KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI, GHANA

ASSESSING THE IMPACTS OF AGRICULTURAL WATER MANAGEMENT ON THE HYDROLOGY OF THE WHITE VOLTA RIVER BASIN: THE CASE OF RESERVOIRS AND DUGOUTS.

ABUNGBA AYIIWE JOACHIM

MSc Thesis

September, 2013

Kwame Nkrumah University of
Science and Technology

ASSESSING THE IMPACTS OF AGRICULTURAL WATER MANAGEMENT INTERVENTIONS ON THE HYDROLOGY OF THE WHITE VOLTA RIVER BASIN: THE CASE OF RESERVOIRS AND DUGOUTS.

By

Joachim Ayiiwe Abungba, BSc (Hons)

A Thesis submitted to the Department of Civil Engineering,

Kwame Nkrumah University of science and

Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in

Water Resources Engineering and Management

Department of Civil Engineering

College of Engineering

September, 2013

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 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.

Joachim Ayiiwe Abungba 10/09/2013
(PG 5857511) Signature Date

Certified By:

Prof. Samuel Nii Odai 11-9-13
(Principal Supervisor) Signature Date

Mr. Frank O. Annor 19/09/13
(Second Supervisor) Signature Date

Dr. G. K. Anornu 27/9/2013
(Third Supervisor) Signature Date

Prof. M. Salifu 28/10/13
(Head of Department) Signature Date

Dedication

To the Almighty God, my son (Hubert Kwoyiiwe Atawope) and My Late Father, Mr. Atawope Abungba.

Abstract

Agricultural water management interventions such as small reservoirs and dugouts are precious assets in semi arid and arid regions of the world. The Upper East Region of Ghana by virtue of its climatic condition is classified as a semi arid region. It has a total of about 239 small reservoirs on record apart from those unrecorded. They are either or not located on streams and rivers upstream of the Ghana portion of the Volta River Basin, with only about fifteen percent (15%) of these reservoirs not in good condition. There have been significant reductions in the flow of water from all the three main tributaries of the Volta River. The impacts could as well be very significant further downstream where the Akosombo Hydro- power dam (the main source of the country's electricity supply) gets its source of flow.

The effect of many Agricultural water management interventions such as small reservoirs in the Upper East Region of Ghana was investigated using the WEAP model. A total of 239 small reservoirs were identified between the periods 1920 to 2010 and were used in the model. The growth rate of the reservoirs in the various catchments was computed and used in generating the business as usual scenario whiles the increase in number of small reservoirs in each catchment of the Basin was generated using some key assumptions. The model was first adapted to the region and calibrated using measured discharge values. Three different scenarios were incorporated to access the impact of the small reservoirs on the White Volta River.

The results obtained indicate that though some of the reservoirs are already experiencing unmet demands, they have some level of impact on the flow of the immediate sub- basins and the White Volta River as a whole. However the creation of more reservoirs as seen in the scenario with increase in the number of reservoirs could have very significant effect from the year 2031 onwards on the flow of the White Volta River and reduce its contribution to the Akosombo Lake which is further downstream in the Volta Basin. Tono and Vea irrigation schemes will record the highest unmet water demand of about 0.00045 Mm^3 in the Nawuni catchment between 2038 and 2039. Reduction in stream flow will be significant between 2017 and 2028.

Table of Contents

List of Tables

List of Figures

List of Plates

List of Abbreviations

BNI	Basic Need Income
CSIR	Centre for Scientific and Industrial Research
CSRC	Community Self Reliance Centre
CRU	Climate Research Unit
CWSA	Community Water and Sanitation Agency
DSS	Decision Support System
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
GEF	Global Environmental Facility
GIDA	Ghana Irrigation Development Authority
GLOWA	Global Change in the Hydrological Cycle
GMet	Ghana Meteorological Agency
GSS	Ghana Statistical Services
GWCL	Ghana Water Company Limited
GWI	Global Water Initiative
HSD	Hydrological services Department
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWM	Integrated Watershed Management
IWRM	Integrated Water Resources Management
IFAD	International Fund for Agricultural Development
MOFA	Ministry of Food and Agriculture
NGO	Non-Governmental Organization
PAGEV	Project for Improving Water Governance in the Volta Basin
SRP	Small Reservoir Project
rrf1	Climate change wet Scenario
rrf2	Climate change dry Scenario
TLU	Tropical Livestock Unit
UER	Upper East Region
UNESCO	United Nation Educational Scientific Organisation

VBA	Volta Basin Authority
VRA	Volta River Authority
WATSAN	Water and Sanitation
WEAP	Water Evaluation and Planning
WRC	Water Resources Commission
WRI	Water Research Institute
WUA	Water Users Association
WVR	White Volta River
WMO	World Meteorological Organisation
ZOVFA	Zuuri Organic Vegetable Farmers Association

Acknowledgements

I am most grateful to the Most High God for the gift of life, guidance and protection throughout this programme; I say may His Holy name be praised. “To you alone, O LORD, you alone, and not us, must glory be given because of your constant love and faithfulness” Psalm 115:1.

