IMPACT OF SMALL RESERVOIRS AND DUGOUTS IN GHANA ON HYDROLOGY AND WATER ALLOCATION IN THE BLACK VOLTA BASIN

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IMPACT OF SMALL RESERVOIRS AND DUGOUTS IN GHANA ON HYDROLOGY AND WATER ALLOCATION IN THE BLACK VOLTA BASIN

By

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Certification

I hereby declare that the submission of this thesis is my own work towards the Master of Science (MSc) degree in Water Resources Engineering and Management and that, to the best of my knowledge, it contains no material previously published by another person or myself nor material which has been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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Dedication

Dedicated to my husband Ane Kwaradam and lovely late mother Janet Atulley Akandi, whose model of womanhood still leaves on.

Abstract

Small reservoirs development has the potential especially the rural to increase water harvesting and storage towards ensuring adequate supply to a wider population, facilitated by the relatively little expenditure required for their construction. Despite their immense significance, developing small reservoirs beyond a certain threshold in a catchment/basin may pose significant adverse effect on the hydrology of that basin. This research therefore sought to explore the impact of small reservoirs and dugouts in the Ghana on hydrology and water allocation in the Black Volta Basin using the Water Evaluation and Planning System (WEAP) and satellite imagery. The methodology involved; analysing hydro-metrological data (1951-2010), demographic data and Satellite Imagery among others. The stream flow gauges for Lawra (Upstream), Bui (midstream) and Bamboi (downstream) were used in analysis.

The results showed no ***significant*** impact on runoff and about 55.6 B m^3 of water flowing downstream untapped. Moreover, unmet livestock and irrigation water requirement range from 1,000 m^3 to 6,500 m^3 and 40,000m^3 to 55,000 m^3 respectively, all of which were recorded in the dry season. This implies excess water during the rainy season and some level of scarcity in the dry season. Finally, the study realized the possibilities of developing up to 350 Small Reservoirs by 2040 (under the extreme case of '5 times growth rate scenario') without impacting negatively on hydrology provided the rainfall pattern persist and no significant developments take place in the upstream countries. In conclusion, there is an abundant untapped water resource in the BVB during the rainy season though the basin suffers some level of scarcity in the dry season due to lack of infrastructure to harness the resource at the time of abundance. On this basis, recommendations were made that 5 reservoirs be constructed annually to expand livestock production and dry season irrigation in especially the northern portions of Ghana as it lie along the fringes of the Sahel which is likely to be hard hit by the Climate Change Menace.

Table of Content

Contents

List of Figures

List of Tables

List of Plates

Abbreviations

BVB	Black Volta Basin
CWSA	Community Water and Sanitation Agency
FAO	Food and Agriculture Organisation
GIDA	Ghana Irrigation Development Authority
GLOWA	Global Change in the Hydrological Cycle
GMet	Ghana Meteorological Agency
GSS	Ghana Statistical Services
GWP	Global Water Partnership
HSD	Hydrological Services Department
IWM	Integrated Watershed Management
IWRM	Integrated Water Resources Management
MOFA	Ministry of Food and Agriculture
NGO	Non-Governmental Organization
SARI	Savannah Agriculture Research Institute
SRI	Soil Research Institute
SR	Small Reservoirs
UWR	Upper West Region
WAS	Water Audit Study
WEAP	Water Evaluation and Planning
WVB	White Volta Basin
WRC	Water Resources Commission
WRI	Water Research Institute
WUA	Water Users Association

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1. INTRODUCTION

1.1 Background

The Black Volta Basin, one of the major sub-basins of the Volta system located in semiarid and subarid Africa is characterized by an unreliable uni-modal rainfall pattern making rain-fed agriculture a risky business (Awotwi, 2010). Meanwhile agriculture is the backbone in rural societies and for a majority, the principal source of income (GLOWA Volta, 1999). Hence, Water is captured and stored in some areas for dry season irrigation to supplement the rainfed farming.

Ghana's fame on the subject of reservoirs is undoubtedly due to Lake Volta, the largest manmade lake of the world regarding its surface extent 8,515 km² (Liebe, 2002). Moving the focus away from reservoirs of such spectacular dimensions to the other extreme, there are a large number of small reservoirs dotted around the entire northern Ghana to ensure a year round growing season, livestock watering and domestic purposes as well (Hagan, 2007). The construction of a lot of small reservoirs and an even distribution of them throughout a region makes it beneficial to the wider population since it facilitates easy access (Liebe, 2002). A survey of 16 small reservoir sites in Ghana indicated that irrigators can derive on average US$350/household/year; this is equivalent to 5 months of work of a single individual if the minimum daily wage set up by the Ministry of Finance and Economic Planning of Ghana is considered (Venot *et al.,* 2012). The special appeal of small reservoirs is the little expenditure required in their construction compared to medium size dams. According to Polak (2005), it is believed that making widely available relatively low-cost AWM technologies such as small reservoirs has the potential to contribute to rural livelihoods.

1.2 Problem Statement

According to Awulachew *et al*., (2005), water scarcity in Africa is primarily due to insufficient storage capacity, signifying that Africa faces crisis of water management and governance rather than water scarcity. With water as a key input for agricultural production, improving water productivity is an obvious entry point to safeguard both people's livelihoods and the environment (Faurès and Santini, 2008). The recent increased attention and promotion of Agriculture Water Management Technologies such as small reservoirs reveals that, improvements in water storage and use are necessary to meet increased demands for crop production due to increasing population (Descheemaeker *et al*., 2010).

Though widespread distributions of small reservoirs upstream in Northern Ghana have the advantage of serving many people, it may also pose some adverse effect on runoff, affecting downstream water users. For instance, within the past 10 years the increased demand for water has triggered the construction of more SR and wells in the Upper West Region (GIDA, 2011). Meanwhile, the attention of researchers has been on the impacts of larger bodies (dams and lakes), mostly focusing on reservoirs that are directly connected to stream and rivers while the influences of smaller scale water storage structures are not well known and available hydrological databases tend to overlook water features less than 10,000 m^2 (Buddemeier *et al.*, 2004). Limited knowledge on the extent/limit to which small reservoir development should be up-scaled is a constraint since developing more reservoirs upstream beyond a certain number may affect water users downstream as well as environmental flows. Hence, the need to make available information on the impacts of small reservoirs on hydrology as well as establish limit to reservoirs development given the rising demand for Small Reservoirs.

1.3 Justification

The average rate of irrigation development for the countries of sub-Saharan Africa from 1988 to 2000 was 43,600 ha / year (FAO, 2001). If this rate continues, then an additional 1 million hectares will be brought into irrigated production by the year 2025. Hence, more reservoirs will be constructed to meet the increasing water demands. Unfortunately no long-term data and projections on the impacts of further development of agricultural water technologies such as these small reservoirs are available (Martin and Van de Giesen, 2005)

Though the wide spread distribution of Small Reservoirs upstream (Northern Ghana) has the advantage of serving many people particularly the rural folks, knowledge on the impacts of these small reservoirs on the hydrology of the Black Volta Basin is necessary to determine a threshold or limit to which reservoirs should be developed as regards to the number (up-scaling limits) in order to sustainably meet upstream demands while ensuring that the required environmental flows and water requirement downstream are met, particularly the Bui dam.

This study therefore sought to establish the impact of small reservoirs in the Upper West Region on the hydrology of the Black Volta basin with regards to runoff downstream and the general flow condition of the river since the region is located upstream of the Ghana portion of the Basin. The research also sought to ascertain the impacts of further development of reservoirs in the Ghana portion of the basin on the hydrology and water allocation in the basin. This will inform decision making on development of Small Reservoirs among policy makers, NGOS, Investors and community members in the area.

1.4 Objectives

1.4.1 Main Objective

The main objective of this study is to assess the impact of Small Reservoirs and Dugouts in the Ghana portion of the Black Volta Basin on hydrology and water allocation in the Basin.

1.4.2 Specific Objectives

The specific objectives that will help achieve the above mentioned main objective are:

- Assess the impact of existing small reservoirs and dugouts on water allocation in the Basin.
- Ascertain the implications of further development of reservoirs on the hydrology of the Black Volta Basin using three Scenarios.
- Evaluate the state of small reservoirs and dugouts in the upstream of Ghana portion of the basin (Upper West Region)

1.5 Research Questions

- How does existing small reservoirs and dugouts influence water allocation in the Black Volta Basin?
- What are the implications of further development of small reservoirs on the hydrology of the Black Volta basin?
- What is the state of small reservoirs and dugouts in the Upper West Region?

1.6 Scope of Work

The study covers all reservoirs that fall within the Ghana portion of the Black Volta Basin which are located in portions of three administrative Regions including; Northern, Brong Ahafo and Upper West Regions. The thesis involved the following

- Identification of the various reservoirs, year of construction, locations as well as measuring their surface area extents.
- Quantification of water for farming, livestock production and other uses from the small reservoirs
- Creation of scenarios and evaluation.
- Modelling with existing reservoirs and simulating with 3 scenarios; reference scenario and increase in rate of shall reservoirs development scenario (3* and 5* growth rate situations). The first scenario is the business as usual situation while the second set of scenarios were informed by the 2010 report of the Ghana Irrigation Development Authority that, there is likely to an increase in small reservoirs development in subsequent years since more NGO's and communities are going in to reservoirs construction.

2. LITERATURE REVIEW

2.1 Definition of Concepts

- **Agricultural Water Management Technologies (AWMT)*:*** This is a general term and includes capture and storage (in dams, small reservoirs, dugouts, ground water) as well as drainage of any water used for agriculture (crops, livestock, fish); lifting and transporting water, in-field application and management of water, including land management practices that affect water availability to crops (Merrey *et al.*, 2006).

- **Small Reservoirs (SR**); According to Venot and Krishnan (2011), defining what 'makes' a small reservoir is indeed not agreed upon, as the criteria (type of infrastructure, size, modes of management, planning approaches) and thresholds (volume, height, irrigated area) can vary widely depending on the vantage point considered and the problems or actors at stake. However, the World Commission on Reservoirs defines small reservoirs as "a structure that has a height less than fifteen meters (15 m) and storage capacity ranging from fifty thousand to one million cubic meters (50,000 to 1×10^6 $m^{3)}$". Meanwhile, Annor *et al., (*2007) also argues that, though small reservoirs can be defined in terms of surface area coverage (water storage systems greater than 1 hec. but less than 100 hec.), the volume of water stored in most reservoirs varies with time mostly as a function of siltation, seepage, evaporation and availability of rainfall. Hence a definition based on capacity will either be misleading or incorrect. On the other hand, Venot *et al.*, (2012) indicated that there is no need embarking upon definitional debates on 'what is – and is not – a small reservoir', rather, in working with small reservoirs there is the need to adopt a multidimensional approach that takes into account the multiplicity of meanings that small reservoirs can assume. Based on the available data on small reservoirs in the region, the study will consider the definition of the world commission on reservoirs.

- **Water Evaluation and Planning System (WEAP)** is a microcomputer tool for integrated water Resources planning and it offers a comprehensive approach to water resources management and studies (WEAP User guide, 2005).

- **Catchment and Basin:** A ***Catchment*** is a portion of the earth's surface that collects runoff and concentrates it at its furthest downstream point, referred to as the catchment outlet. The terms watershed and basin are commonly used to refer to catchments (www.aboutcivil.org). Generally, ***watershed*** is used to describe a small catchment (stream watershed), whereas ***basin*** is reserved for large catchments (river basins)..

2.2 Background on AWMT

The term covers a wide range of technologies and practices available for improving water and land management. In recent years there has been increasing recognition of the importance of managing water to improve food security and reduce poverty, especially in the rural areas that are home to three-quarters of the world's hungry people (Merrey *et al.*, 2006). Molden, (2007) added that small reservoirs can provide opportunities for multiple use of water including domestic consumption, environmental sustenance, aquaculture and livestock watering. According to the framework of FAO's Special Program of Food Security, AWMT are categorized based on the following characteristics; Capture, Storage, Lifting and Application (FAO, 1998). The focus of this research is on the storage technologies specifically, small reservoirs and dugouts since they are said to be the most prominent AWMT in Ghana.

2.3 Small-scale Water Harvesting Infrastructure

Water harvesting encompasses any practice that collects and stores runoff for productive purposes (FAO, 1994). It includes a watershed area to produce runoff, storage facility and target area for beneficial use of the water such as agriculture, domestic and industry (Merry, 2006). Storage technologies in rainwater harvesting include surface or subsurface tanks, graded bunds, dams, flood control reservoirs and small reservoirs (Fox and Rockström, 2000). These and many others are described and illustrated in Mati, (2006) and Ngigi (2003).

Small reservoirs according to Venot and Krishnan (2011), have been increasingly seen over the last three decades as a way to develop small-scale irrigation, especially in sub-Saharan Africa. SRs are known under multiple names in various regions of the world: tanks or Johads in South Asia, Açudes in Brazil, small reservoirs or micro-dams in sub-Saharan Africa, and Lacscollinaires in North Africa (Venot *et al.*, 2012). Meanwhile, what 'makes' a small reservoir is however not agreed upon as the criteria and thresholds considered can vary widely among regions and actors. For water harvesting structures including small reservoirs to be successful, the communities must participate in the planning and construction of the structures and accept responsibility for their operation and management (Seleshi *et al.*, 2009). Hence, community participation is very necessary for the sustainability of Small Reservoirs.

2.4 Overview of Small Reservoirs in Ghana

The spatial and temporal variability of water resources in Sub-Saharan Africa (SSA) is influencing agricultural development that can ultimately lead to food insecurity and poverty in the region (Anayah and Kaluarachchi, 2009). Following Ghana's independence in the 1960s, considerable investments were made in small reservoirs. Ironically, the priority of the national development agenda in subsequent years was shifted towards medium and large scale dams with little attention to small reservoirs (Venot *et al.*, 2011). Nonetheless, the mid-1990s to date has experienced renewed interest in small reservoirs mainly due to large donor-driven investments in northern Ghana among which include; World Bank Village Infrastructure

Project (VIP), IFAD Upper West Agricultural Development Project (UWADEP) and Land Conservation and Smallholder Rehabilitation Projects (LACOSREP) 1 and 2. Between 1995 and 2009, 222 small reservoirs were constructed in the country, of which 82 were in the three northern regions. Meanwhile, about 80 dams were rehabilitated in the Upper East and Upper West Regions during the same period and the International Fund for Agricultural Development (IFAD) together with Africa Development Bank (AfDB) plan to invest a further US$30 million by 2015 to build or rehabilitate an additional 50 small dams in the three northern regions of the country (Venot and Cecchi, 2011).

2.5 Uses / Benefits of Reservoirs and Dams

To overcome water scarcity alongside creating new income sources for steadily growing populations, hundreds of small-multi-purpose reservoirs were built; by the British colonial administration more than 60 years ago and continued by the Ghana government after independence in 1957 with support from various international donor organizations (Hauck, 2010). Small reservoirs serve about 2,500 people (about 400 households) and a survey of 16 small reservoir sites in Ghana indicated that irrigators can derive on average US$350/household/year; this is equivalent to 5 months of work of a single individual if the minimum daily wage set up by the Ministry of Finance and Economic Planning of Ghana is considered (Venot *et al.*, 2012).

According to Boelee, Laamrani and Van der Hoek (2007), the local population value small reservoirs because they are said to be dynamic in terms of uses including:

- SRs make water readily available for agriculture-related purposes, the result of which is improved food security, enhanced income and reduced migration

- SRs improve water availability for domestic purposes which in turn enhance women's position within their household. Thus, they spend less time fetching water and divert more time towards other beneficiary activities
- SRs make water available for small-scale commercial purposes such as brick making, pottery and mat weaving.
- SRs improve greenness and increased biodiversity

While it is commonly recognized that small reservoirs yield multiple benefits for local populations, many studies point out their high costs and under-performance with regard to their potential (Cecchi, 2007). Scholars then recommend a suite of technical institutional interventions such as investing in Water User Associations to maintain reservoirs (Mdemu *et al.*, 2009).

2.6 Environmental Effects of Small Reservoirs

Water is an indispensable part of the ecosystem since proper functioning of flora and fauna depends to a large extent on water (Avakyan *et al.*, 2001). Emerging evidence shows that uses of small reservoirs can contribute towards environmental deterioration including; erosion of the shoreline, declining water quality and adverse health impacts such as malaria (Ghebreyesus *et al.*,1999), though adequate management can lead to improved human health (Andreini *et al.*, 2009). Apart from serving as breeding grounds for mosquitoes when not properly managed, erosion of the banks of the reservoirs during floods can inundate nearby farmlands and cause significant damage to other property.

2.7 Efficient Water Use and Performance of Irrigation Systems

According to FAO (2006), Ghana has a renewable water resource of 53.2 km^3 out of which 0.25 km^3 is used for crop production. Though the potential cultivable land is about 42% of the total area of the country, only 4.25% is actively under cultivation. Indicating that, water and land resources in the country are woefully under utilized for irrigation as well as rain fed agriculture (Venot *et al.,* 2012). Ghana has the potential of developing 384,000 ha of irrigation based on water and land availability (World Bank Report, 2005). Despite limitations with the supply of freshwater in several regions, considerable amounts of water are lost through several mechanisms such as; evaporation, leakage, runoff and uncontrolled drainage among others. Wallace (2000) suggests that, some of the water "lost" from irrigated fields may return to aquifers or streams from which it can be extracted again provided the necessary infrastructure is available and the water quality has not deteriorated beyond acceptable limits.

2.8 Hydrological Response and Runoff

According to Smakhtin (2001), water can flow over the land surface through the zone of aeration or the zone of saturation. Meanwhile, water that enters the water table and is discharged into a stream called base flow sustains stream flow during dry periods. The water that infiltrates the top layer of the soil and does not percolate to the water table but flows laterally through the subsurface is called interflow or subsurface flow (Smakhtin, 2001). Overland flow occurs when the soil infiltration capacity is filled and water moves across the land surface into a water body (Dune and Leopold, 1979). Estimation of runoff volumes helps predict stream flow and is needed for effective management of water resources including management of floods, water quality, supply, and power generation (Brandes *et al.,* 2005). Climatologic and geophysical characteristics of the landscape have a large influence on stream discharge and hydrological responses of watersheds.

Hydrological response of watersheds can be analyzed by examining stream flow and its response to different patterns of precipitation in a watershed. Stream flow can be characterized by a large array of different hydrologic indices. The five indices describe the magnitude, frequency, timing, duration, and rate of change of different high and low flow events (Peters and Seth, 2001). Different indices describe different hydrologic responses of watersheds including runoff. Rainfall-runoff ratios describe the percentage of precipitation that discharges into streams as runoff, and it is measured by dividing the annual runoff depth of a watershed by the total annual precipitation depth (Chang, 2007). Land use has a large effect on water resources and stream flow. Examples of major land use categories include crop land, pasture, forests, and urban land use. Urban areas tend to have a larger percent of precipitation forming into runoff and as a result tend to have faster hydrological responses and decreases in water quality (Doughtery *et al.*, 2007).

