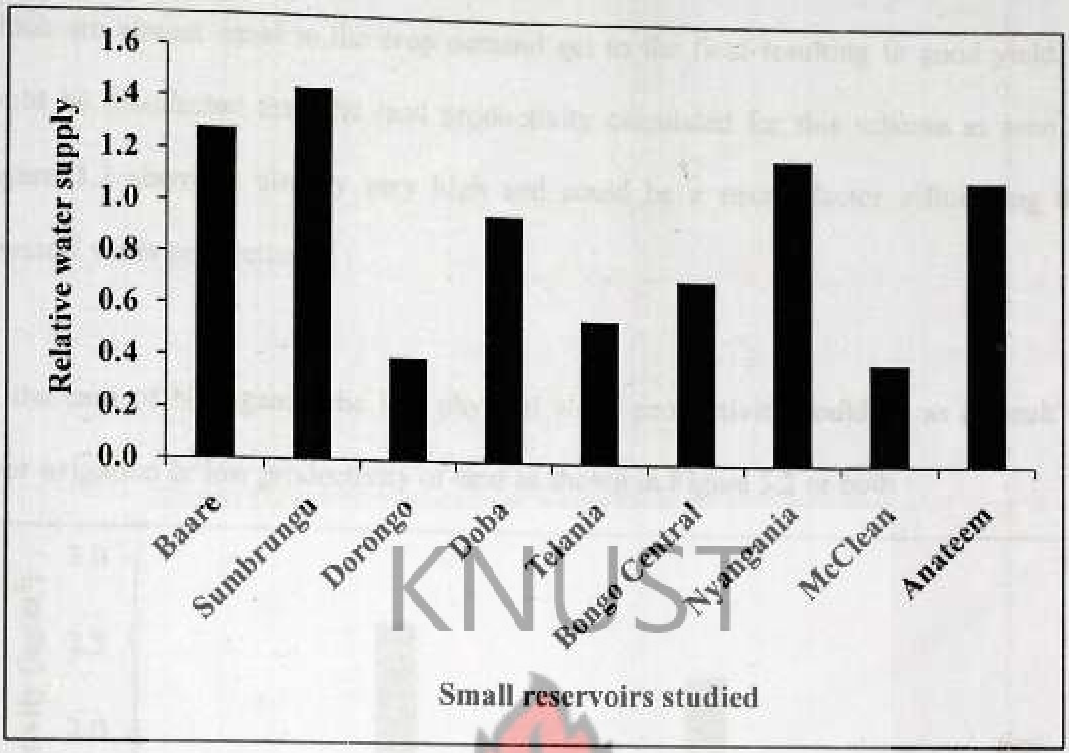

Figure 5.3: Evaluation of performance using relative water supply

5.3.3.2 Physical water productivity

Sumbrungu, Dorongo and Anateem show relatively high out-put per cubic meter of irrigation water as depicted in Figure 5.4 below, with Telania, Baare, McClean and Bongo Central showing appreciable physical water productivity. It was observed that the schemes which practiced deficit irrigation had very good physical water productivity with the Dorongo scheme having the highest. On the contrary, the Sumbrungu scheme where water use efficiency was observed to be relatively poor also showed good productivity. This could be explained from the fact that, during field observation of the infrastructure at the Sumbrungu scheme, the canal system was observed to have fractures at various points which are likely to give rise to losses. That is, there is the possibility that even though large volumes of irrigation water could be released, volumes which are almost equal to the crop demand get to the field resulting in good yield. It could be recollected that, the land productivity calculated for this scheme as seen in Figure 5.2 above is already very high and could be a strong factor influencing the physical water productivity.