My warmest gratitude goes to my supervisors Prof. S. N Odai, Mr. F. O. Annor and Dr. G. K. Anornu whom apart from their wonderful contributions and constructive criticisms towards the successful completion of this research were more than fathers to me. To them I say may the Almighty God bless you bountifully.

I sincerely want to say I am very grateful to the Challenge Programme on Water and Food (CPWF) for sponsoring my MSc. Programme.

I wish to express my heartfelt gratitude to the entire staff of WRESP of the Civil Engineering Department, KNUST for their wonderful tuition and guidance throughout the programme. Thanks to you all and I wish you God’s blessings. I would like to thank the entire staff of the Water Resources Commission especially, Mr Ben Ampomah, Madam Linda Grace Enison and Mr. Aaron Bundi Aduna. I really appreciate the opportunity given me and your assistance throughout the programme. Special thanks also go to Mr. Badmous Biola, Dr. Benjamin D. Dovie, Mr. Sylvester Darko (HSD, Bolga) and Mr. Maxwell Boateng-Gyimah for their immense contributions to this work.

I also acknowledge the support of my entire course mates especially Mr. Francis Dramani, Mss. Olivia Bushell, and Mr. Adane S. and to my friends Mr. Paul Tontie Binado (Actionaid International, Tumu), Mr. Julius Awareja (ORGIIS) and Dr. Joseph Amikuzuno (Lecturer, UDS).

Lastly, I am highly indebted to my family especially my wife (Mrs. Gane Christiana), my mother, Madam Gertrude Kamagse, my brother, Samson Kolana Abungba, my sisters, Patience Abungba and Modester Abungba for their love and support throughout this programme. I really appreciate each of their efforts that have contributed to the successful completion of this programme.

1.0 INTRODUCTION

1.1 Background to Study

Majority of the communities in the White Volta River Basin are rural in nature. Small-scale agriculture is their main economic activity. A key resource that supports their livelihood enhancement is water that is located in the main White Volta River channel and its tributaries as well as groundwater systems which serve domestic and irrigation water needs while contributing to the national hydropower production in the downstream reach at Akosombo and Kpong. Agricultural productivity is low and only a limited size of agricultural land is irrigated. This coupled with the erratic and increasingly unreliable rainfall trend threatens food security. Thus improving irrigation is an important step towards increasing and securing agricultural production (Van den Berg, 2008).

As the growing population needs food and jobs, agricultural water management practices such as the use of shallow wells with buckets/ water pumps, dugouts, small reservoirs with lined or earth canals, stone and earth bunds and water pumps in rivers and wells in river beds have become a growing phenomenon in the Basin (Laube *et al.*, 2008).

1.2 Problem Statement

Livelihood vulnerability, food insecurity and poverty are major problems of the inhabitants of the White Volta Basin. The major activity in the basin is rainfed agriculture, which employs approximately 70% of the inhabitants, yet erratic and unreliable precipitation leads to low production. Irrigation is only available for an extremely low percentage of cropland, resulting in a low percentage of irrigated land in the dry season, which is approximately 1% of the total agricultural land (GVP Report, 2007).

The population growth rate for Ghana is approximately 2.5% percent, which implies that the population doubles every 30 years (GSS, 2010). Population growth leads to an increasing need for food security and therefore puts more pressure on water for agricultural activities since agriculture is practiced by the largest part of the inhabitants. More irrigable land and irrigation water is needed to improve agricultural production for food supply for the growing population.

1.3 Justification of the Study

There is no doubt that water is one of the most important inputs in agricultural production in Ghana apart from labour. More importantly almost all agricultural production activities are rainfed. Therefore, crop yields are decreasing and will continue to be on the decline due to the erratic nature of the rainfall. The available water resources are already decreasing. The annual rainfall trends continue on a downward trend, ranging from about 500 mm/year in the northern-most portions to about 1300 mm/year in the mountainous areas in lower Volta and Oti sub-basins (IUCN, 2012).