2.9 Distribution and Hydrologic Effects of Small Water Bodies

Small reservoirs and dugouts play crucial roles in meeting the water needs of humanity especially in sub-Saharan Africa and the world at large. According to Bartley *et al.,* (2002) reservoirs have significant environmental and hydrologic effects because in sections of landscapes above these reservoirs, the export rates of water, sediment, and nutrients are reduced. Below the reservoirs, there is usually less surface water due to losses from evapotranspiration, human consumption, and groundwater infiltration and this starves the downstream areas of water (Bartley *et al.*, 2002, 2005). Previously, the focus of researchers has been on impacts of larger water bodies (dams and lakes), mostly focusing on reservoirs that are directly connected to stream and rivers. Small water bodies though outsized by larger reservoir features, they are more numerous and can have a significant hydrological consequence on the landscape. On a per area basis, smaller water bodies are more effective at reducing sediment and nutrient export from watersheds (Bartley *et al*., 2002, 2005).

Not denying the fact that Small Reservoirs play significant role; especially in the lives of rural communities in Ghana, it is relevant to manage carefully their number and distribution to avoid water resources degradation. Though several reservoirs upstream will benefit upstream users, it can have tragic impacts on the livelihoods of people further downstream. There are two major branches of hydrology (Surface and Ground Water Hydrology) and the focus of this study is on the surface water hydrology while the hydrological processes under consideration include, Overland flow, Surface Runoff and Precipitation.

2.12 Institutional Framework of Small Reservoirs

Institutions / actors assume different and complementary roles that contribute to good governance of small reservoirs and dugouts in the country. Reservoirs in most parts of Ghana are constructed through projects funded by various donor agencies and the Government of Ghana. The functions performed by relevant stakeholders are discussed below.

- **Communities;** In most communities, Water committees e.g., Water User Associations (WUAs) are identified as being the main decision-making body on small reservoirs. Their main tasks are considered as minor maintenance and daily management. The WUA play a key role in decision making in the communities with regards to sustainable management and governance of small reservoirs (IFAD, 2009). Traditional authorities are seen as the most important decision makers regarding the uses and management of reservoirs. They are also crucial in settling disputes, resolving conflicts, maintaining social cohesion and overseeing land allocation.
- **District Assemblies & Beneficiary communities;** They represent the government at the local level and are the main decision makers in procurement and construction processes of small reservoirs. They act as brokers between policy-making /planning and implementation: they are effectively the ‘foot soldiers’ of national governments that seek rapid development. Community members, on the other hand, are the final stewards and these small reservoirs are constructed in their name. Beneficiary communities and the District

Assemblies play key roles in the management of these reservoirs. While the community folks are in charge of the day to day management of the reservoirs, the District Assemblies in collaboration with Ministry of Food and Agriculture provides training avenues for them to better equip them to manage the facilities.

- **Ministry of Food and Agriculture (MoFA);** MoFA is the lead Institution in agriculture and related issues in the country. It supervises farming including crops, animals and fisheries as well as support farmers in various aspects such as extension education and marketing. The ministry is thus, ultimately accountable for the state of national food production. The functions of this ministry include; coordination and formulation of agriculture policies. The policies result in the Development and issuing technical guidelines on efficient production technologies and their management.

- **Ghana Irrigation Development Authority (GIDA);** GIDA is mandated by law to oversee the construction and management of reservoir systems in the country to ensure food security in the various communities. Though a lot of institutions including NGOs and individual communities engage in reservoirs construction, most of who do not contact GIDA. Thus, little or no coordination among organizations (SRP, 2006).

2.13 Water Resources Models

Models are increasingly becoming indispensable tools for planning, design and management of hydrologically related infrastructure. A model is an imitation of reality which stresses those aspects that are assumed to be important and omits all properties considered to be unnecessary. According to Singh (1995), a model is a systems methodology approach and helps to define and evaluate numerous alternatives that represent various possible compromises among the conflicting groups, values and management objectives and trade offs. Most computer based models provide useful information in facilitating water resources development and management and these are based on the water balance equations (Rukuni, 2006). The WEAP model used in this study illustrates the potential of modeling as a dynamic and flexible tool to assist in the planning and decision making of water resources at catchment level.

There are two basic modeling approaches:

- ***Simulation models (methodology/ conceptual)***

A simulation model relies on trial and error to identify near optimal solutions. Decision variables are set and the resulting objective values evaluated (Loucks *et al.*, 1981). Simulation models are highly non-linear; however they are able to solve water resources system planning issues. Examples of simulation models include Pitman, HEC 5 and WEAP (Rukuni, 2006).

- ***Optimization models (mathematical)***

Optimization techniques include linear programming, geometric and quadratic programming among others. Optimization models are highly mathematical e.g. GLSNET and HSPF models. They analyse reservoir using residual techniques to estimate a regional regression equation to predict flow characteristics at engaged sites (Rukuni, 2006).

2.15 Applications of the Water Evaluation and Panning (WEAP) Model

Water Evaluation and Planning System (WEAP) is a microcomputer tool for integrated water resources planning and water allocation, developed by the Stockholm Environmental Institute (SEI) Boston (WEAP User guide 2012). It is easy to use and offers a comprehensive approach to water resources management. The model functions on the principle of water balancing.

Since the first version of the model was developed in 1990, it has been applied in a lot of research work conducted in quite a number of basins in different countries. Specifically, it has been applied to Lake Naivasha in Kenya to develop an integrated water resource management plan for economic and ecological sustainability (Alfara, 2004). Also, WEAP has been applied in complex situations such as the Aral Sea to evaluate water resources development policies. In that study, some scenarios in the model were used to provide a structured approach to integrated water-demand analysis (Raskin *et al.*, 1990). Under the ADAPT project, the model was again applied to the Volta Basin to investigate the effect of changing climate on the already stressed water resources, food security as well as the environmental and the socio-economic consequence on the people living in the basin (Andah *et al.*, 2003). The model has been applied in the following areas: In South Africa, it was applied on water demand management scenario in a water stressed basin. In the River Basins in Zimbabwe and Volta in West Africa, it was used for Planning and Evaluating groups of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security tools (SRP, 2006).

3. STUDY AREA

3.1 Introduction

This chapter describes the following: location and administrative boundaries, climate, vegetation, land use, population and socioeconomic activities, drainage relief, geology and soil.

3.2 Location and Administrative Boundaries

The Black Volta basin lies between latitude 7° 00’ 00’’ N and 14° 30’00’’ N and longitude 5° 30’ 00’’ W and 1° 30’ 00’’ W and covers an estimated area of about 130, 400 km^2 which is about 21% of the Volta basin system. Meanwhile, the Ghana portion of the BVB covers an area of 18,384 km^2 constituting 14% of the basin and is made up of 5 sub catchment including; Lerinord, Nwokuy, Dapola, Noumbiel and Bamboi (Barry *et al.,* 2005), Administratively, the basin comprises 9 Districts in Ghana (based on the 170 District demarcations); 14 provinces in Burkina Faso; 2 Departments in Cote d’Ivoire; and 3 Regions in Mali (Annor, 2012). It covers a distance of about 1,350 km from Burkina Faso to the Volta Lake with thirteen main tributaries and accompanying catchment draining into the BVB (Barry *et al.*, 2005).

The study was carried out in the Ghana portion of the basin narrowing down to the Upper West Region portion (Figure 3.1). The Upper West Region is situated at the north western corner of Ghana and covers 18,847 km^2 that is 7.7 % of the total land area of Ghana. The region is bordered by Northern Region to the south, Upper East Region to the east and Cote d Ivoire to the west. Six districts in the Upper West Region were considered (Lambussie-Karn, Wa Municipal, Nadowli, Jirapa, Lawra-Nandom and Wa West) in this study.

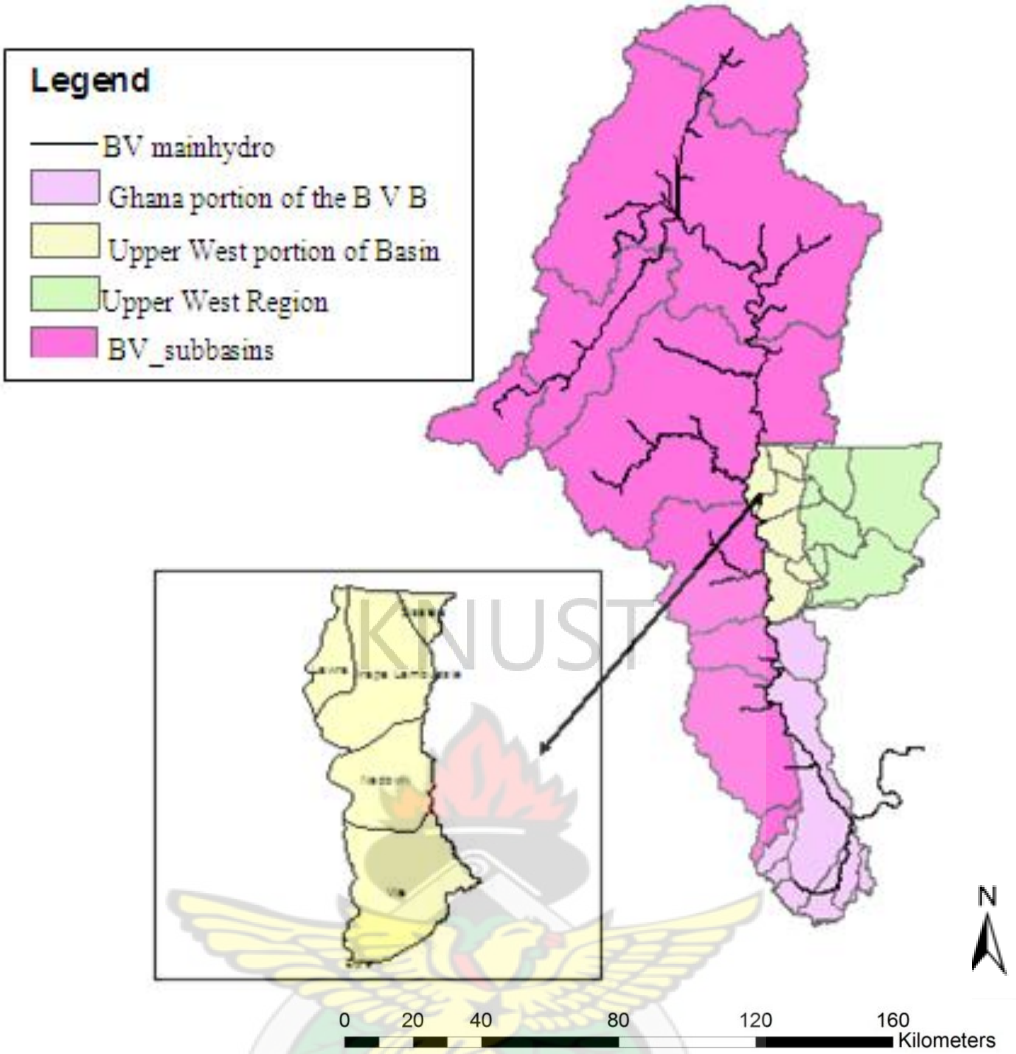


Figure 3.1: Upper West Regional portion of the Black Volta Basin

3.3 Climate

The Black Volta Basin is agro ecologically composed of Sahel, Sudan savannah from the upper part of the basin, guinea savannah and transitional zone at the middle portion and moist semi deciduous forest at the lower portions of the basin. The annual mean temperature in the Volta system is between 27-30 °C and specifically in the Black Volta basin it is 26 °C. Daily temperature rises as high as 44 °C during the day and could fall to as low as 15 °C at night (Barry *et al.*, 2005). The hottest months are March and April while the coolest is August and the hamatan season is from November to January.

The basin experiences uni-modal rainfall which is as a result of the Inter-tropical Convergence Zone (ITCZ) which influences the climate of the entire West Africa region (Sultan *et al.*, 2005). ITCZ is the inter-phase of the hot, dry and dusty northeast trade winds that blows from the Sahara in the north of the region and the cool, moist south west trade winds that blows over the sea from the south Atlantic. ITCZ moves across the Black Volta basin once resulting in a uni-modal rainfall and bimodal rainfall in areas that it crosses twice (Andah *et al.,* 2003). The mean annual rainfall vary from 1043 mm-1270 mm, annual evapotranspiration is between 1450 mm/ year to 1800 mm/year. An average runoff of about 243 m^3/ month is experienced in the Basin (Barry *et al.*, 2005).

3.4 Vegetation and Land Use

The region belongs to Guinea and Sudan savannah Agro ecological zones (AEZ) and the dominant vegetation in the region is that of savannah woodland (Figure 3.2) characterized by short scattered drought resistant trees and grass species such as *Heteropogen spp* and *Andropogen gayyanus.* According to Agorsah (2003) in GWI (2009), these grasses dry up and burn during the long dry season while, the trees have thick barks hardened by seasonal fires but with the tendency to produce from dormant buds. The most common trees of economic value include; Shea butter (*Butyrosprmum parkii*) and Dawadawa (*Adansonia digitata*).

A land cover map for the Ghana portion of the Black Volta Basin was prepared from the Volta shape file which was obtained from the Volta Basin Starter Kit July (2006) and this is presented in figure 3.2.

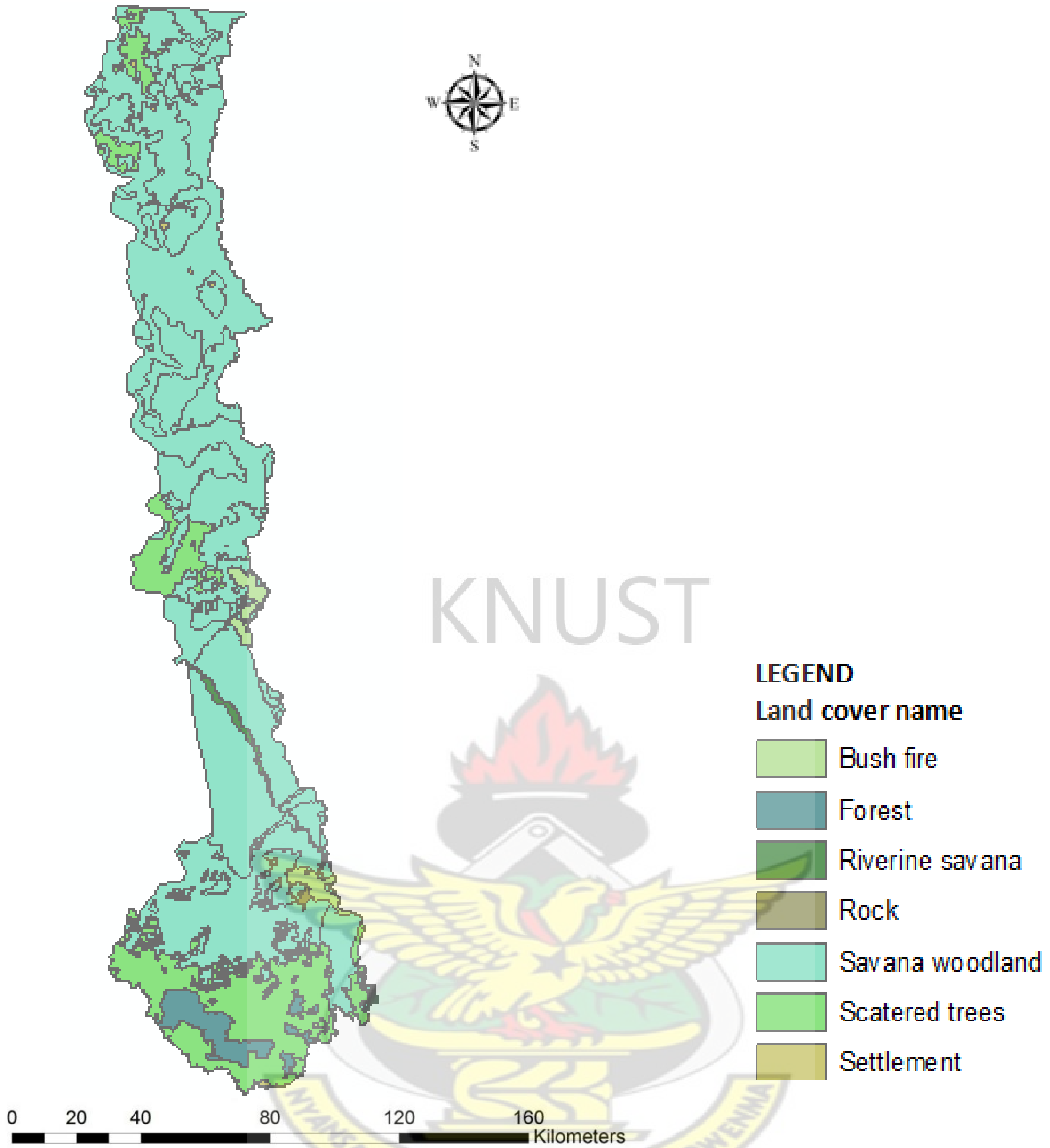


Figure 3.2: Land cover map for the Ghana portion of the Black Volta Basin

In the Black Volta basin, most lands are used for agriculture and the food crops cultivated under rain-fed are mostly rice, millet, maize, yam, beans, and cassava while vegetables cultivated in the dry season include cabbage, tomatoes, okro and lettuce.

Generally, livestock grazing in the dry season is usually done on free range with some herdsmen migrating in search of greener pasture and water in neighbouring communities (Barry *et al.*, 2005). Some communities such as Busa is an exception where livestock are allowed to graze freely in the rainy season since farmers do not cultivate around their homes unlike in the case of Lawra where natives do compound farming thus, pegging the livestock at uncultivated areas to graze. Since there are no clear demarcations for grazing, most herdsmen migrate from Burkina Faso and Mali to the lower parts of the basin in Ghana (Annor, 2012). Meanwhile, their movement to a place largely depends on the presence of green vegetation and their migration has a greater consequence on the recipient communities which sometimes leads to conflict between herdsmen and communities.

3.5 Population and Socioeconomic Activities

The population of the basin stood at 4.5 million people as at 2000. Thus in Ghana, Burkina, Cote d Ivoire and Mali and this was estimated to grow to 8.0 million in 2025 (Annor, 2012). Population density in the basin ranges from 8 to 133 people/ km^2 with Sissala district having the lowest of 8 and Lawra district the highest of 133people/ km, while the average population density is 43 people/ km^2 (GSS, 2012). The total population of the Upper West Region as at 2010 stands at 702,110 people recording about 18 % increase relative to 576,583 in 2000 (GSS, 2012).

Field survey conducted in the BVB within Ghana has shown that population aged 18-40 years mostly migrate to Kumasi and Accra for non-existing job while the active age engaged in subsistence farming lies between 45 and 60 (Barry *et al.*, 2005). Livestock and poultry are reared under free range system in almost all households in the Region.