In the case of Nyangania, the low physical water productivity could be as a result of over-irrigation or low productivity of land as shown in Figure 5.2 or both

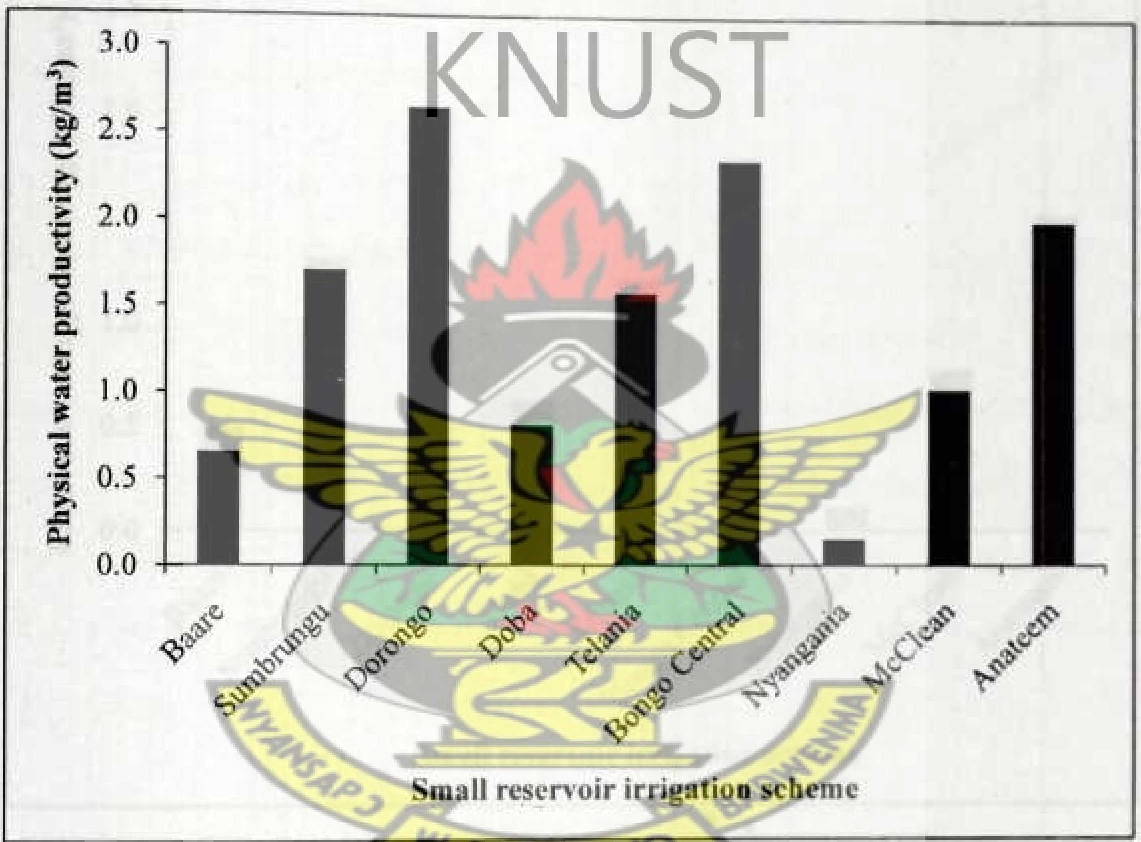

Figure 5.4: Evaluation of performance using physical water productivity

5.3.3.3 Economic water productivity

This is used to describe the return on water consumed. From Figure 5.5 below, it is revealed that Sumbrungu, Dorongo and Anateem have high crop water productivity, in monetary terms, which is indicative of proper water utilisation. The Nyangania scheme, as seen in Figure 5.5, has very low economic water productivity which is a reflection of the very low physical water productivity seen in Figure 5.4.