3.6 Drainage and Relief

A large portion of the basin in Ghana falls within the Guinea savannah zone, characterized by gentle undulating slopes resulting in high runoff within a short time after rains**.** The region is partly drained into the Black Volta, White Volta and its tributaries respectively and the BVB drains eastwards into the White Volta Basin. The Black Volta basin is drained by the Bougouriba, Gbongbo, Grand Bale, VounHou, Sourou, Wenare, Bambassou, Bondami, Mouhoun (main Black Volta), Tain and Poni rivers as main tributaries. However, most of these rivers dwindle to hardly any or no flow in the dry season with only pockets of stagnant water remaining (Annor, 2012). The mean runoff in the Black Volta is estimated at 7 km^3 per annum.

3.7 Geology and Soil

Northern Ghana has two distinct geologic characteristics; Precambrian basement rocks and Palaeozoic rocks from the Voltaian sedimentary basin. According to Gordon and Amatkpor (1999), the geology of the Black Volta basin is mostly granite, Brimian (known for its gold potential), Voltaian and Tarkwaian systems. The Brimian system is made of metamorphosed lavas, pyroclastic rocks, phyllites, grits conglomerates and schist. In the basin, ground water occurs mostly as a result of fractures in rocks not its inherent porosity (WRC, 2004).

Soil map for the Ghana portion of the Black Volta Basin was prepared from the Volta shape file, obtained from the Volta Basin Starter Kit July (2006) and represented in figure 3.3.

As shown in Figure 3.3, the predominant soils are luxisols and glycols with lixisols being dominant in the UWR portion. which comprise of soils that have higher clay content in the subsoil than in the top soil as a result of pedogenetic processes (particularly clay migration) leading to an organic subsoil horizon. The soils have predominantly light textured surface horizon, shallow and low in soil fertility, weak with low organic matter content and predominantly coarse textured (Barry *et al.*, 2005). Also, Soils in Valley areas have high natural fertility due to nutrients deposits during flooding in the rainy season but are more difficult to till and are prone to seasonal water logging and floods

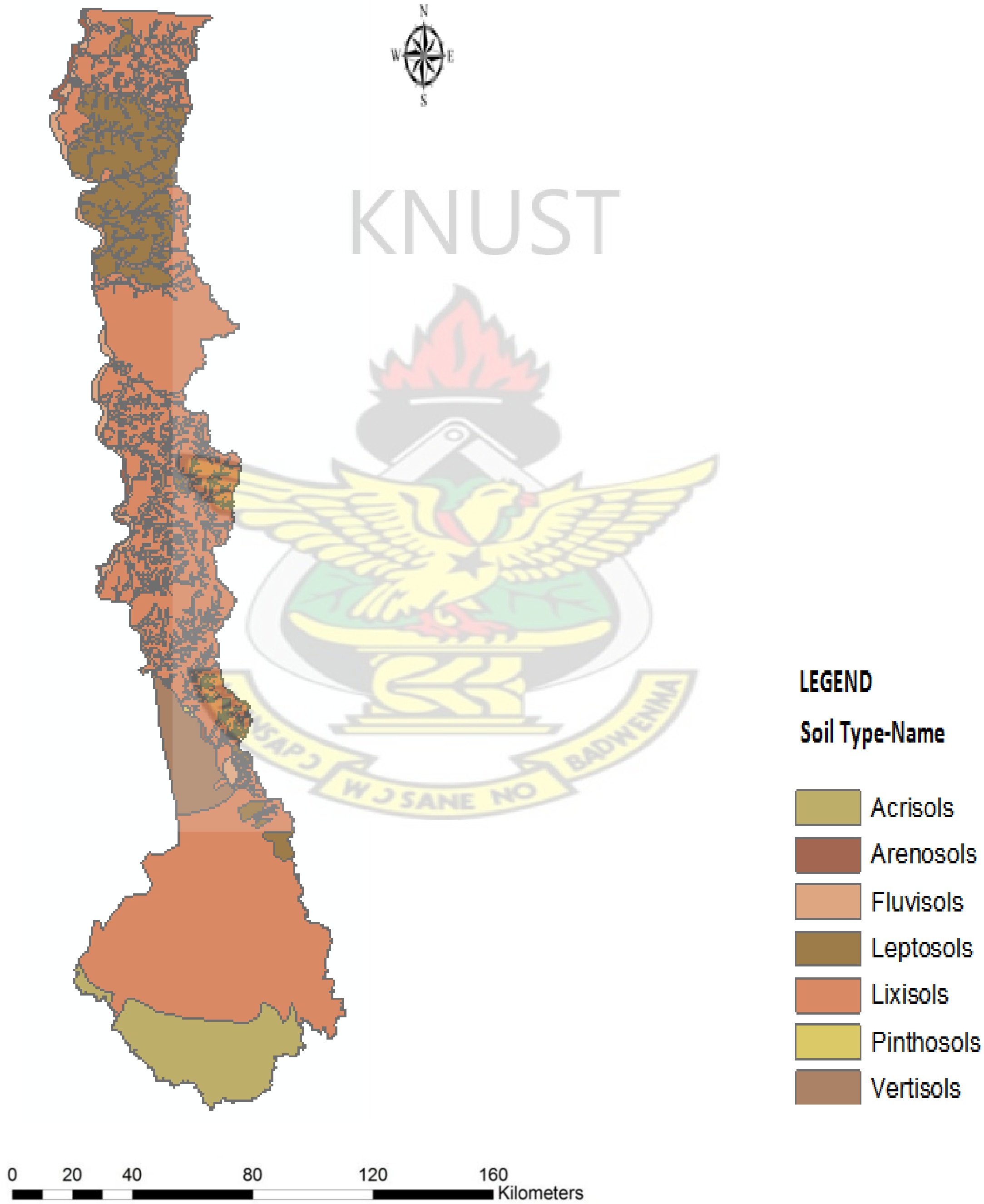


Figure 3.3: Dominant Soil types in the Ghana portion of the Black Volta Basin

4. METHOOLOGY

4.1 Desk Study

Relevant literature on AWMT, small water storage structures and small reservoirs were studied and reviewed. The materials used include articles, journals, published and unpublished thesis, reports from government institutions and NGOs. Software used for data processing (WEAP and ArcGIS) were also studied and reviewed to facilitate the data analysis process.

4.2 Data Acquisition

Primary and secondary data that characterizes the Black Volta basin were acquired through; field visits, focus group discussion, the Global Visualization Website and stakeholder consultation. The data was then processed and organized into formats usable in WEAP.

4.2.1 Field Visits

The list of reservoirs was obtained from GIDA and a series of random visits made to reservoirs site to ascertain the state of the reservoirs and to understand their contribution to the livelihood of beneficiary communities by direct observation and interaction with water users. The coordinates and areas of 21 reservoirs were taken with aid of GPS and this was complemented by a satellite image which was used to locate the position of all reservoirs in the Black Volta Catchment.

4.2.2 Focus Group Discussions

Purposive sampling technique was used to select four communities each from Lawra, Jirapa and Nadowli, three from Wa municipal, one from Wa East and five from Wa West districts respectively. In all, six districts in the Upper West Region were considered. One reservoir was selected from Wa East and five from Wa West because the entire Wa West falls within the BVB while a little fraction of Wa East falls within the study area. Discussions were done with assistance from the Regional Agronomist of GIDA who did the translation. A detail of the location and area of reservoirs are indicated in appendix.

Table 4.1 Districts and communities visited.

District	Reservoir/community
Wa Municipal	Siiri, Busa and Tanina
Wa East	Logu
Jirapa Lambusie	Chaare, Konzokala, Karni and Duori
Lawra	Tanchara, Eremon Babile and Kokoligu
Wa West	Yeliyili, Ga, Baleofilli, Ladayiri, and Pingbenben
Nadowli	Sankana,Takpo, Jang and Kaleo

4.2.2 Remotely Sensed Data Acquisition and Processing

LANDSAT 7 wet season image was acquired from the Global Visualization Viewer Website (GVV). The 8-band image was captured on September 2002. One major characteristic of this image is that, it covers a larger area at a time with less detail because the sensor is far off from the earth surface. The data processing entailed; extracting and stacking to produce a single image using the ERDAS software. The image was then re-sampled to ensure a standard spatial resolution of all the bands and the image was then added to the ArcGIS ArcMap 9.3 for classification and digitization of the small reservoirs. Digitization was done by redrawing out the shape of the water bodies in the processed image and the shape file of the digitized reservoirs was then added onto the study area shapefile.

4.2.4 Secondary Data for the WEAP Model

- **Hydrological data**: Historical data of river flow as observed at various gauges along the Black Volta Rivers were obtained from the Hydrological Service Department (HSD). Average monthly runoffs for 3 gauge stations (Lawra, Bui, and Bamboi) were considered taking into consideration the upstream (Lawra), midstream (Bui) and downstream (Bamboi) points. Meanwhile, there are 6 gauge stations along the main Black Volta (Lawra, Daboya, Chache, Bui, Bamboi and Bupe).

- **Meteorological data;** Historical data on Relative humidity, monthly rainfalls, mean monthly temperature, mean wind speed, mean monthly sunshine, latitudes/ coordinates and cloudiness fraction were obtained from the Ghana Meteorological Agency (GMet.).

- **Water requirements and demands;** water use/requirements were assessed for various needs in the basin. Hydropower and environmental requirements together with four consumptive uses were identified in the Basin (Domestic water for key towns, Livestock, Irrigation and Industrial water requirements). Meanwhile in the model, only Livestock, Irrigation and small reservoirs water requirements were considered. The per capita water consumption in urban and rural settings was considered to be 85 lit/day and 55 lit/day respectively, informed by the 2010 annual report of Community Water and Sanitation Agency.
  - ✓ **Livestock water requirements**: Data on livestock population was sourced from the draft report of the diagnostic study of the Black Volta Basin carried out by the Global Water Initiative (GWI) (2012). The tropical livestock unit (TLU) was applied the livestock population and the water requirements were assessed. The data was projected for the 30 year simulation period (2010 - 2040).

- ✓ **Irrigation water requirements**: There are no major irrigation schemes in the basin except for the Bui irrigation scheme which is downstream. Nonetheless, minor irrigation schemes exist in the region (Sankana, Busa and Siiri Irrigation schemes). The volume of abstruction was not known since the technical officer of Mofa indicated it may range from 3-5.5 Mm^3. hence 5 Mm^3 was assumed and used over the simulation period

Climate and runoff data were then categorized into;

- ✓ Pre impact stage – Before massive reservoirs construction (1951-1980)
- ✓ Post impact stage – After reservoirs construction (1990-2010).

4.3 Catchment Delineation

Determination of the catchments was done using the spatial analyst tool in ArcGIS version 9.3 and the SRTM 90. A shape file of the Black Volta Basin was created using the Volta shape file which was obtained from the Volta Basin Starter Kit July (2006). According to Ashe (2003), DEMs include pits or ponds that should be removed before being used in hydrological modelling. Pits are points where water would accumulate when drainage patterns are being extracted. These pits are sign of errors in the DEM arising from interpolation. These pits were removed by an algorithm known as SINK filling. The processes include: Creating a

- Depressionless DEM
- Flow direction
- Flow accumulation
- Watershed pour points
- Delineating watersheds

4.4 Tools for Data Processing, Analysis and Presentation

Excel, ArcGIS and WEAP were employed in processing and analyzing the data.

4.4.1 WEAP Model Structure

Water resource system is represented in terms of groundwater, reservoirs withdrawal, ecosystem requirements and water demands among others. The model can be customized to reflect the limits caused by restricted data (Sieber *et al.,* 2005).

The model consists of five main views:

- **Schematic;** The study area is defined in the schematic view. It is a GIS based tool which allows vector or raster layers to be imported and used as background layers. It uses a drag and drop method in which objects such as demand nodes and reservoirs among others are positioned. This allows for easy changes and modifications.
- **Data;** The data view is where required data such as climate, reservoir data etc are entered into the program. Data can also be imported from Excel.
- **Result;** The results display every model output which can also be exported to excel for further modification.
- **Overview;** This allows for easy accessibility of key indicators in the model.
- **Note;** This view allows for notes to be added to the model for documentation of the key assumptions

4.4.2 Modelling Process of WEAP

Levite (2000) outlined the following steps in modelling a watershed using the WEAP

- Definition of the study area and time frame; setting up the time frame includes the last year of scenario creation and the initial year of application.
- Creation of the Current Account which is the existing water resources situation in the study area. Under the current account, available water resources and existing demand

nodes are specified which can be used for calibration of the model to adapt it to the existing situation of the study area.

- Creation of scenarios based on future assumptions and expected increases in the indicators. This forms the core or the heart of the WEAP model since it allows for possible water resources management processes to be adopted from the results generated from running the model. The scenarios are used to address a lot of "what if situations", like what if reservoirs operating rules are altered, what if groundwater supplies are fully exploited, what if there is a population increase. Scenarios creation can take into consideration factors that change with time.
- Evaluation of the scenarios with regards to the availability of the water resources for the study area. Results generated from the creation of scenarios help the water resources planner in decision making.

4.4.3 Input Data

- GIS based vector layers of the Upper West Region portion of the Black Volta Basin was obtained from the Volta Basin Starter Kit July (2006). The kit provided information on runoff data and other relevant data.
- The current account (CA) year was considered to be 2010 and runoff data for the CA was obtained from the Hydrological Services Department.
- Boundaries of the study area were set using the raster layer of the Volta Basin system. Streams in the area were redrawn using the drag and drop button of the river button in the WEAP model.
- Data on the water use and areas of irrigation was obtained from community interviews, MOFA and GIDA

4.4.4 Calibration of the Model

WEAP was calibrated to determine values of a set of key parameters which represent the physical characteristics of the catchments after which scenarios were developed. The key parameters included soil water capacity, root zone conductivity and runoff resistance factor, and exploring how well the model reproduced river flows as observed at any given gauge station. The historical river flow data used dated from 1965 to 2007.

One aspect is to check the quality of calibration by analyzing with the Nash and Sutcliffe coefficient (1970) defined by the equation:

$$E = 1 - \frac{\sum_{t=1}^{N} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{N} (Q_o^t - \overline{Qo})^2}$$

Where Q_o is observed discharge, and Q_m is modeled discharge. $Q_o{}^t$ is observed discharge at time t and N is the number of observations on monthly time step. The coefficient compares the sum of squared errors in estimation to the variance of Q. The greater its value, the better the model reproduced observations, and 1 being exact reproduction. The river flows were estimated to range between 10.5% and 19% of volume of annual rainfall, 70% to 77% volume contributed to evapo-transpiration whiles the rest went for groundwater recharge (Liebe, 2002). Demand sites were limited particularly to hydropower, environmental flows, irrigation, and livestock watering. The demand sites in the model were denoted with the corresponding name of the town or catchment where the small reservoir is located.

4.4.5 Priority for Water Allocation

The "demand priority" ranges from 1 to 99 depending on the significance attached to the demand site and water demand with priority "1" means that as long as there is flow in the river or stream, that demand must be satisfied first and so on, whereas 99 will be served last.

In the case of this study, the highest priority is given to domestic and environmental needs and the lowest is industrial (Table 4.1). Meanwhile, the water stored in the small reservoirs would fulfil partly the water needs of small scale irrigation activities while serving as water source to livestock. The simulation was based on the trend of reservoirs construction over the past 50 years 1951-2010

Table 4.2: Demand Priority for demand site

Demand	Priority
Domestic	1
Environmental flows	1
Irrigation	2
Livestock	2
Hydropower	3
Industrial uses	4

.

4.4.6 Development of Scenarios

This section focuses on development of scenarios to assess the effects of increasing number of small reservoirs on water availability and allocation among various water users including projected development(s). The Scenarios were developed over a 30-year period with the "base" or "current" year of simulations being 2010. For the purpose of this study, three scenarios were created as follows: 'reference', '3* and 5* increase rate of small reservoirs development" scenarios.

- ✓ **Reference scenario**

In this scenario, there was no change in the rate of small reservoirs development relative to historical trends (1.7 %). Average growth rate of reservoirs development in the respective catchments were computed given the historical trend from 1951 to 2010 which was found to be 1.7 % per annum**.** The current trend of growth rate was then used in the respective key assumptions for the various catchments. Presently, there are 190 SRs in the Ghana portion of the Basin and an annual growth rate of 1.7% implies, 90 more reservoirs will be added to the 190 from 2010 to 2040 resulting in 280 small reservoirs by 2040.

- ✓ **Scenarios under increase in number of SR**

These set of scenarios were informed by the 2011 annual report of GIDA which indicated that trend of reservoirs development in the Upper West Region is likely to increase beyond the historical trend as more donor funds are being channelled into their construction and rehabilitation while NGOs and CBOs also engage in small reservoirs and dugouts development. The report however, did not indicate the specific expected growth rate. Hence, this scenario assumed the growth rate to be 3 and 5 times the historical trend (1.7%) in order to analyse their possible impact on runoff in the Black Volta. Two situations were considered under this scenario:

- ***3 times growth rate relative to historical trend***
- ***5 times the growth rate relative to historical trend***

This scenario evaluates the impact on runoff **assuming** the growth rate relative to historical trend (1951-2010) which is 1.7 % is tripled (3×) or multiplied by 5. The average growth rate of reservoirs developments in the various catchments (1.7%) were then multiplied by the respective key assumptions (3 and 5) against the number of reservoirs recorded in the reference scenario for the catchments.

With the three times annual growth rate (3*1.7%), 10 reservoirs will be added on a yearly basis resulting in about 490 small reservoirs by 2040.Also for the five times annual growth rate (5*1.7%), 12 reservoirs will be added on a yearly basis resulting in about 550 small reservoirs by 2040.

5. RESULTS AND DISCUSSION

5.1 Delineation of Sub-catchments of the Black Volta Basin

There are nine sub catchments in the Black Volta basin (Figure 5.1) out of which five fall within Ghana (Dapola, Noumbiel, Vonkoro, Bui and Bamboi). Meanwhile, the Upper West portion of the basin as indicated in Figure 5.2, comprise of three sub catchments (Dapola, Noumbiel and Vonkoro) and the WEAP model developed, looked in detail at water allocation in this portion.

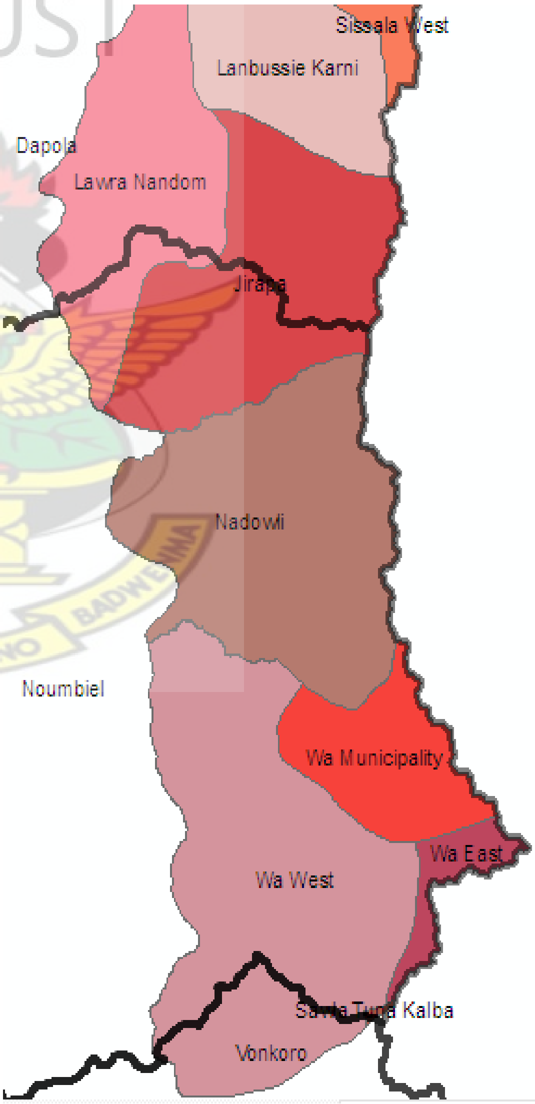


Figure 5.1: The Black Volta sub catchments **Figure 5.2: UWR portion of the BVB**

5.2 Results from the WEAP Model

Having "inputted" monthly hydro-meteorological data and water consumption requirements of various water uses, the model was run and WEAP explored to ascertain the available water resource as well as the impact of small reservoirs and dugouts on the resource while examining the extent to which projected reservoirs developments over 30 years will impact on water allocation. The various demands considered in the model are as shown in Figures 5.3

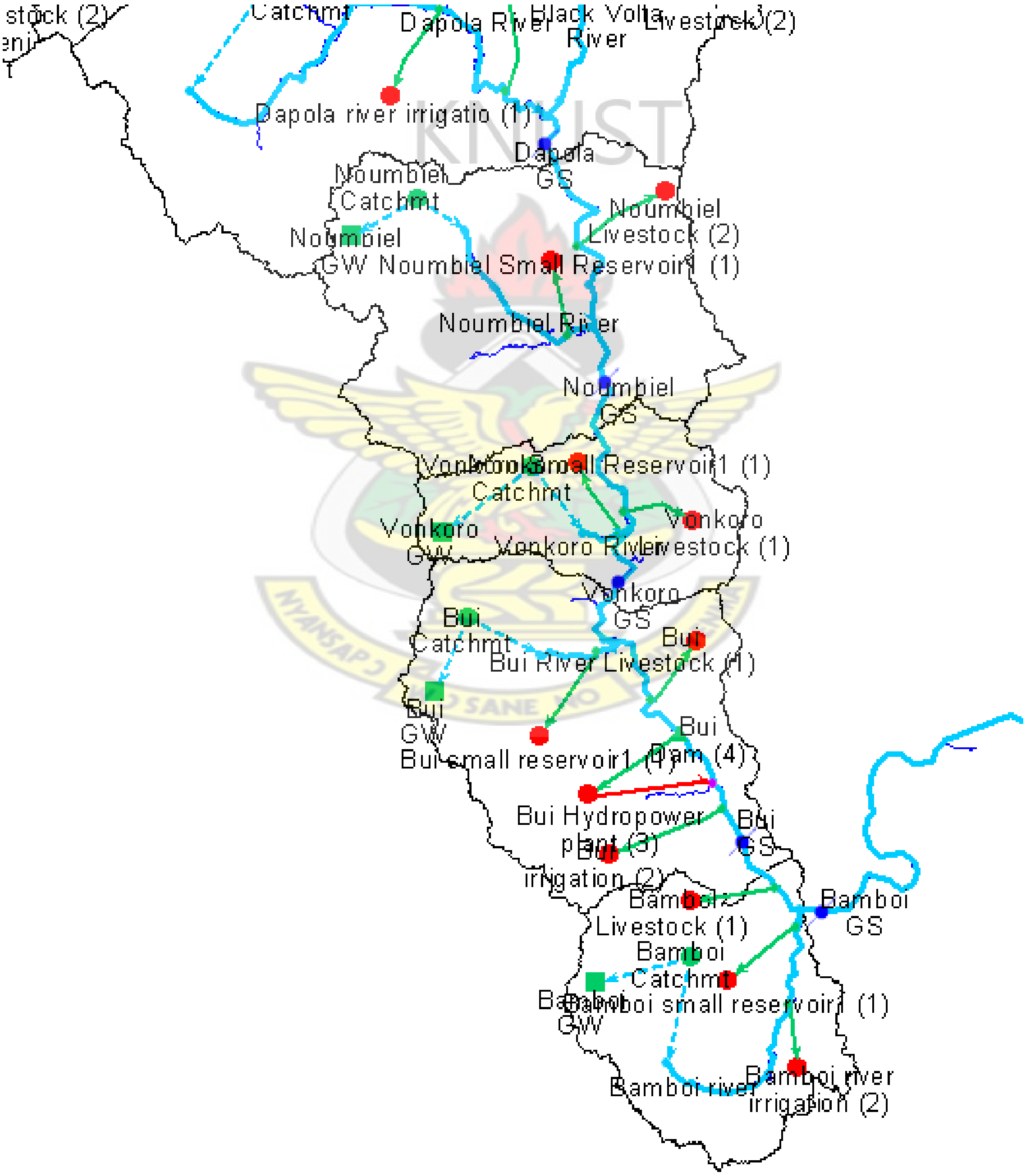


Figure 5.3: Schematic view of the WEAP Model for the Ghana portion of the Basin

Water for exploitation derived from precipitation is introduced into the model through a catchment object represented by a ***green dot,*** Demand site (water use) is shown in the Model's schematic as ***red dots***, ground water objects as ***green box*** and gauge stations as ***blue dots***.

5.3 Water Resource Assessment with WEAP

5.3.1 Annual Renewable Water Resource

Like any other hydrologic model, precipitation contributes to runoff, groundwater recharge, evapo-transpiration and storages. As a result, WEAP extracted the volume of water available for use from the "inputted" monthly precipitation data. As shown in Figure 5.4, the annual precipitation volume in the five catchments in Ghana ranges between a minimum of 47 Billion m^3 and maximum of 79 Billion m^3 under the ***reference*** condition. The maximum infiltration runoff is about 8 Billion m^3 and the minimum is 790 Million m^3 (Figure 5.5).

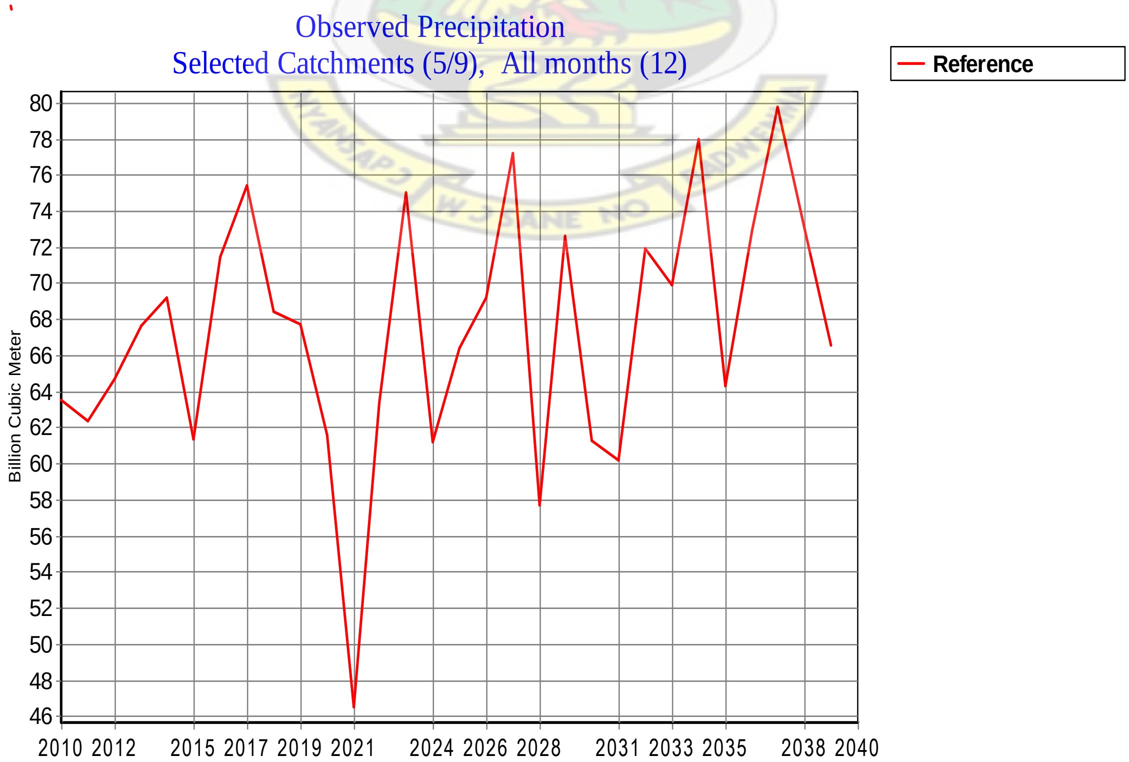


Figure 5.4: Annual total precipitation volume in Ghana portion (5 sub catchments)

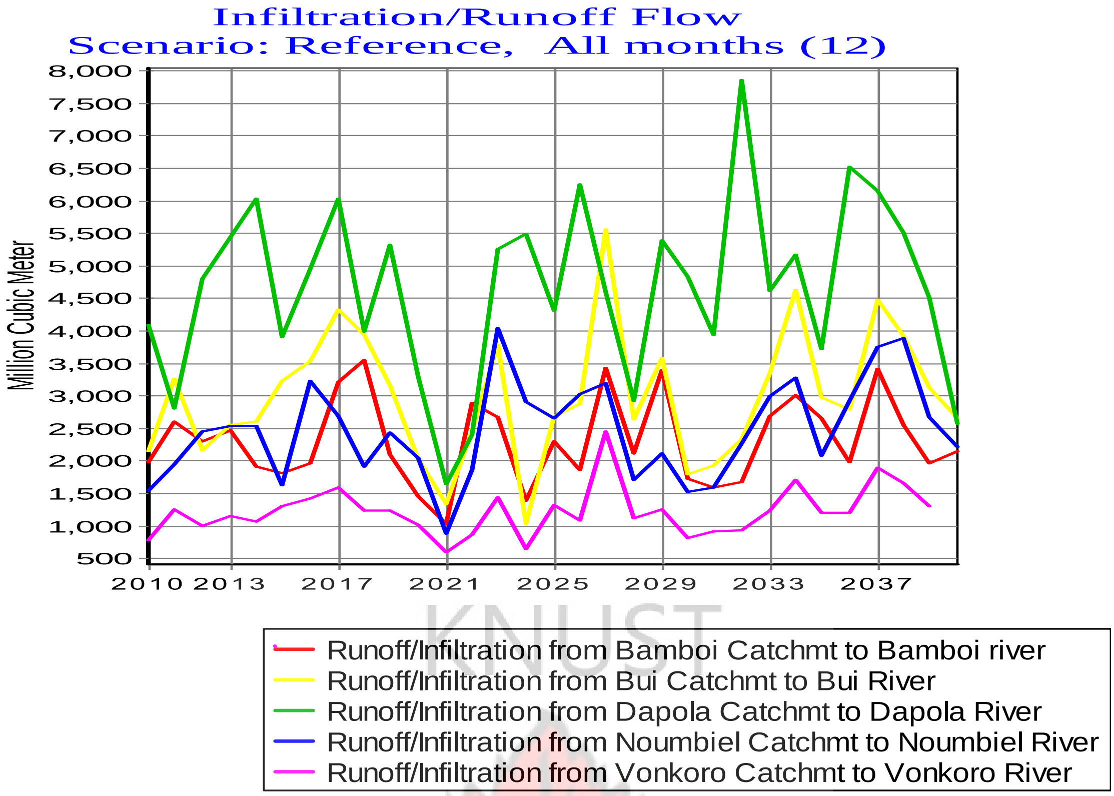


Figure 5.5: Infiltration-runoff in the Black Volta sub catchments within Ghana

5.3.2 Exploitable Water Resource

The Black Volta River and its main tributaries (Bougouriba, Gbongbo, Grand Bale, Voun Hou, Sourou, Wenare, Bambassou, Bondami, Mouhoun (main Black Volta), Tain and Poni rivers) constitute a relatively evenly distributed surface water drainage network and the mean runoff in the Black Volta is estimated at 7 km^3 per annum. Most of these tributaries decrease to little or no flows in the dry season and the driest and wettest months are March and September, respectively (Annor, 2012). Figures 5.6 and 5.7 depict the flows for September during which peak runoff is experienced in the BV at Lawra (upstream) and Bamboi (downstream) gauge stations.

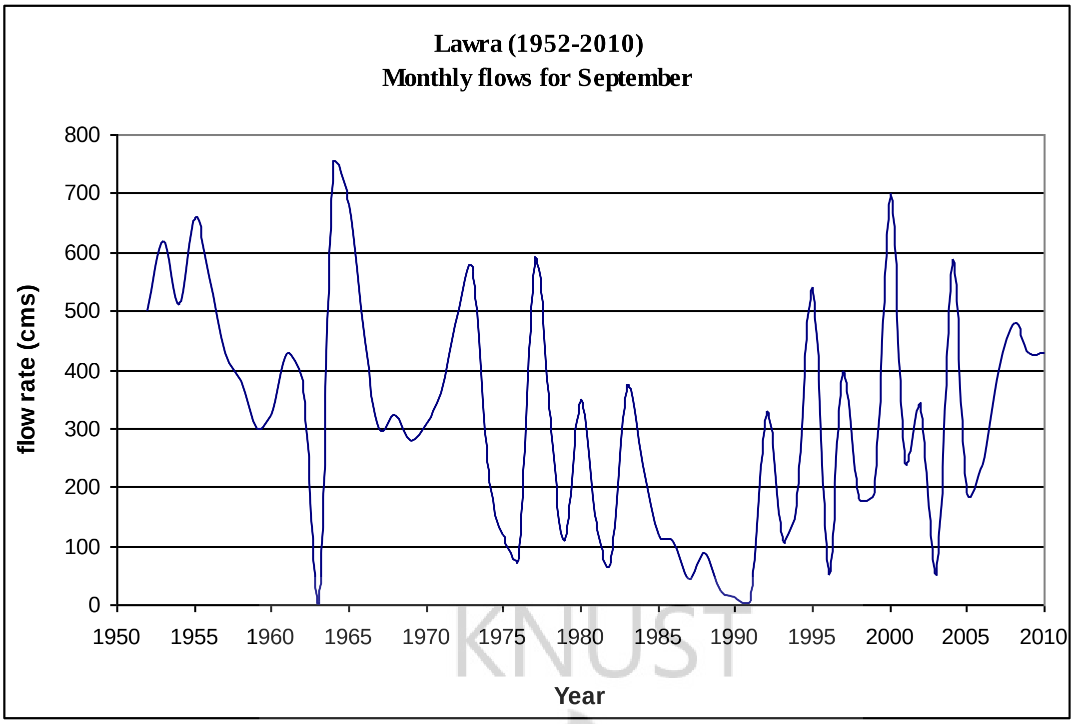


Figure 5.6: Monthly flows for Lawra (1952-2010)

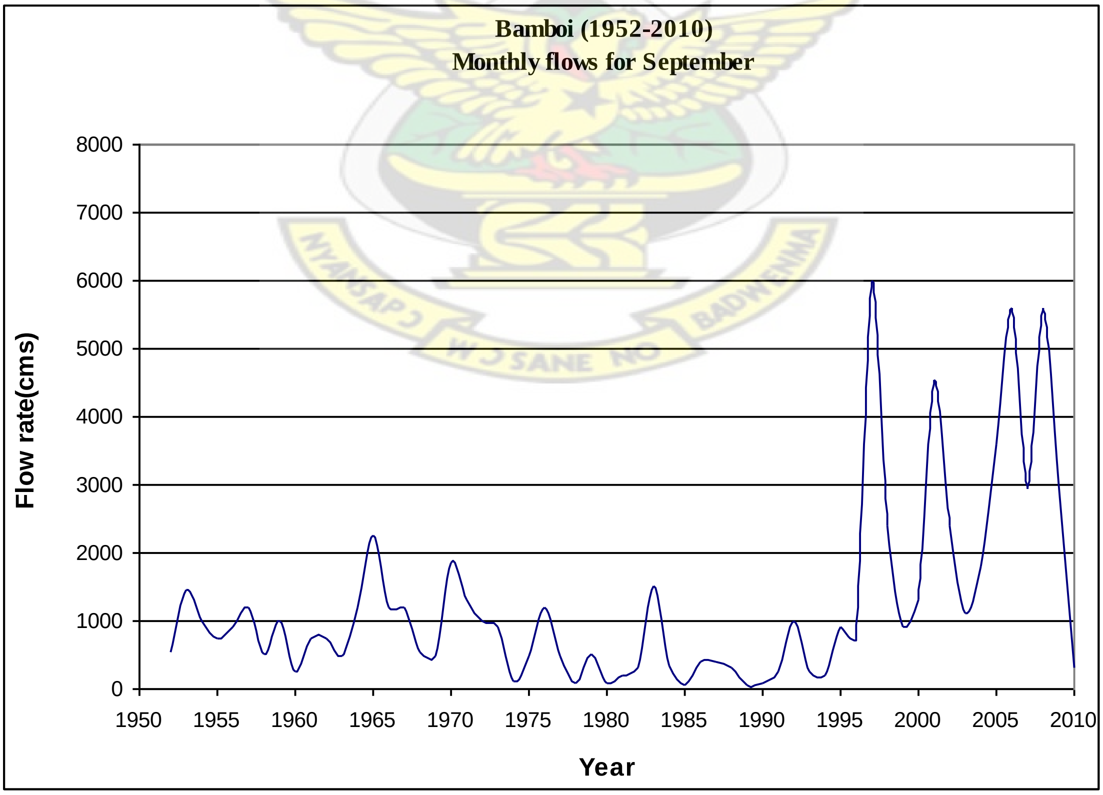


Figure 5.7: Monthly flows for Bamboi (1952 – 2010)

The minimum monthly gauge flow in Lawra is about 8 m^3/s (Figure 5.6) and the maximum is 600 m^3/s in Bamboi (Figure 5.7). Both gauge stations experienced similar trend but a more sudden rapid increase from 1996 in the case of Bamboi. The relatively high flows in Bamboi could be attributed to its location at the downstream end, as water from all the upstream catchments flows through it. More over, Barry *et al.* (2005) indicated that Bamboi falls within the moist semi deciduous forest zone where rainfall is relatively higher than Sahel savannah where the Lawra station is located.

The annual volume of water flowing from Dapola catchment into the Black Volta River (main) as indicated in Figure 5.8, is the highest of about 36 Bm^3 and Vonkoro contributes the least volume of about 4 Bm^3.