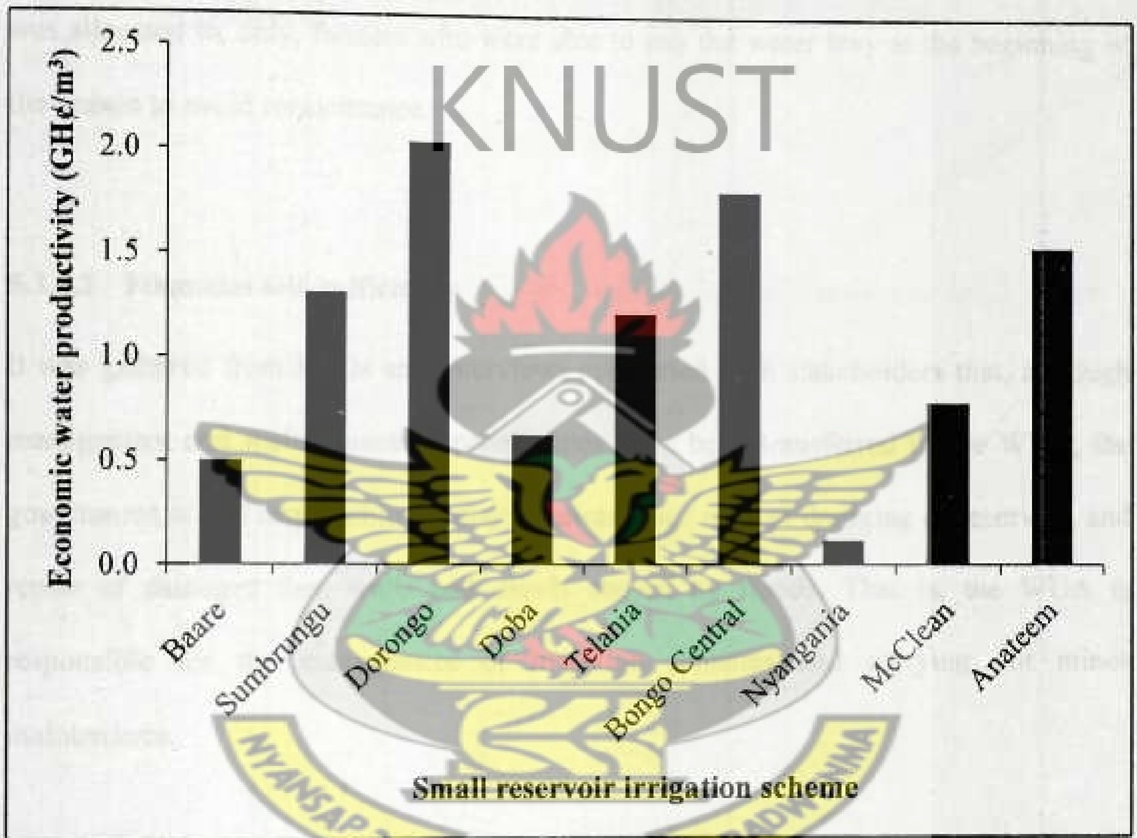

Figure 5.5: Evaluation of performance using economic water productivity

5.3.4 Economic performance criteria

5.3.4.1 Efficiency of water fee collection

According to data collected from WUA executives at all the study sites, the efficiency of water fee collection was 100% for all. It was indicated that the total amount of water levy collection rate by end of season is 100%. That is, time of payment in the season is not important. At the Baare reservoir irrigation scheme, as a precautionary measure, land was allocated to, only, farmers who were able to pay the water levy at the beginning of the season to avoid recalcitrance.

5.3.4.2 Financial self-sufficiency

It was gathered from FGDs and interviews conducted with stakeholders that, although management and maintenance responsibilities have been transferred to the WUA, the government is still responsible for major maintenance such as dredging of reservoir, and repair of damaged dam walls and canals caused by floods. That is, the WUA is responsible for the management of irrigation schemes and carrying out minor maintenance.

According to data collected from the WUA executives on the income and expenditure of the schemes, it was observed that only four of the study sites namely, Dorongo, Bongo Central, McClean and Telania, have had some expenditure on operation and minor maintenance after the rehabilitation of the schemes. The financial self-sufficiency was, thus calculated for only those schemes.

Table 5.2 below shows the financial sustainability of the schemes indicated by the calculated financial self-sufficiency. After rehabilitation of the small reservoir irrigation schemes in 1999, it is evident from Table 5.2 that using financial self-sufficiency as an indicator, all the WUAs of the schemes studied have excellent financial self-sufficiency (>1) with Telania having the highest.

The least expenditure on operation and maintenance calculated for the McClean scheme could be due to the small number of users (38) of infrastructure resulting in less pressure on it as compared to Dorongo with WUA members numbering 150 which has the highest expenditure on operation and maintenance.

It could be deduced from Table 5.2 that the financial self-sufficiency of small reservoir irrigation schemes is primarily dependent on the total number of WUA members and the amount paid as levy.