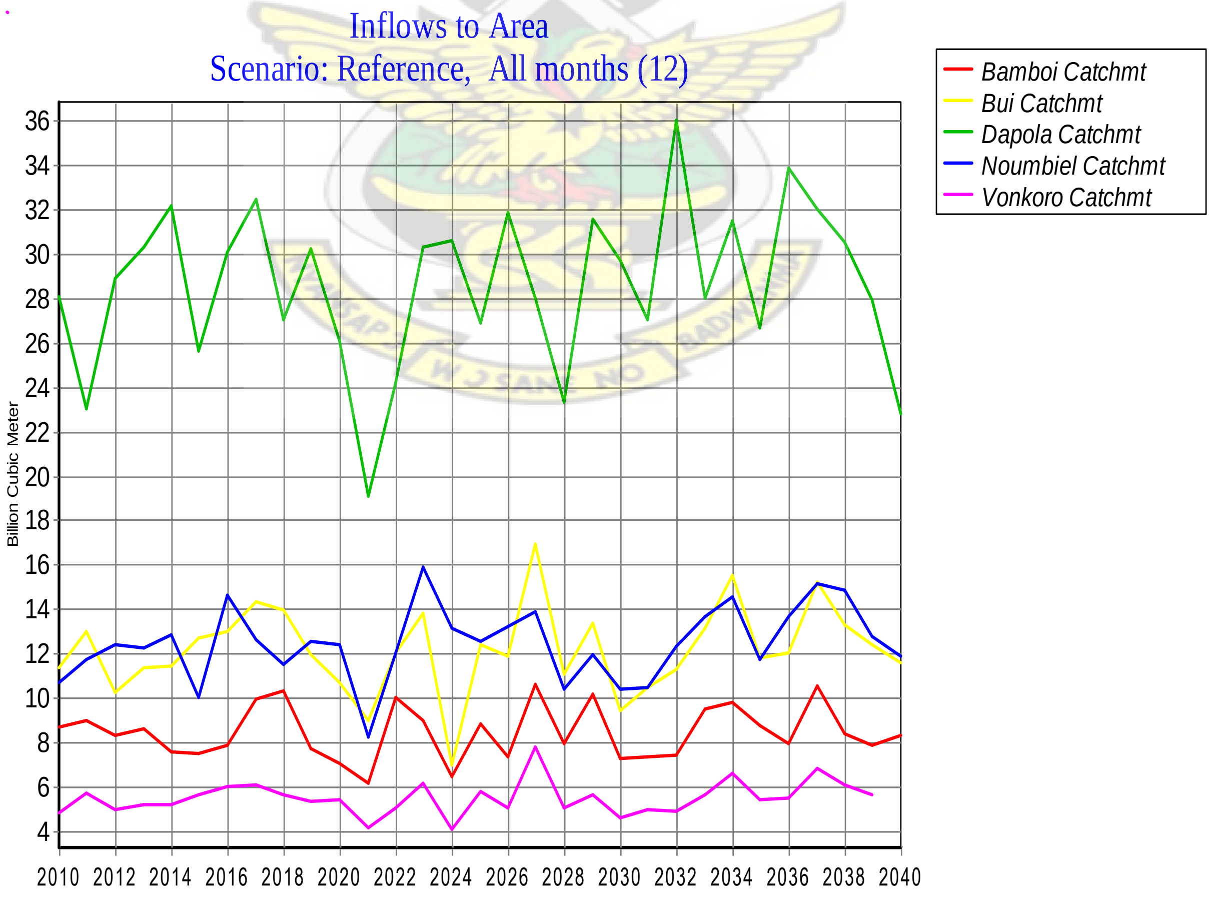


Figure 5.8: Inflows from the various catchments

Howarth and Sefton, (1998) indicated that Climatologic and geophysical characteristics of the landscape have a large influence on stream discharge and hydrological responses of watersheds. This not withstanding, the area of the catchments may also play a role as the flow is highest for Dapola which has the largest area and then Noumbiel, Bui, Bamboi and Vonkoro in that order (Table 5.1) .

Table 5.1: Area of sub catchments in the Black Volta Basin (km^2)

Name	Bamboi	Bui	Dapola	Noumbiel	Vonkoro	**Total**
Area of Sub-basin (km^2)	7525	11590	31680	12499	5347	**68641**

5.4 Impacts of SR on Water Allocation -Assessment with WEAP

Based on the field assessment, the main water requirements considered in the model include; Bui hydropower requirement, Environmental flow and three consumptive uses;

- ✓ Small reservoir water requirements
- ✓ Livestock water requirements
- ✓ Irrigation development projects/schemes

5.4.1 Small Reservoir Water Requirements

Water demand is estimated at 102 Mm^3 for the entire Volta Basin while the in the Upper West Regional portion of the Black Volta Basin alone, the annual water demand for small reservoirs was found to be 4.2Mm^3 representing about 4% with respect to small reservoir demand for the entire Volta Basin (Annor, 2012).

There are about 190 small reservoirs and dugouts in the entire Ghana portion of the Black Volta Basin which falls within three administrative regions (Upper West, Northern and Brong

Ahafu). The distribution of small reservoirs under the three regions based on sub catchments is given in Table 5.2.

Table 5.2: Inventory of small reservoirs per catchment in the Basin

Catchment	Districts Under catchment	No. of Reservoirs
Dapola	Lambusiee- Karne, Parts of Lawra, Jirapa & Small part of Sissala West,	57
Noumbiel	Nadowli,Parts of Lawra, Wa Municipal Wawest & small fraction of Wa East and Jirapa	62
Vonkoro	Small fraction of Wa West and Bole-Bamboi	19
Bui	A greater portion of Whenchi, some parts of Suyani, Berekum, Jaman, Techiman and small fraction of Kintampo.	23
Bamboi	Some parts of Kintampo and Bole-Bamboi	29
Total		**190**

The number of reservoirs in the basin varies from catchment to catchment. As shown in figure 5.9, Noumbiel catchment has the highest number of small reservoirs and dugouts with Bamboi having the least number. It is important to note that because Bui and Bamboi are forested areas, locating water collecting systems on the image during image processing was a bit challenging since almost every part appears to be covered with vegetation.

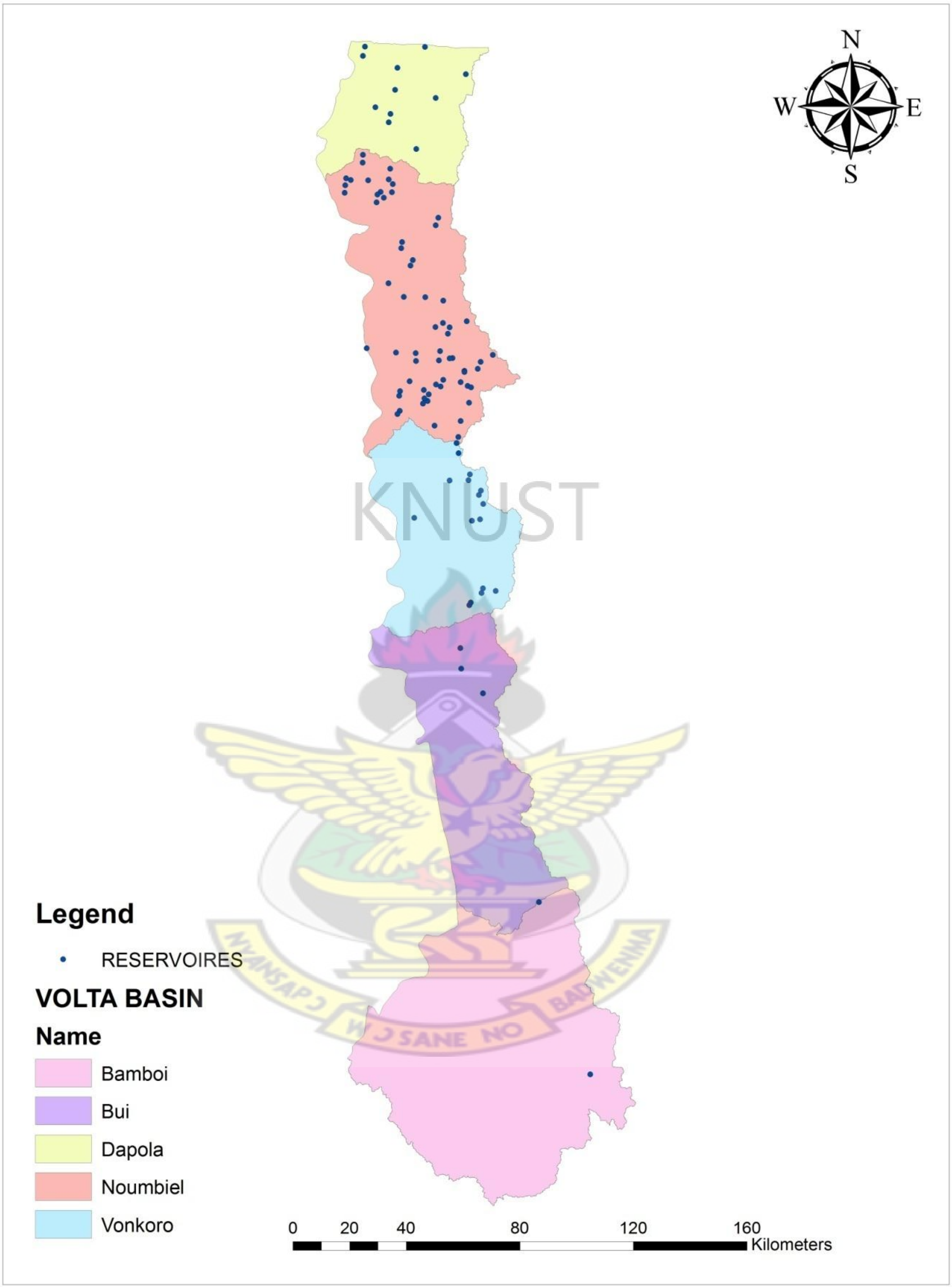


Figure 5.9: Distribution of Small Reservoirs and Dugouts in portion of the BVB within Ghana

As indicated in Figure 5.10, the water requirements of small reservoirs in all five sub-catchment are fully met under the extreme condition of "increased rate of small reservoir development scenario" since the percentage of requirement met is 100 for all months except for the month of April where the coverage is 96.8 %. The month of April is the peak of dry season with water levels in most reservoirs reducing to the lowest level. It's important to note that reservoirs refilling begins at the latter parts of April since there are usually few minor rains.

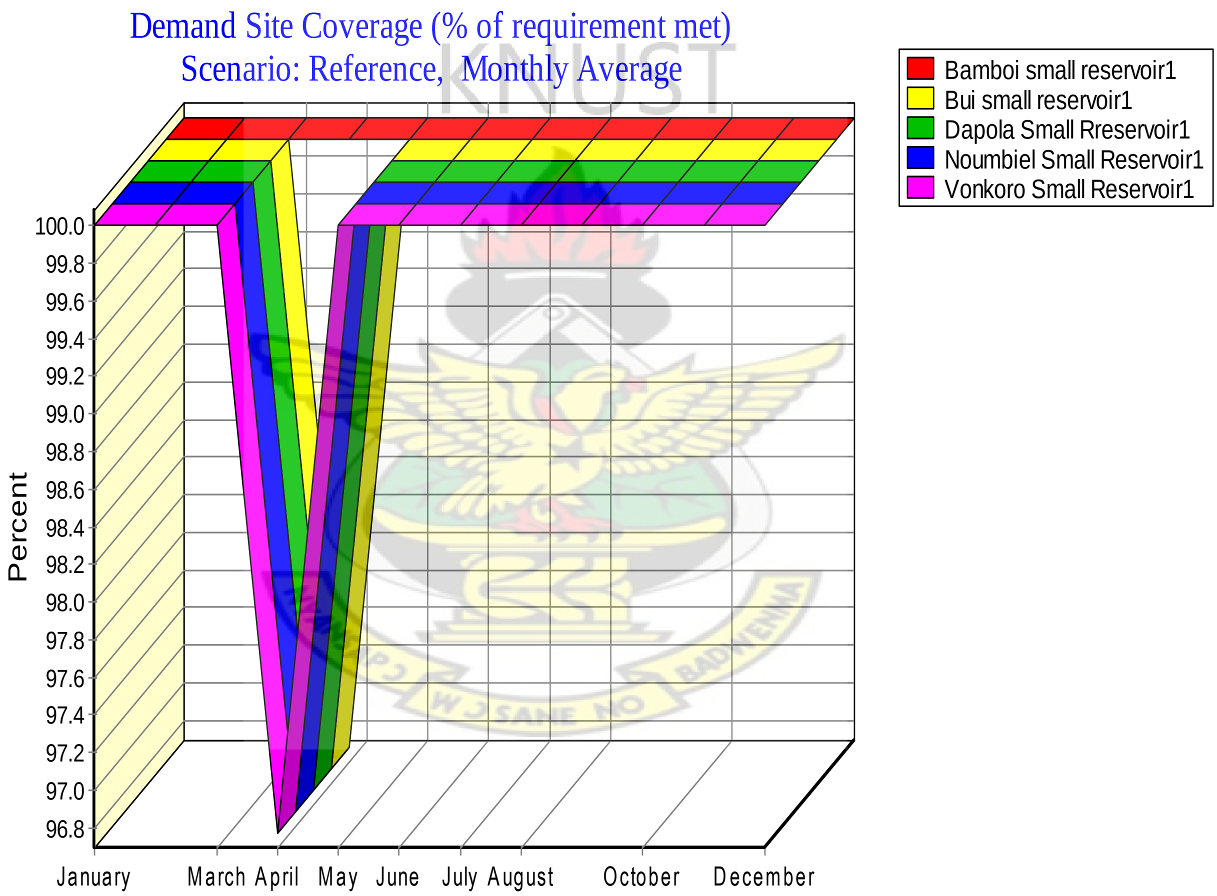


Figure 5.10: Small Reservoirs demand coverage

5.4.2 Irrigation Development Projects/Schemes

Almost all irrigation schemes in the UWR are small-scale who's requirement are met with SR. Bui irrigation is the only large irrigation scheme in the basin within Ghana and has an estimated water use rate of 20,000 m^3/ ha/ year and a projected irrigable land of about 800 ha by 2030 (Annor, 2012).

As indicated in Figure 5.11, water in the basin can meet fully irrigation water requirement from the month of May to December. Unmet demand for January and February is about 40 thousand cubic meters while the month of March and April which are the peak of dry season recorded 55 thousand cubic meters of unmet water requirement. This means the projected increased Small reservoirs development would rather improve upon water availability leading to decreasing unmet demand for irrigation in the dry season period.

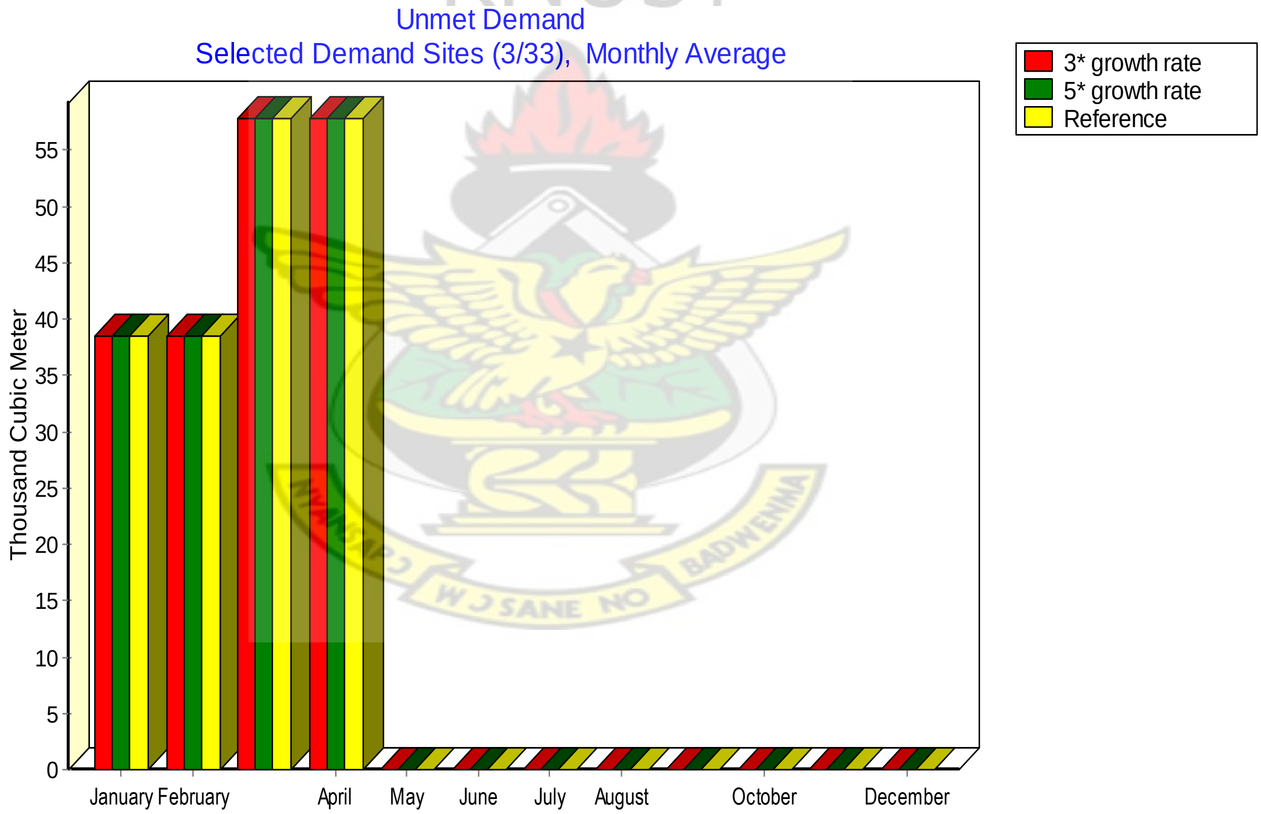


Figure 5.11: Unmet demands for all scenarios in 3 catchments

5.4.3 Livestock Water Requirements

Small ruminants like goats and sheep obtain water from dugouts and small reservoirs but occasionally use rivers, streams and water trough of boreholes while livestock such as cattle, donkey and horses water from the rivers and sometimes small reservoirs. The number of goats is a little over 200,000 herds (Table 5.3) which are the major livestock kept in the region with an annual water use rate of about 1.7 Mm^3. The tropical livestock unit (TLU) was applied to the livestock population and the water requirements assessed (Table 5.4).

Livestock watering in the WEAP model is considered to be from the river. Hence, if their demand was unmet in the model, practically they will be met by the small reservoirs and dugouts. However, since the demand site coverage (Percentage of requirement met) for May to December is 100 % (Figure 5.12), livestock requirements are met within this period despite their huge population in the basin (Table 5.3).