Table 5.2: Evaluation of financial self-sufficiency for 1999 – 2009

Reservoir	No. of WUA's members (1)	WUA Levy (GH¢) (2)	Income per season (GH¢) (3)=(1)*(2)	O&M per season (GH¢) (4)	Financial self-sufficiency (5)=(3)/(4)
Dorongo	150	3.00	450	26.08	17.25
Bongo Central	320	0.50	160	10.57	15.14
McClean	38	4	152	6.84	22.22
Telania	220	3	660	24.02	27.48

For the schemes which have not had any expenditure on operation and maintenance since rehabilitation, the situation could be as a result of implementation of good management policies (such as; valve key to be handled by caretaker alone, water allocation being the sole responsibility of the Water Allocation Committee etc.) or merely due to the neglect of maintenance.

5.4 Evaluation of overall performance of schemes

To actually know whether targets are being met or not, the calculated indicators were compared to the ranges recorded by MOFA for land and water productivities in Ghana. Table 4.2 gives a summary of the productivities of land and water calculated for the study schemes as well as the MOFA ranges.

Table 5.3 shows that, physical land productivities of the Baare, Doba and McClean schemes fall in the range recorded by the MOFA whereas Sumbrungu, Anateem and Dorongo have land productivities above the range. Only the Nyangania scheme has physical land productivity below the range.

Comparing the physical and economic water productivities with the MOFA ranges it was realised that, the productivities which were calculated for the Baare, Doba and McClean schemes fell in the range whereas the Sumbrungu, Anateem, Dorongo and Telania schemes fell above the range. Once again, both physical and economic water productivities calculated for the Nyangania scheme fell below the MOFA range.

Table 5.3: A comparison of calculated productivities with the MOFA ranges

	Performance criteria		
	Physical land productivity (t/ha)	Physical water productivity (kg/m^3)	Economic water productivity (GH¢/m^3)
MOFA	**10 – 20**	**0.7 – 1.4**	**0.5 – 1.1**
Study schemes			
Baare	5.9	0.7	0.5
Sumbrungu	17.3	1.7	1.3
Dorongo	14.0	2.6	2.0
Doba	5.5	0.8	0.6
Telania	6.2	1.6	1.2
Bongo Central	11.9	2.3	1.8
Nyangania	1.3	0.2	0.1
McClean	2.9	1.0	0.8
Anateem	15.7	2.0	1.5

CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings revealed that:

1. The irrigable area is put to full capacity use.
2. Four of the schemes have average land productivity while five have low land productivity when compared with the MOFA range.
3. Five of the schemes have high water productivity while three have average water productivity. The Nyangania scheme however has low land productivity when compared with MOFA range. The level of water productivity was seen to be chiefly, influenced by the productivity of land recorded for the schemes.
4. The WUA is financially sustainable and capable of carrying out the responsibilities of management, operation and maintenance. This is because of a 100% efficiency of water fee collection.
5. Based on the comparison of calculated indicators used for the evaluation with the MOFA ranges, all the schemes, except Nyangania, are performing well.

6.2 Recommendations

1. There should be a frequent evaluation of performance of the schemes for effective planning and management.
2. The Water Users Association should collaborate with GIDA to dredge silted reservoirs to increase capacity. This will actually enhance the irrigation water supply.
3. The Water Users Association should maintain the 100% efficiency of water fee collection for financial sustainability, since the water levy is the only source of income.
4. Further research is necessary to ascertain reasons for low land productivity.

REFERENCES

Abaka-Yankson, E. (2009). Impact of management and policy on small reservoirs for irrigation in the Upper East Region of Ghana: Msc. Thesis, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology. pp 1–85

Adu, S. V. (1969). Soil of Navrongo-Bawku Area upper Region, Ghana. Memoir No 5. Soil Research institute, Kumasi, Ghana

Andreini, M., Boelee, E., Van de Giesen, N., Andah, W., Senzanje, A., Huber-Lee, A., Rodrigues, L. N., Cecchi, P., Steenhuis, T., Liebe, J. R. (2005). Small Reservoirs Project (SRP) - Planning and Evaluating Ensembles of Small, Multi-purpose Reservoirs for the Improvement of Smallholder Livelihoods and Food Security: Tools and Procedures, GTZ Annual Progress Report, International Water Management Institute (IWMI), pp.1 – 8.

Annor, F. O. (2007). Delineation of small reservoirs using radar imagery in a semi-arid environment: A case study in the Upper East Region of Ghana. Msc. thesis, UNESCO-IHE Institute for Water Education, Delft, the Netherlands, pp 13

Asante, K. (2009). Assessing the Potential Impacts of Climate Change on Irrigation Water Use in Upper East Region of Ghana: A case study of Tono and Vea Irrigation Projects. MSc. Thesis. Department of Civil Engineering. Kwame Nkrumah University of Science and Technology. pp: 6, 19

Balazs, C. (2006). Rural Livelihoods and Access to Resources in Relation to Small Reservoirs: A Study in Brazil's Preto River Basin, MSc. thesis, University of California, Berkeley, USA

Behailu, M., Abdulkadir, M., Mezgebu, A. and Yasin, M. (1996). Performance Evaluation of Community Based Irrigation Management in the Tekeze Basin: A case study on three small-scale irrigation schemes (microdams): A collaborative project btween Mekell University, ILRI and EARO: Funded through the IWMI-Comprehensive Assessment of Water for Agricultural programme.

Bekisoglu, M. (1994). Irrigation Development and Operation and Maintenance Problems in Turkey. Proceedings of the conference on Development of Soil and Water Resources. General Directorate of State Hydraulic Works, Ankara, pp: 579 – 586.

Birner, R., Schiffer, E., Asante, F., Gyasi, O. and McCarthy, N. (2005). Analysis of Governance Structures for Water Resources Management in the White Volta Basin Ghana. Report

Çakmak, B., Polat, H. E., Kendirli, B. and Gökalp, Z. (2009). Evaluation of Irrigation Performance of Asartepe Irrigation Association: A Case Study of Turkey. Akdeniz Üniversitesi Ziraat Fakültesi Dergisi. 22(1), 1 – 8.

Chavula,G. (2000). The Potential of Using Community Based Small Earth Dams for Irrigation Development, The World Commission on Dams, www.dams.org/kbase. Accessed on 12/04/08.

Döll, P. (2002). Impact of Climate Change and Variability on Irrigation Requirements: A Global Perspective, Climate Change 54(3), 269 – 293. **Döll, P., and Siebert, S. (2001)**. Global Modelling of Irrigation Water Requirements, Water Resources Research 8 (4) 1029 – 1035.

Dorsan, F., Anac S. and Akcay, S. (2004). Performance Evaluation of Transferred Irrigation Schemes in Lower Gediz Basin. Journal of Applied Sciences, 4(2), 231 – 234.

EPA (2003). National Action Programme to Combat Drought and Desertification. Environmental Protection Agency, Accra, Ghana

Faulkner, J. W. (2006). Water use, Productivity and Profitability of Small Scale Irrigation Schemes in Ghana's Upper East Region. MSc. Thesis. Faculty of Graduate School. Cornell University. pp. 2.

Ferguson, C.A. (1989). Modelling water utilization in large-scale irrigation systems. A qualitative response approach. Water Resources Bulletin (AWRA). 25(6): 1199 – 1204.

Food and Agriculture Organization of the United Nations (2002). Land Tenure and Rural Development. FAO Land Tenure Studies No. 3. FAO Rome. pp. 7.

Frazoa, F. F. and Perreira, L. S. (1993). Application of Indicators to Compare the Performance of Irrigation Systems. ICID 15th Congress. The Netherlands.

GSS 2005 (2000). Population and housing census of Ghana. Ghana statistical services

Gyasi, K. O. (2002). Determinants of Success of Community-Based Irrigation Management in Northern Ghana. Doctoral Seminar-Center for Development Research (ZEF)-University of Bonn. pp. 1 – 9.

Gyasi, K. O. (2005). Determinants of Success of Collective Actions on Local Commons: An Empirical Analysis of Community-Based Irrigation Management in Northern Ghana. Peter Lang. 49, 3 – 27.