Table 5.3: Livestock population (herd) in the Upper West Region

District	Livestock type					
	Cattle	**Sheep**	**Goats**	**Swine**	**Donkeys**	**Horses**
Jirapa-Lambussie	20442	18486	43173	20318	1949	1
Lawra-Nandom	11696	13528	31201	14761	341	1
Nadowli	11539	15666	41295	12694	124	4
Sissala East	22459	8481	15055	487	726	7
Sissala West	15829	9069	14222	2390	1558	2
Wa East	14502	4383	13580	1829	20	0
Wa Municipal	7100	9368	15455	3418	385	230
Wa West	18601	17156	34941	14085	378	1
TOTAL	**122168**	**96137**	**208922**	**69982**	**5481**	**246**

Sorce*:* Annor, 2012

Table 5.4: Livestock Water demand in the Upper West Region of Ghana

Livestock	Number of herds	TLU per Livestock	Total TLU	Water demand (Mm^3)/year
Cattle	122168	0.7	85518	1.092
Sheep	96137	0.1	9614	0.123
Goats	208922	0.1	20892	0.267
Swine	69982	0.2	13996	0.179
Donkeys	5481	0.4	2192	0.028
Horses	246	0.7	172	0.002
Total	**502936**	**2.2**	**132384**	**1.691**

Sorce:Annor, 2012

Figure 5.12 shows some unmet demand from January to April with Vonkoro having the least unmet demand for the same period. Bamboi recorded the highest unmet demand of 2,500 and 2,000 cubic meters for January and February respectively. Also, Dapola, Bui and Noumbiel recorded the highest unmet demand in March and April through out the simulation period. This could be attributed to the fact that, these four months (January February March and April) are the dry season period and the situation may limit the expansion of livestock in these catchments. Nonetheless, constructing more reservoirs to capture water in the rainy season may help since the situation is due to drying up of reservoirs and rivers in the dry season, putting livestock into cyclical migration to seek water and greener pasture in other communities where there is water or otherwise the main Black Volta.

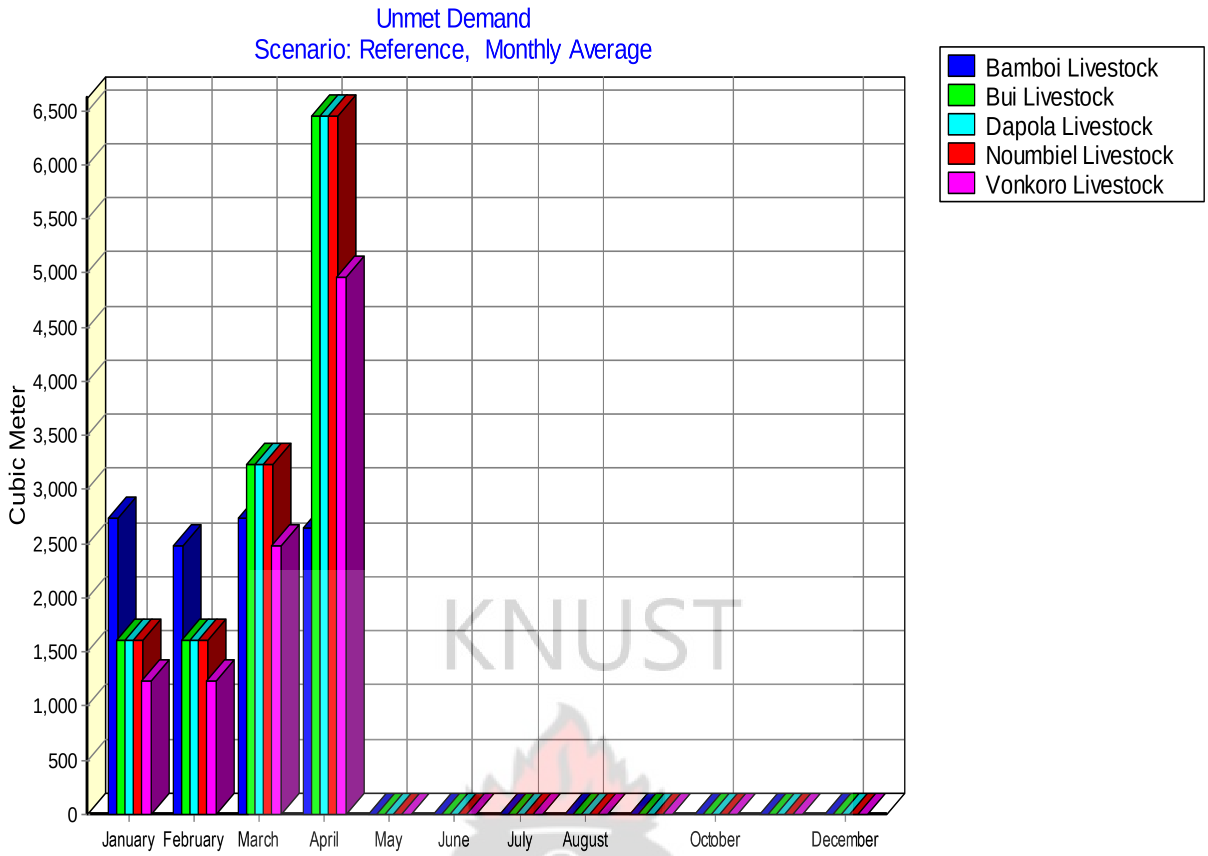


Figure 5.12: Unmet demand for livestock in all years

5.4.4 Other Water Requirement

Other water requirement such as domestic, fishing and industrial were not included in the model as demand sites though they were identified in the study area. The populace of the Upper West Region obtain potable water supply largely from GWCL which supply urban dwellers and CWSA supply water to the rural populace. Rural domestic water demand is estimated as 50 l/c/day while that of urban population in the basin is estimated at 120 l/c/day.

5.5 Implications of Reservoirs Development on the Hydrology of the Basin

5.5.1 Trend of Reservoirs Development

Following Ghana’s independence in 1957, considerable investments were made in small reservoirs in the 1960’s. The late 1980s and early 1990s saw a revamp of small reservoirs development (Venot, 2011). This situation is true in the case of this study since only 31 small reservoirs were constructed in the Upper West Region between 1950-1980 while 114 were constructed between 1985 and 2010. Hence, the period (1981-2010) is referred to post-impact phase and before the massive construction of SR (1951-1980) is referred to as pre-impact phase.

The trend of reservoirs development (cumulative) in the Upper West Region is shown in Figure 5.13. Projections were made based on the current trend. The average rate of small reservoir development from 1955-2010 is about 1.7 % per annum. This was used in the model for the "reference scenario".

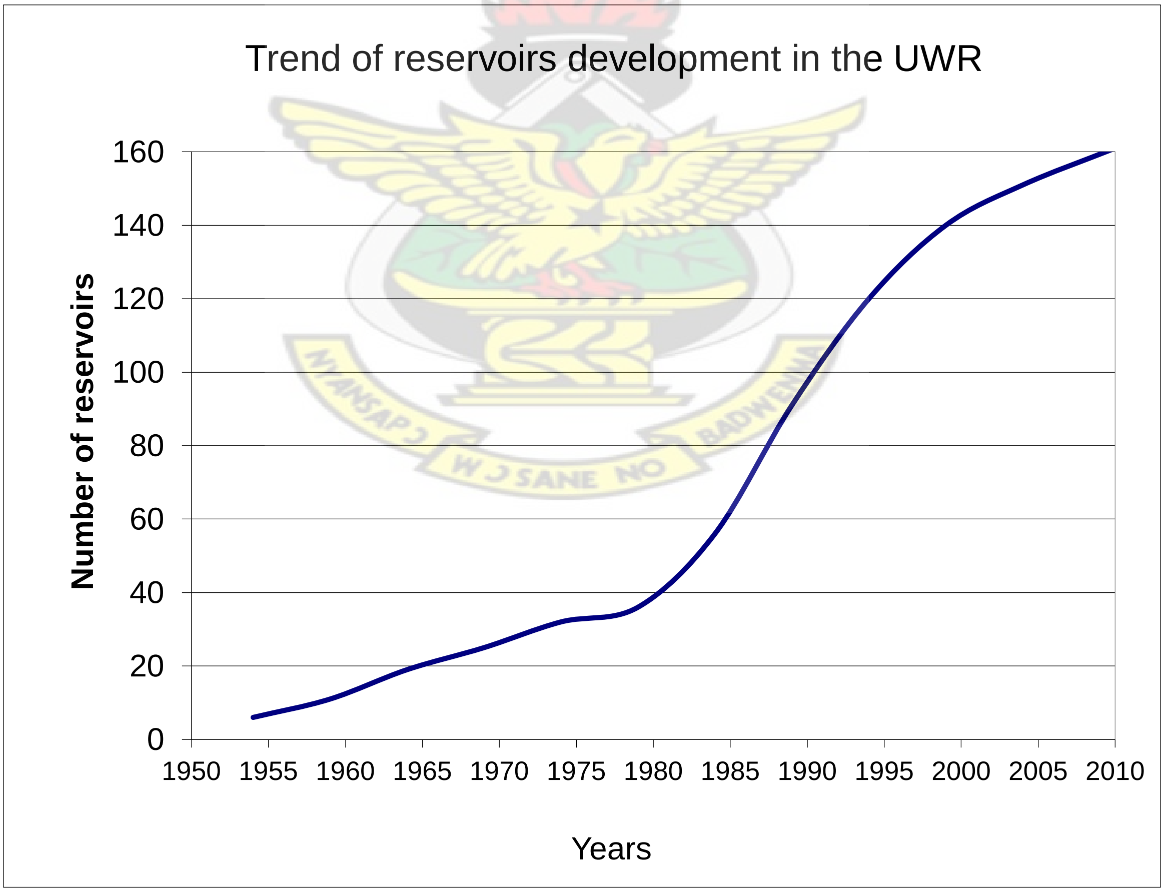
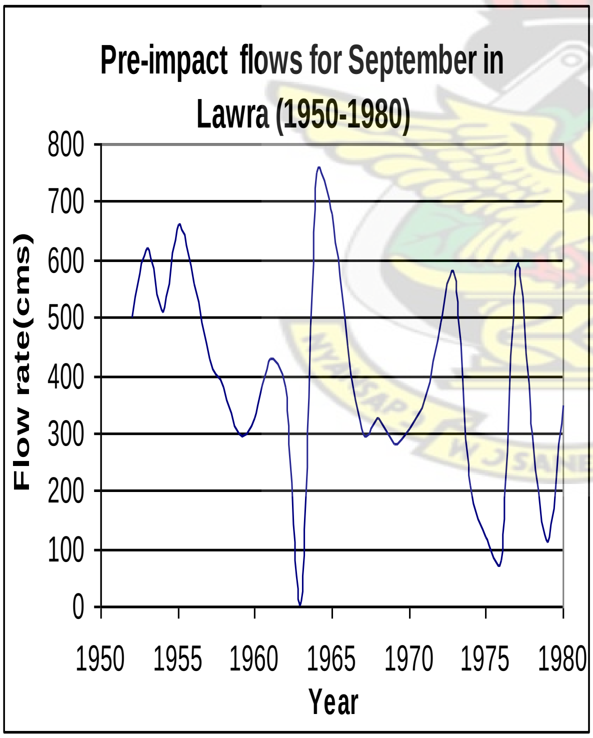


Figure 5.13: Trend of reservoirs development in the Upper West Region

5.5.2 Impacts of Reservoirs on Flows in the Black Volta

As shown in Figure 5.14 and 5.15, the maximum monthly gauge flow for Lawra in the pre-impact phase is the highest of about 750 m^3/ s while that of the post-impact phase is 700 m^3s. The general trend of flows shows a decline in runoff into the Black Volta from the 1990s to date. Also, the Bui gauge station experiences a similar trend with the maximum runoff during the pre-impact phase being 2,350 m^3s which is far higher than that of the post impact phase which is 1,400 m^3s (Figure 5.16 and 5.17). Despite the decline in flows towards the post impact phase in both gauge stations, it is important to note that the decline is not significant though a sharp decline was recorded from 1960 to 1965 in the Bui gauge station.



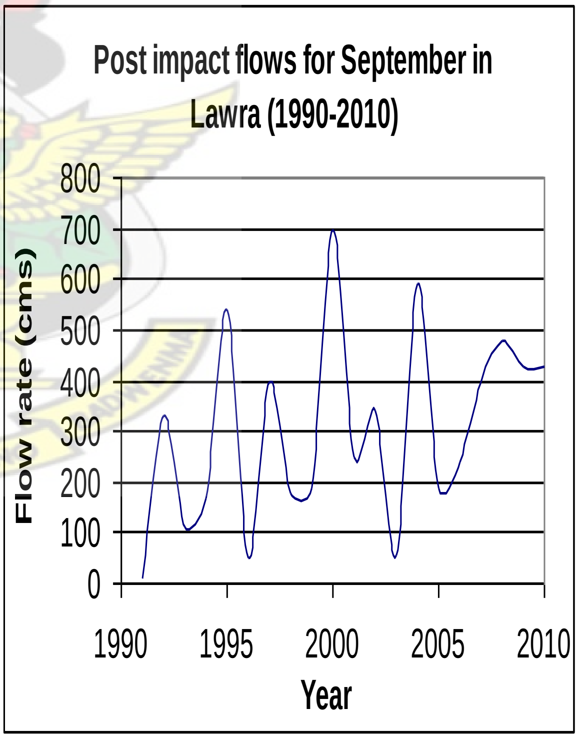


Figure 5.14: Pre-impact flows at Lawra

Figure 5.15: Post-impact flows at Lawra

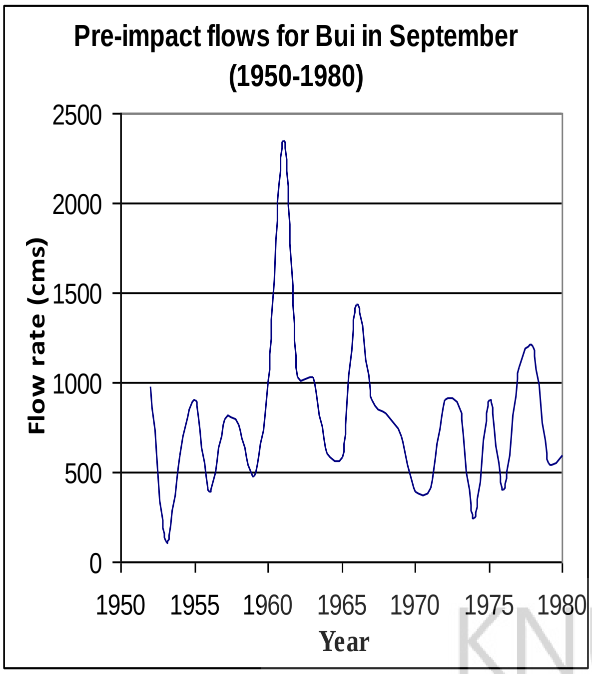


Figure 5.16: Pre-impact flows at Bui

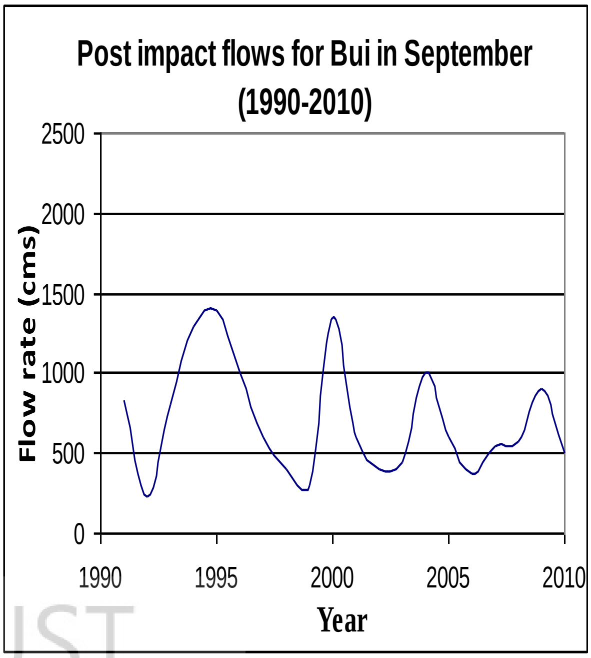


Figure 5.17: Post-impact flows at Bui

As shown in Figure 5.18, the highest total rainfall (precipitation) which is 350 mm was recorded in the year 2000 which is within the post impact era. Generally, there is also no significant decline in rainfall pattern. .

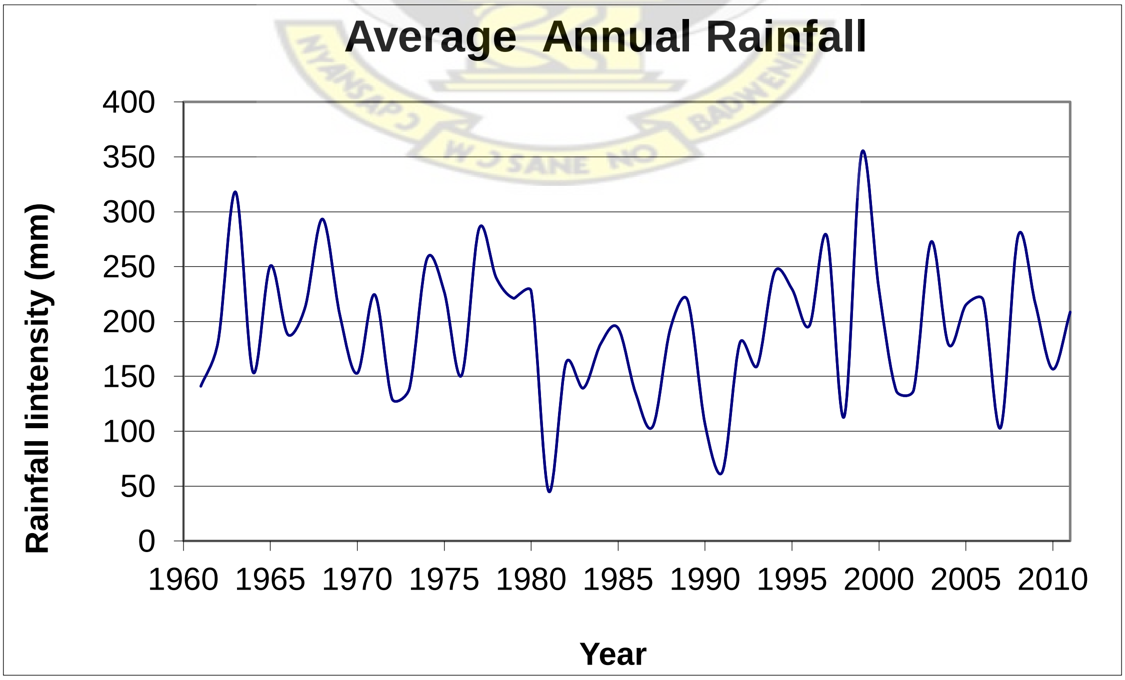


Figure 5.18: Total monthly precipitation for the Upper West Region

The decline in river flow (though not significant) suggests that increasing trend of reservoirs construction and development upstream of the basin (Burkina Faso) contribute to the declining flows since reservoirs collect water which would have otherwise been emptied into the river course. Apparently, Peters and Seth (2001) indicated that, increase water storage systems on the landscape in the form of small reservoirs and ponds among others, are important land use changes that influences the river systems. Not denying the fact that urbanization with its associated increase area of imperviousness is key to impacting the hydrology of rivers.

Though there is evidence of the small reservoirs playing a role in declining river flow, the contribution of possible development in Burkina Faso (upstream) were not considered in this study. Hence, it is important to know the role these small reservoirs play in declining runoffs.

5.5.3 Extent of Reservoirs Impact on Runoff

The total inflows from the five sub-catchments is about 68.5 Billion m^3 (Table 5.5) and the average total volume of reservoirs excluding the Bui dam in the Ghana portion of the Black Volta basin is estimated at about 0.0063 Bm^3. Also, the total infiltration per annum is 0.225 Bm^3 and the Full Supply Level (FSL) of the Bui dam is 12.7 Billion m^3. This suggests that out of the 68.5 Billion m^3 of water that comes into these catchments via rainfall-runoff, only 12.93 Billion m^3 is actually collected by Bui dam, small reservoirs, dugouts and infiltration to ground water. Consequently, the remaining 55.57 Billion m^3 flows away from the catchment. Thus, a large quantity of water resource flows down to the Volta Lake and subsequently to the sea untapped. Although these flows are useful for hydropower production downstream, there is great opportunity to construct more reservoirs upstream to capture the fugitive resource to harness water upstream for productive uses to improve livelihoods while still meeting hydropower needs downstream in the Bui dam and Akosombo.

Table 5.5 Average volume of reservoirs and inflows from sub-catchments

Sub-Catchment	No. of reservoirs	AVG.Vol. of SR (Bm^3)	Total Vol. of reservoirs (Bm^3)	AVG. inflows from catchment (Bm^3)	Infiltration (B m^3)
Dapola	57	0.000019	0.001083	29	0.0825
Noumbiel	62	0.00005	0.0031	12	0.040
Vonkoro	19	0.00002	0.00038	6	0.020
Bui	23	0.000011	0.000253	13	0.0475
Bamboi	29	0.00005	0.00145	8.5	0.035
Total Vol.	**190**	**0.00015**	**0.0063**	**68.5**	**0.225**

5.5.4 Possible Impacts on Downstream Water Users

The Bui dam which is due to be in full operation in 2014 is a key water infrastructure for the country and the dam is located downstream of the Ghana portion of the Black Volta Basin with a potential storage volume of about 12.7 Bm^3. Figure 5.19 indicates no (0) unmet demand for all the sub catchments in the Ghana portion of the basin including Bui. This implies the water requirement of the Bui dam is fully met and consequently, the current and projected reservoirs development seems to have no negative impact on the Bui dam which is the major demand site downstream.

5.5.5 Potential for Further Reservoirs Development and their Impacts on Hydrology

The unmet demand is 0 for the five catchments under all scenarios including the extreme case of 5*growth rate scenario where 360 SRs will be added making 550 by the year 2040 (Figure 5.19). This implies the demands of all water users in the five catchments are fully met; hence it is possible from the hydrological point of view to develop up to 350 reservoirs (the case of 5*growth rate scenario) without impacting negatively on the water users downstream as well as environmental flows.

Contrary to Bartley *et al*. (2002) statement that, there is ***usually*** less surface water downstream of reservoirs posing significant environmental and hydrologic effect while starving the downstream areas of water, this study found out that, the downstream areas do not experience any water shortage even with the projected increased rate of reservoirs development. Rather, water resources' emanating from the various sub-catchments is underutilized or untapped. Hence it is important to note that, 'upstream reservoirs affecting downstream demands' vary with catchments/ basins as the quantum of runoff/overland flow from the various catchments are a function of Climatologic and geophysical factors.

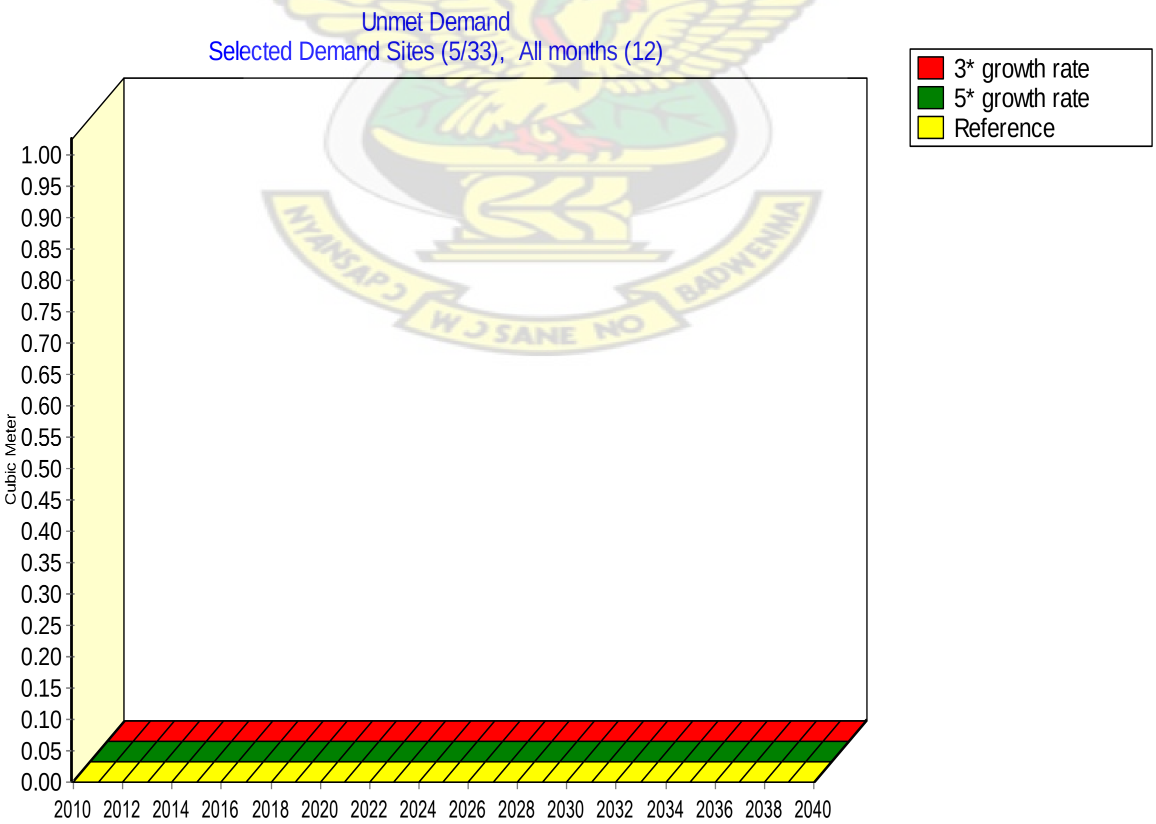


Figure 5.19: Unmet water demands for all scenarios in the five catchments

Developing large numbers of small reservoirs will help solve food security problems, meeting the Millennium Development Goal one (1) which is aimed at eradicating extreme poverty and hunger. However, monetary investments coupled with increasing demand for land due to population growth are major limiting factors to this regard. Though it is possible from the hydrological perspective, it is not feasible from the socioeconomic viewpoint.

5.6 State of Dams and Dugouts

In northern Ghana and other semi-arid regions of the world, reservoirs are most precious assets. There are about 145 small reservoirs and dugouts dotted around the nine districts of the Upper West Region and these reservoirs have varying surface areas ranging from 1 to 25 ha with the number of reservoirs varying from district to district (Table 5.6). Wa Municipal and Jirapa have the highest number of small reservoirs with a total area of 323 ha.

Table 5.6: Number of reservoirs in the various Districts

District	**No. of reservoirs**
Nadowli	20
Jirapa	25
Lawra	24
Lambussie-Karn	7
Wa Municipal	25
Tumu	16
Sissala East	23
Sissala West	5
Total	145

According to GIDA (2012), there are more small reservoirs and dugouts in the Region but they are not documented due to the non-involvement of the institution in the process of reservoirs citing and construction in the communities.

Presently, less than 10% of the irrigable area downstream of reservoirs in the UWR is put into effective use though most of the reservoirs have been designed to meet all irrigation demands as well as making provision for livestock and other domestic uses. The reason being that, most of these reservoirs dry up in the dry season when water is needed most for irrigation and livestock watering, leaving farmers with no option but to dig wells to continue watering crops using the bucket and rope system which is very tedious and ineffective. The problem of water shortage arose largely as a result of siltation and seepage of reservoirs. The routine water shortage discourages young folks from venturing into farming since they have to invest so much energy and resources only to make very little profit or even losses in some cases due to crop failure. As a result, migration of the energetic youth to urban areas in search of "none existing white colour jobs" accounts for the age of farmers ranging between 45 and 65. This confirms Barry *et al.* (2005) finding that, "population aged18-40 years mostly migrate to Kumasi and Accra while the active age engaged in subsistence farming lay between 45 and 60".

As shown in Figure 5.20, only 52.4 % of small reservoirs in the Upper West Region are in good condition while the rest of the 47.6 % are either silted, broken or breached. About 28 small reservoirs out of the total 47 silted reservoirs are heavily silted with 70%-95% of the reservoirs volume filled with sand or silt and this drastically reduces the volume of water contained in the reservoirs. This confirms Annor *et al., (*2007) argument that, the volume of water stored in most reservoirs varies with time mostly as a function of siltation and seepage among others and this in the case of Chari community, the situation was attributed to farming activities upstream of reservoirs. Meanwhile, desilting in most cases is not carried out by community members since they have limited, or no capacity or resources to deal with these problems and they also claim it is difficult and requires heavy equipment.

Plate 5.1 Seepage in Eremon SR

Plate 5.2 Heavily silted Ga SR

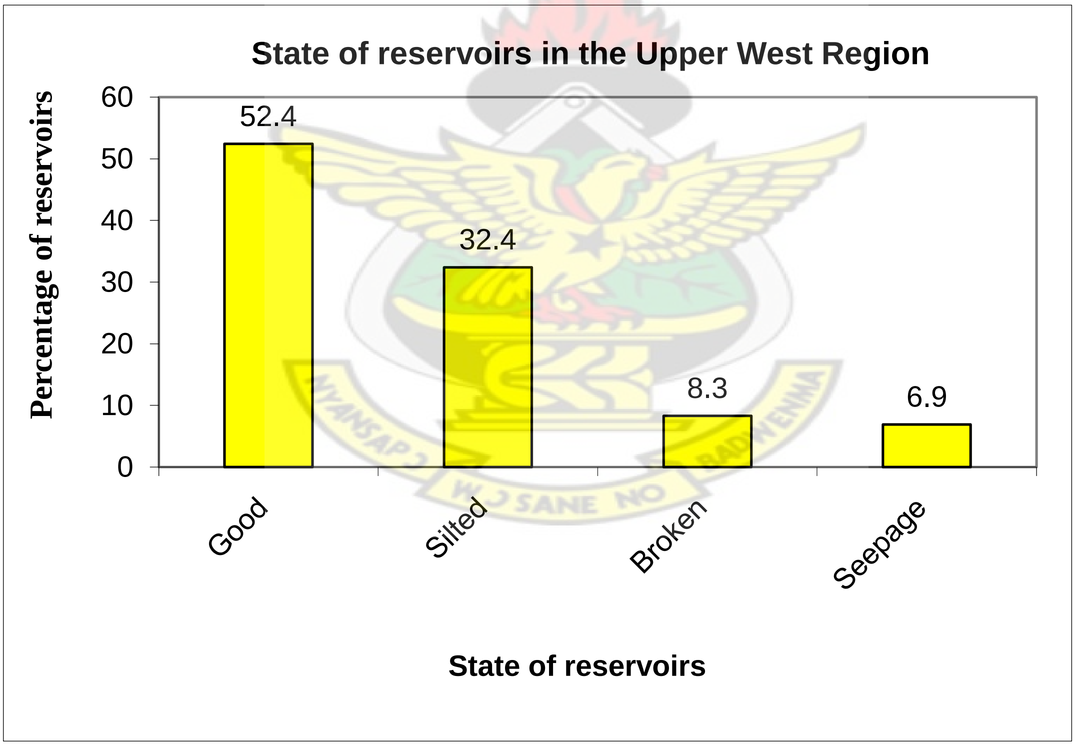


Figure 5.20: State of reservoir in the Upper West Region

The criterions for describing reservoirs include;

- Reservoirs are said to be **Good** if the embankment is neither broken nor eroded and the silt in reservoirs does not occupy more than 25 % of the initial design volume

- **Broken**- when part of the reservoirs' embankment is broken
- Reservoirs are considered **silted** when 50 % or more of the initial reservoirs volume at construction is occupied by sand or silt.
- **Seepage** –when water leaks out from the dam wall towards the downstream portion of the reservoir

5.7 Constrains Regarding Use and Management of Water Resource in the Region

- Most farmers do rainfed farming and the erratic rainfall pattern coupled with poor soil fertility in the area leads to low crop yields especially the early millet.
- Lack of water distribution systems (laterals and canals) makes watering of crops very difficult. Example, in Konzokala, there is sufficient land and water but since there are no water distribution systems; farmers cultivate a maximum of 2 plots since the extent of one's plot depends on their ability to afford pumping machines and labour.
- Lack of fencings leading to crop destruction by animals.
- Farmers compete for suitable land as regards to proximity to the water and since the land close to the water is small, parcels of suitable land is distributed ½-1 plot per family which is woefully inadequate. A farmer in Pimbingbing indicated that, the scenario of "its better little than none" works a lot.
- Women do not own plots in the Irrigable areas of some communities as in the case of Pimbingbing since the competition is so high and has become survival of the fittest (only the stronger ones have plots).
- Shortage of water at the peaks of flowering and fruiting leading to crop failure

Plate 5.3 Water shortage resulting in crop failure

- Some farmers dig shallow wells and use buckets and ropes or watering cans which is inefficient as it wastes a lot of water and very tiresome with large irrigable areas.
- Irrigation schemes in the area are vital for increasing food security though not widely adopted due to cultural reasons among others.
- Fulani herdsmen pose so much challenge to farmers since they allow cattle to destroy crops and this leads to conflict between farmers and herdsmen.
- Different types of failures particularly seepage problems occurs as a result of poor or lack of maintenance of reservoirs, confirming Nelson (1996) account that, Small reservoirs are constructed in most cases from earth materials and often suffer different types of failures as a result of poor or lack of maintenance. Other technical constrains include; heaps of sand upstream during construction leading to siltation, broken flumes and low spillways leading to loss of water.

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The reservoirs do not have ***significant*** impact on water allocation in the basin since no unmet demand was recorded in the rainy season and about 55.6 Bm^3 of water flow downstream untapped. Meanwhile, Unmet demand for livestock water requirement range from 1,000 m^3 to 6,500 m^3 and the unmet irrigation water requirement range from 40,000m^3 to 55,000 m^3 all of which were recorded in the dry season.

There is abundance untapped water resources in the BVB during the rainy season though the basin suffers some level of scarcity in the dry season due to lack of infrastructure to harness the resource at the time of abundance. Hence, constructing more reservoirs will help increase the potentials of expanding livestock production and irrigation agriculture.

Though it is possible to develop up to 300 and 350 small reservoirs by 2040 (in the case of 3* and 5* growth rate scenarios respectively) without impacting negatively on hydrology of the Basin with regards to water shortage, it is not feasible from the socioeconomic view point since demand for land keep increasing due to increasing population growth

Out of the 145 small reservoirs and dugouts in the Upper West Region, only 52% are in good condition while 48% are broken, silted or breached. Due to the inherent challenge of water shortage and its consequent crop failure related to the 48%, most are not being used productively.

6.2 Recommendation

Based on the above analyses, the following recommendations were drawn:

- With the abundant under-tapped resources in the Black Volta, Constructing at least 5 small reservoirs annually (evenly distributed across the country) would be critical in the coming years as water would be essentially needed for improved socio-economic activities of the people in the area and the fact that, the northern portions of Ghana lie along the fringes of the Sahel which is likely to be hard hit by the Climate Change Menace

- Further study should be conducted on the contribution of small reservoirs and possible development upstream (Burkina Faso) to the declining flows since development there could also play a significant role in declining river flow.

- Socioeconomic factors were not considered in this analysis hence; a study should be conducted to ascertain the impact of increasing small reservoirs development on socioeconomic aspect.

- Further development of reservoirs should be coordinated and targeted at improving the existing ones through desilting and enforcement of bylaws to prohibit farming upstream of reservoirs.

- Women should also be considered in the land allocation since they are central in most families

REFERENCES

Alfara, A. (2004). Modelling Water Resource Management in Lake Naivasha. Msc. Thesis. International Institute for Geo-information Science and Earth Observation, the Netherlands.

Anayah, F. and Kaluarachchi, J. J. (2009). Ground water resources of northern Ghana; initial assessment of data availability. College of Engineering Utah State University Logan, UT 84322-4100 USA.

Andah E., Van de Giesen, N. and Binney, C. A. (2003). Water, Climate, Food and Environment in the Volta Basin. Adaptation Strategies to Changing Environment. Contribution to the Adapt Project.

Andreini, M., Schuetz, T. and Harrington, L. (Eds.). (2009). Small reservoirs toolkit. Colombo, Sri Lanka: International Water Management Institute (IWMI). Available at www.smallreservoirs.org/full/toolkit/ (accessed on May 4, 2012).

Annor, F. O. (2012). Diagnostic Study of the Black Volta Basin in Ghana. In-Service Training Centre, Upper West Region- Ghana, 11th July, 2012.

Annor, F. O., Van de Giesen, N., Liebe, J., Van de Zaag, P., Tilmant, A. and Odai, S. N. (2007). Delineation of small reservoirs using Radar Imagery in Arid Environment; A case study in the Upper East Region of Ghana. Physics and Chemistry of the Earth 34, pp 309-315

Avakyan, A. B. and Podol'skii, S. A.(2002). Impact of Reservoirs on the Fauna. *Water Resources publishers*, Chapter 29(2): 123-132.

Awoti, A. (2010). Assessing the Impact of Land cover and Climate Changes on Water Balance Components of White Volta Basin in West Africa. BSc. Project, Royal Institute of Technology.

Awulachew, S. B., Merrey, D. J., Kamara, A. B., Van Koppen, B., Penning de Vries, F. and Boelee E. (2005). Experiences and Opportunities for Promoting Small-Scale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. IWMI Working Paper 98. Colombo.

Barry, B., Obuobie, E., Andreini, M., Andah, W. and Pluquet, M. (2005). Comprehensive assessment of water management in agriculture. Comparative study of river basin development and management. IWMI working paper 57, Accra-Ghana

Bartley, R., Buddemeier, W., Renwick, W. H. and Smith, S. V. (2002). Distribution and significance of small, artificial water bodies across the United States landscape. The Science of the Total Environment 299 (2): 21–36

Brandes, D., Cavallo, G. J. and Micheal N. (2005). Baseflow trends in Urbanizing Watersheds of the Delaware River Basin. *Journal of the American Water Resources Association*. 41:1377-1392.

Buddemeier, S., Robert W. and Dymond, R. L (2004). Detection and Characterization of Small Water Bodies. A Final Technical Report for the Landscape-Scale Detection and Classification of Small Water Bodies project: Temporal Integration of Diverse Types of Data.

Cecchi, P. [Ed].(2007). L'eau en partage : les petits barrages de Côte d'Ivoire. Collection Latitudes 23, IRD Editions, Paris, pp. 261-284.