Gyasi, K. O. and Schiffer, E. (2005). Community needs assessment and local water governance appraisal in the upper east region, Ghana. Report, pp. 1 56.

Hatcho, N. and Tsutsui, H. (1998). World Irrigation (IX): Irrigation Management Transfer and Participatory Irrigation Management, Rural and Environmental Engineering. 35(8), 5 – 14.

GIDA (2007). Inventory of dams in the Upper East Region. Irrigation Development Authority Regional office, Bolgatanga.

IFAD (1991). Water resources development, Upper East Region land conservation and smallholder rehabilitation project. Working paper 6.

IFAD (1999). Upper-East Region Land Conservation and Smallholder Rehabilitation Project – Phase II. Report and Recommendation EB 99/66/R.14

Japan International Co-operation Agency (2004). Technical Guideline for Irrigated Agriculture designed for Ghana Irrigation Development Authority. Small Scale Irrigated Agriculture Promotion Project – Follow up. DELARAM.

Keller, A., Sakthivadivel, R. and Seckler, D. (Undated). Water scarcity and the role of storage in development. http://www.iwmi.cigiar.org/pubs/Pub039/RR039.htm. Accessed on 6/12/09

Kyei-Baffour, N. (1994). Future irrigation prospects and actions in Ghana. In proceedings of the 1st National Conference on Agricultural Engineering at the Department of Agricultural Engineering, KNUST, Kumasi, from 25 – 29 September 1994. (eds Dzisi, K. A., Twum, A. and Lamptey, D. L.) pp: 65 – 75.

Lemoalle, J. (2006). Challenge Programme Water for Food Basin Focal Projects: Volta Proposal. Project Proposal (unpublished), Institut de Recherche pour le Developpement (IRD), Paris, France.

Liebe, J. (2002). Estimation of Water Storage Capacity and Evaporation Losses of Small Reservoirs in the Upper East Region of Ghana. Diploma Thesis. Geographische Institute Der Rheinischen Friedrich. Wilhelms. Universität Bonn.

Liebe, J., van de Giesen, N. and 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 (6 and 7) 448 – 454

Martin, L. R. (2005). A survey of Agricultural Economics Literature. American Agricultural Economics Association

Mdemu, V. M. (2008). Water Productivity in Medium and Small Reservoir in the Upper East Region (UER) of Ghana. Doctorial Thesis Report, Rheinischen Friedrich-Wilhelms-Universität zu Bonn, pp. 1 – 118.

MOFA (2007). Food and Agricultural Sector Development Policy (FASDEP II) First Draft-Second Revision. Ministry of Food and Agricultural, Government of Ghana, pp. 1 – 56.

MOFA/IFAD (1998). Proceedings on Training of Trainers Course for Agricultural Extension Agents on Water Users' Associations and Irrigated Agriculture. Land Conservation and Smallholder Rehabilitation Project (LACOSREP) Report. Upper East Region. Bolgatanga. Controller and Accountant General (CAG) Conference Hall, 8–10 December. pp. 1 – 6

Needham, R. (1993). Natural Resources and Livelihood Systems: The Upper East Region of Ghana. Ph.D. thesis, Sussex University, England

Nelson, K.D. (1985). Design and Construction of Small Earth Dams. Inkata Press. Melbourne. Australia. pp. 111 – 112

Poolman, M. (2005). Developing small reservoirs – A participatory approach can help. MSc Thesis, Faculty of Technology, Policy and Management, Technical University of Delft, pp. 1 – 116.

Quansah, C. (2005). Oncho Transborder Project. Burkina Faso and Ghana. Natural Resources use and management report.

Rusere, S. (2005). An Assessment of Multiple Uses of Small Dams, Water Usage and Productivity in the Limpopo Basin. BSc. Thesis (Unpublished), University of Zimbabwe

Sawunyama, T. (2005). Estimation of Small Reservoir Storage Capacities in Limpopo River Basin using Geographical Information Systems (GIS) and Remotely Sensed Surface Areas: A Case of Mzingwane Catchment. MSc. Thesis. Department of Civil Engineering. Faculty of Engineering. University of Zimbabwe. pp: 14 – 26.