Chang, H. (2007). Comparative Streamflow Characteristics in Urbanizing Basins in the Portland Metropolitan Area, Oregon, USA**.** *Hydrological Processes* 21: 211-222.

Deneke, R. and Brigitte, N. (1997). Why 'Very Shallow' Lakes are More Successful Opposing Reduced Nutrient Loads. *Hydrobiologia* 343: 269-284.

Descheemaeker, K., Amede, T. and Haileslassie, A. (2010). Improving water productivity in mixed crop–livestock farming systems of sub-Saharan Africa. Agricultural Water Management 97, 579–586.

Dougherty, M., Dymond, R. L., Godrej, A. N., Grizzard, T. J., Randolp, J. and Ziper, C. E. (2007). Quantifying Lon-Term Hydrologic Response in an Urbanizing Basin. *Journal of Hydrologic Engineering* 12: 33-42.

Dublin Statement and Conference Report (1992). "The Dublin Statement on Water and Sustainable Development" Adopted by the participants at the Conference on Water and the Environment (ICWE) in Ireland

Dune, T. and Luna, B. L. (1978). Water in Environmental Planning. Published by Freeman and company, W.H -. New York: 1st edition (August 15, 1978) pgs 421-426.

FAO (1998). Crop evapotranspiration: Guidelines for computing crop water requirements By: Allen R.G., Periera, L.S., Raes, D., and Smith, M. Irrigation and drainage paper #56. Rome

FAO (2001). Smallholder Irrigation Technology: Prospects for Sub-Saharan Africa. International Programme for Technology and Research in Irrigation and Drainage, Knowledge Synthesis Report #3. Rome

FAO. (1994). Water Harvesting for Improved Agricultural Production. Proc. FAO Expert Consultation, 21–25 November 1993, Cairo. Water Report No. 3. Rome.

FAO. (2006a). Demand for irrigated products in sub-Saharan Africa. Water Report No. 31. Rome.

Faurès, J. M. and Santini, G. (2008). Water and the Rural Poor. Interventions for Improving Livelihoods in Sub-Saharan Africa. FAO, Rome

Fox, P. and Rockström, J. (2000). Water Harvesting for Supplemental Irrigation of Cereal Crops to Overcome Intra-seasonal Dry Spells in the Sahel. Physics and Chemistry of the Earth (B) 25(3): 289-296.

GIDA (Ghana Irrigation Development Authority (2011). Annual report of the Upper West Region, Unpublished.

Ghana Statistical Service (2012).population and housing census carried out in 2010

Ghebreyesus, T. A., Haile, M., Witten, K. H., Getachew, A., Yohannes, A. M., Yohannes, M., Teklehaimanot, H. D., Lindsay, S. W. and Byass, P. (1999). Incidence of malaria among children living near dams in northern Ethiopia: community based incidence survey. British Medical Journal 319: 663-666.

GLOWA Volta Project Proposal (1999): Sustainable Water Use under Changing Land Use, Rainfall, and Water Demands in the Volta Basin. ZEF. Bonn.

Gordon, C. and Amatekpor, J. K. (1999). The Sustainable Integrated Development of the Volta Basin in Ghana. VBRP, University of Ghana-Legon 159 p

Hagan, I. (2007). Modelling the Impact of Small Reservoirs in the Upper East Region of Ghana, MSc. Thesis. Division of Water Resources Engineering Department of Building and Environmental Technology, ZEF. Bonn.

Howarth, S. M. and Sefton, C.E.M. (1998). Relationships Between Dynamic Response Characteristics and Physical Descriptors in England and Wales. Journal of hydrology 211: 1-16.

IFAD. (2009). Research and Innovation for Smallholder Farmers in the Context of Climate Change. Discussion paper prepared for the Round Table organized during the Thirty-second session of IFAD's Governing Council, 18 February 2009

Liebe, J. R. (2002). Estimation of water storage capacity and evaporation losses of small reservoirs in the Upper East Region of Ghana. Diploma thesis, University of Bonn, Germany September 2002.

Loucks, D. P., Stedinger, J. R. and Haith, D. A. (1981). Water Resource Systems planning and Analysis. IWRI, Englewood Cliffs, NJ: Prentice-Hall Inc.

Martin, R. and Van De Giesen, N. (2005). Spatial Distribution of Groundwater Production and Development Potential in the Volta River Basin of Ghana and Burkina Faso. IWRA, Water International, Volume 30, Number 2, June 2005

Mati, B. (2006). Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa. IWMI Working Paper 105. Colombo, Sri Lanka: IWMI

Mdemu, M. V., Rodgers, C., Vlek, P. L. G. and Borgadi, J. J. (2009). Water productivity (WP) in reservoir irrigated schemes in the upper east region (UER) of Ghana. Physics and Chemistry of the Earth, Parts A/B/C 34(4-5): 324-328.

Merrey, D. J. Namara, R. and De Lange, M. (2006). Agricultural water management technologies for small scale farmers in Southern Africa: An inventory and assessment of experiences, good practices and costs. Report submitted to USAID and FAO Investment Center. Pretoria, South Africa: IWMI (available on CD).

Molden, D. (2007). Water for food water for life. A comprehensive assessment of water management in agriculture. Chapter 7, 279-310. International Water Management Institute, Colombo, Sri Lanka and Earthscan, London

Nash, J. E. and Sutcliffe, J. V. (1970): River flow forecasting through conceptual models, Part I - A discussion of principles, *Journal of Hydrology*, 10(3), 282–290.

Ngigi, S. N. (2003). What is the limit of up-scaling rainwater harvesting in a river bas in? Physics and Chemistry of the Earth 28, 943-956.

Peters, N. E. and Seth, R. (2001). Effects of Urbanization on Stream flow in the Atlanta area (Georgia, USA): a Comparative Hydrological Approach. *Hydrological Pr*ocesses 15: 1441-1457.

Polak, P. (2005). The big potential of small farms. Scientific American, September 2005.

Raskin, P., Hansen, E., Zhu, Z., IWRA, M. and Stavisky, D., Simulation of Water Supply and Demand in the Aral Sea Region [Online] pp 55-67 [Available on http://www.weap21.org/downloads/aralsea.pdf]

Seleshi, B., Awulachew, P. and Lemperiere, T. (2009). Water harvesting and development for improving Productivity, Module 2: Improving Productivity and Market Success (IPMS) of farmers project, Addis Ababa, Ethiopia January 2009.

Sieber, J., Chris S. and Huber-Lee A. (2005). WEAP User guide, Stockholm Environmental Institute, the Netherlands**.**

Singh, V. P. (1995). Computer models for watershed hydrology, Water Resources Publications, Colorado.

Smakhtin, V. (2001). Review Low Flow Hydrology: A Review. *Journal of Hydrology* 240:147-186.

Small Reservoirs Project (SRP) website (2006). [web document] www.smallreservoirsproject.

Sultan, B., Baron C., Dingkuhu, M., Sarr, B. and Janicot, S. (2005). Agricultural Impacts of Large Scale Variability of the West Africa Monsoon. Agriculture and Forest Meteorology 128;1 2,Pp93-110 *The Science of the Total Environment*. 299: 21-36.

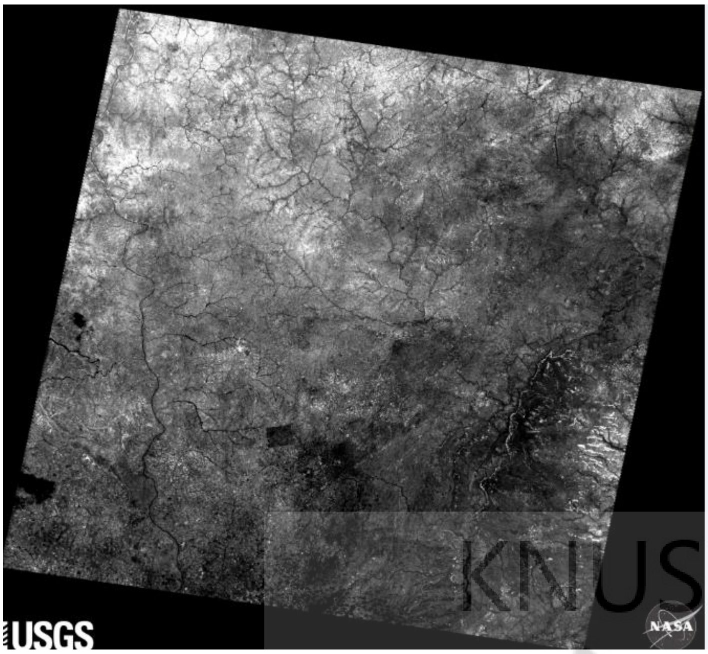
Venot, J. P. and Krishnan, J. (2011). Discursive framing: Debates over small reservoirs in the rural South. Water Alternatives 4(3): 316-324.

Venot, J. P., Andreini, M. and Pinkstaff, C. B. (2011). Planning and corrupting water resources development: The case of small reservoirs in Ghana. Water Alternatives 4(3): 399-423.

Venot, J. P. and Cecchi, P. (2011). Valeursd'usageou performances techniques: Comment apprécier le rôle des petits barrages en Afriquesubsaharienne. Les Cahiers de l'Agriculture20(1-2): 112 117.

Venot, J. P., De-Fraiture, C. and Ernest N. A. (2012). Questioning Dominant Notions: A review of Costs, Performance and Institutions of Small Reservoirs in sub-Saharan Africa, IWMI Research Report 145. Colombo.

APPENDICES



LANDSAT 7 wet season image of the study area

Mosaic image of study area

Table 1; name, area and location of small reservoirs visited in the study

	Location			
Reservoir Name	**N**	**W**	**Area (acre)**	**Area (ha)**
Konzokala	10^0 31’ 14’’	2^0 45’ 6’’	21.9	8.76
Babile	10^0 33’ 00’’	2^0 51’ 18’’	38.2	15.28
Tapko	10^0 11’ 31’’	2^0 40’ 9’’	17.7	7.08
Yele-Yiri	09^0 53’ 04’’	2^0 35’ 29’’	56.6	22.64
Pingbengben	9^0 55’ 03’’	2^0 33’ 29’’	29.6	11.84
Ga	9^0 47’ 49’’	2^0 31’ 40’’	5.9	2.36
Sirri	09^0 55’ 51.9’’	2^0 32’ 44’’	62.1	24.84
Ladayiri	9^0 52’ 30’’	2^0 36’ 26.5’’	21.6	8.64
Sankana	10^0 01’ 52’’	2^0 29’ 29’’	227.66	91.06
Busa	10^0 00’ 41’’	2^0 23 13’’	41.4	16.56
Jang	10^0 12’ 32’’	2^0 27’ 59’’	19.9	7.96
Tanina	10^0 11’ 17’’	2^0 36’ 12’’	21.3	8.52
Baleofilli	10^0 53’ 51’’	2^0 40’ 50’’	27.4	10.96
Eremon	10^0 38’ 38’’	2^0 47’ 46’’	41.48	16.59
Chaari	10^0 33’ 1’’	2^0 44’ 21’’	15.3	6.12
Tanchira No.1	10^0 32’ 59’’	2^0 51’ 18’’	22.7	9.08
Karni	10^0 39’ 52’’	2^0 37’ 52’’	43.7	17.48
Duori	10^0 34’ 41’’	2^0 45’ 54’’	11.8	4.72
Kaleo	10^0 10’ 26’’	2^0 32’ 32’’	18.3	7.32
Logu	9^0 51’ 48’’	2^0 27’ 45’’	33.1	13.24
Kokoligu	10^0 31’ 27’’	2^0 50’ 28’’	23.5	9.4

It is important to note that, most Small reservoirs take the name of the communities in which they are located.

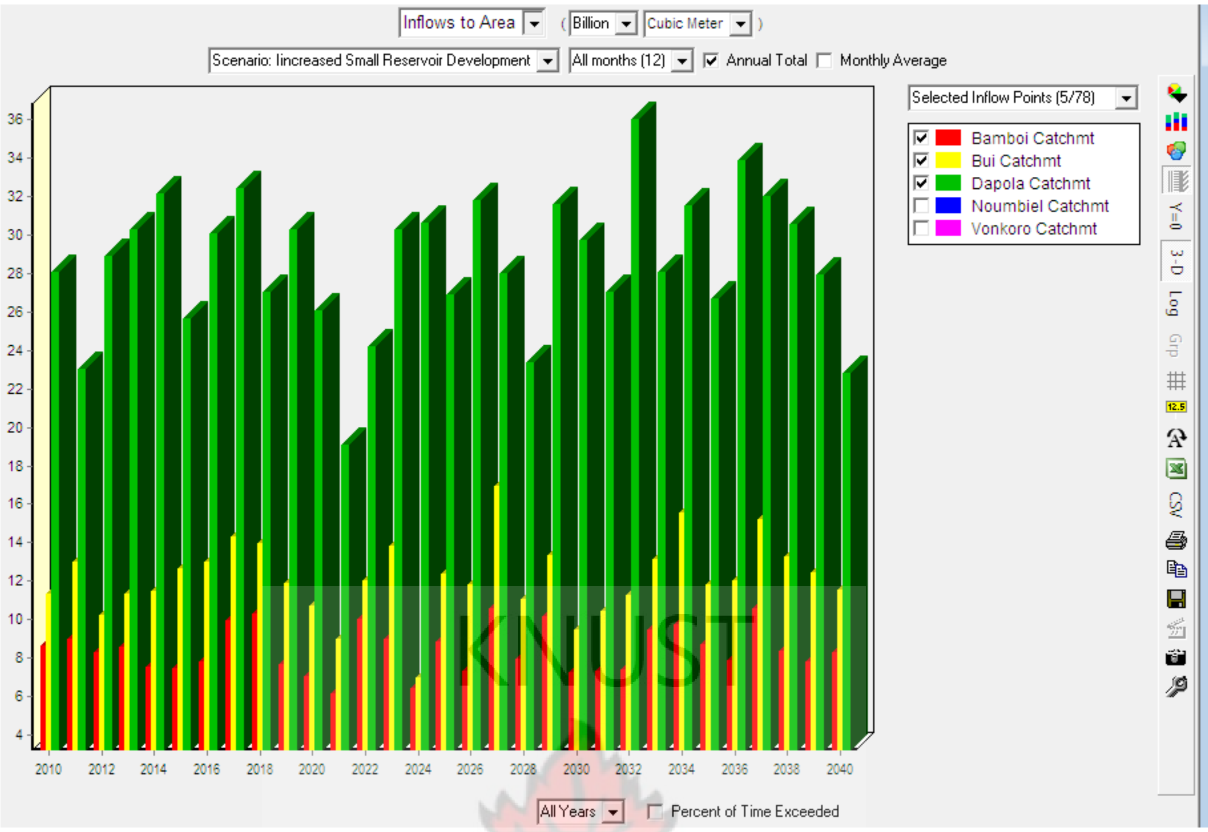


Table 2; State of reservoirs in the various districts of Upper West Region

District	Total No.	State of reservoirs		
		Good	**Silted**	**Broken**
Wa Municipality	18	10	6	2
Wa East	12	8	3	1
Wa West	12	7	4	1
Nadowli	16	9	5	2
Jirapa	20	11	8	1
Lawra	11	6	5	0
Lambusie Karne	14	8	4	2
Sisale East	17	8	6	3
Sisale West	25	13	7	5
Total	**145**	**80**	**48**	**17**

Table 3 Stat of reservoirs in the Upper West Region

State of R.	Percentage	Number
Good	52.4	76
Silted	32.4	47
Broken	8.3	12
Seepage/Breached	6.9	10

Table 4: Gauge Stations of Interest to the Black Volta Basin in Ghana

Station	Latitude	Longitude
Dapola	10.570	-2.920
Lawra	10.630	-2.920
Noumbiel	9.680	-2.770
Vonkoro	9.190	-2.710
Bui	8.281	-2.238
Bamboi	8.150	-2.030

Table 5; Number of small reservoirs in the post and pre impact periods

Year	Number of Reservoirs
1950-1954	6
1955-1959	5
1960-1964	9
1965-1969	6
1970-1974	6
1975-1979	4
1980-1984	15
1985-1989	29
190-1994	23
1995-1999	21
2000-2004	11
2005-2010	10

Table 6; Number of reservoirs in the various districts during the pre and post impact period

District	Pre-impact (1951-1980)	Post-impact (1981-2010)
Nadowli	3	18
Jirapa	7	21
Lawra	5	15
Lambusie/Karne	1	5
Wa municipal	4	2
Wa East	2	4
Wa West	6	5
Nadowli	4	6
Tumu	4	19
Sisal East/West	1	15
TOTAL	**35**	**110**

Table 7; Computation of the growth rate for the varies sub-catchments

year	**Vonkoro**	**Cum.**	**GR-r=(p1/p0)^0.2-1**	**Noumbiel**	**Cum.**	**GR-r=(p1/p0)^0.2-1**	**Dapola**	**Cum.**	**GR-r=(p1/p0)^0.2-1-1**
1955	**1**	**1**	**-1**	**1**	**1**		**2**	**2**	
1960	**0**	**1**	**1**	**1**	**2**	**0**	**2**	**4**	**0**
1965	**6**	**7**	**1**	**8**	**10**	**0.51571657**	**5**	**9**	**0.201124434**
1970	**3**	**10**	**-0.12945**	**1**	**11**	**-0.340246**	**1**	**10**	**-0.275220336**
1975	**1**	**11**	**-0.19726**	**2**	**13**	**0.14869835**	**4**	**14**	**0.319507911**
1980	**1**	**12**	**0**	**3**	**16**	**0.08447177**	**2**	**16**	**-0.129449437**
1985	**1**	**13**	**0**	**4**	**20**	**0.05922384**	**5**	**21**	**0.201124434**
1990	**1**	**14**	**0**	**20**	**40**	**0.37972966**	**10**	**31**	**0.148698355**
1995	**1**	**15**	**0**	**7**	**47**	**-0.1893869**	**11**	**42**	**0.019244876**
2000	**3**	**18**	**0.245731**	**13**	**60**	**0.13179837**	**4**	**46**	**-0.18316665**
2005	**0**	**18**	**-1**	**1**	**61**	**-0.4012971**	**6**	**52**	**0.084471771**
2010	**1**	**19**	**0**	**1**	**62**	**0**	**5**	**57**	**-**

									0.035807496
totals			**0.31**			**0.348**			**0.35**
Avg. vol. SR			**0.026**			**0.032**			**0.035**

Table 8; Area and volume of small reservoirs take with the GPS

Reservoir	Area	Volume (m^3)
Pinbengbeng	7600	3225.118749
Yeleyili	22916	15746.79796
Pole	78281	91980.7447
Baleofili	2874	797.6066303
Busa	167671	274763.8323
Siiri	98465	127887.7382
Tanina	46578	43627.08839
Kaleo	8967	4090.242064
Sankana	92132	116238.3364
Tapko	71632	80967.95295
Tanchira No.1	91940	115890.4732
Eremon	1671	365.9578669
Babile	8516	3797.959981
Karni	17829	10979.30782
Jirapa	9880	4701.626486
Duri	7648	3254.423446
Konzokali	88527	109760.1136
Chaari	5.2743	0.093436171