Senzanje, A. and Chimbari, M. (2002). Inventory of Small Dams in Zimbabwe, IWMI, Colombo, Sri Lanka

Svendsen, M., Johnson III, S. H. and Gonzalez, F. (2002). Options for Institutional Reform in the Irrigation Sector. Keynote paper at the Sixth International Seminar. 21 – 27 April, 2002. Beijing. China

Twikirize, D. (2005). An Assessment of Traditional Water Management Practices and their Implications for Improved Water Governance in the Limpopo Basin: A case Study of the Sibasa Dam in Mzingwane Catchment, Zimbabwe. MSc. Thesis (Unpublished), University of Zimbabwe, Harare

UNDP (2007). Fighting climate change: Human solidarity in a divided world. Human development report 2007/2008. Available at http:// www.undp.org. Accessed on 16/01/2008

Vogelsang, F. (1998). After land reform, the market? FAO pp. 21.

Walker, H. O. (1962). Weather and climate, in J.B. Wills (ed). Agriculture and land use in Ghana. Oxford University Press, England, pp 7 – 28

Wiafe, K. and Nyaledzigbor, K. (1994). The role of the Civil Engineer in irrigation development in Ghana. Departmental Seminar, Department of Civil Engineering, KNUST, Kumasi.

Yamoah-Antwi, D. (2009). Productivity of stored water in small reservoirs in the upper east region of Ghana. MSc. Thesis. Department of Civil Engineering. Kwame Nkrumah University of Science and Technology. pp; 5, 48

APPENDICES

Appendix A: Calculation of relative water supply (RWS)

Reservoir	Volume of water supplied (m^3/ha)	*CWD (m^3/ha)	**RWS**
Baare	8998	7030	**1.28**
Sumbrungu	10123	7030	**1.44**
Dorongo	5273	7030	**0.75**
Doba	6749	7030	**0.96**
Telania	3937	7030	**0.56**
Bongo Central	5062	7030	**0.72**
Nyangania	8436	7030	**1.20**
McClean	2812	7030	**0.40**
Anateem	7874	7030	**1.12**

* Crop water demand

Appendix B: Calculation of physical land productivity, PLP (t/ha)

Reservoir	Yield (Crate)	Yield (kg)	Cultivated area (ha)	PLP(kg/ha)	**PLP (t/ha)**
Baare	433	22542	3.84	5870	**5.9**
Sumbrungu	996	51816	3.0	17272	**17.3**
Dorongo	1773	92202	6.6	13970	**14.0**
Doba	442	22992	4.2	5474	**5.5**
Telania	712	37293	6.0	6216	**6.2**
Bongo Central	1783	92720	7.8	11887	**11.9**
Nyangania	148	7682	6.0	1280	**1.3**
McClean	332	17239	6.0	2873	**2.9**
Anateem	1272	66142	4.2	15748	**15.7**

Appendix C: Calculation of physical water productivity, PWP (kg/m^3)

Reservoir	PLP(kg/ha)	Volume of water supplied (m^3/ha)	**PWP (kg/m^3)**
Baare	5870	8998	**0.7**
Sumbrungu	17272	10123	**1.7**
Dorongo	13970	5273	**2.6**
Doba	5474	6749	**0.8**
Telania	6216	3937	**1.6**
Bongo Central	11887	5062	**2.3**
Nyangania	1280	8436	**0.2**
McClean	2873	2812	**1.0**
Anateem	15748	7874	**2.0**

Appendix D: **C**alculation of economic water productivity (GH¢/m^3)

Reservoir	Yield(GH¢/ha)	Volume of water supplied (m^3/ha)	**EWP (kg/m^3)**
Baare	4516	8998	**0.5**
Sumbrungu	13286	10123	**1.3**
Dorongo	10746	5273	**2.0**
Doba	4211	6749	**0.6**
Telania	4781	3937	**1.2**
Bongo Central	9144	5062	**1.8**
Nyangania	985	8436	**0.1**
McClean	2210	2812	**0.8**
Anateem	12114	7874	**1.5**