Research has shown that the development of agricultural water management activities through irrigation can contribute significantly to food production. In recent times however, falling groundwater levels and drying up of wells and dugouts occur, which lead to the perception that current water extractions especially groundwater exceed sustainable levels. Unfortunately no long-term data and projections on the impacts of further development of agricultural on water levels are available (WRC, 2011).

The assessment of the hydrological impact of Agricultural Water management activities could therefore go a long way to enhance, or otherwise inform decision on any further Agricultural Water development in the Basin.

1.4 Objectives of the Study

1.4.1 Main Objective

The overall objective of this research work is to assess the Impacts of Agricultural Water Management interventions on the Hydrology of the White Volta River Basin using reservoirs and dugouts.

1.4.2 Specific Objectives

The specific objectives of the research are to:

i. Evaluate the state of reservoirs and dugouts with respect to agricultural water management in the basin.
ii. Examine the extent of agricultural water uses/interventions on the hydrology of the basin.
iii. Ascertain the implications of further agricultural water development on the hydrology of the basin using different Scenarios.

2 LITERATURE REVIEW

2.1 Introduction

Water, it is said, may become as precious as oil during this century. Even though the total quantity of water made available by the hydrologic cycle is enough to provide the world's current population with adequate freshwater, most of this water is concentrated in specific regions leaving other areas water-deficient (Pimentel *et al.,* 1999). Because of the uneven distribution of water resources and population densities worldwide, water demands already exceed supplies in nearly 80 countries with more than 40% of the world's population (Bennett, 2000).

Agriculture commands more water than any other activity on this planet.

These facts reveal that it is time for sustainable management of available water resources based on global, regional, and site-specific strategic options (Nicholas, 2010):

i. Understanding the concept of 'virtual water' and potential use of this water as a global solution to regional deficits, i.e. the water-short countries may import a portion of food crops or other commodities that require more water and export those that need less water in production;

ii. Improvement in ~~current~~ efficiencies of agricultural water use and conservation, both in the rain-fed and irrigated agriculture, i.e. to produce more with the existing resources with minimum deterioration of land and water resources;

iii. Use of efficient, economic, and environmentally acceptable methods for the amelioration of polluted waters and degraded soils; and

iv. Re-use of saline and/or sodic drainage waters via cyclic, blended, or sequential strategies for crop production systems, wherever possible and practical.

The amount of precipitation that contributes to groundwater is principally impacted by the climatic conditions. For instance, according to Tyler *et al.,* (1996) and Bouwer (2002), about 30-50% of the precipitation contributes to groundwater in temperate and humid climates; it ranges from 10 to 20% in the Mediterranean climate; the amount of precipitation ending up in groundwater is the lowest in hot and dry climates, which may be as little as 2% or even less.

Agriculture is the largest single user of water with 65-75% of freshwater being currently used for irrigation (Bennett, 2000; Prathapar, 2000). In some cases, it draws as much as 90% of the total water (Allan, 1997). The following factors, either alone or in different combinations, have contributed or may continue to affect the availability of good-quality irrigation water in different regions of the world:

- Inherited shortage of water in certain areas as a result of their geographical location where rainfall is very low, groundwater use is not feasible due to economic, political and/or technical reasons, water treatment options have economic limitations, and transportation of good-quality water from other areas is not practical.
- Increased cropping intensities on already cultivated lands consuming more water per unit area cultivated, i.e. vertical expansion of irrigated agriculture, which has simultaneously resulted in degradation of the land and associated water resources at some places.
- Cultivation of crops on new lands requiring additional quantity of water, i.e. horizontal expansion of irrigated agriculture. Such expansion has deteriorated surface and groundwater quality at places where marginal lands were brought under cultivation without appropriate management practices.
- Increased industrial and domestic use of good-quality water as a result of an increase in population coupled with higher living standards.

- Contamination of surface and groundwater resources by a variety of point and non-point pollution sources.

Since freshwater has always been an integral component of food production, it is obvious that the water requirements associated with producing food for the future world population are huge. It is, therefore, apparent that strategic water management will be the key to future agricultural and economic growth and social wealth, both in developed and developing countries.

2.2 Efficient Water Use and Conservation Strategies

Despite limitations with the supply of freshwater in several regions, considerable volume of water is lost through one or any combination of mechanisms such as:

- evaporation from soil surface during conveyance and irrigation
- leakage during storage and transport to the fields where crops are grown
- runoff, and
- uncontrolled drainage

Under irrigated agriculture, about 30% of water to be used as irrigation is lost in storage and conveyance. There are also other losses such as runoff and drainage when this remaining 70% water reaches the farmers' fields. Postel (1993) has estimated the worldwide irrigation efficiency, i.e. the volume of water used as evapo-transpiration compared to the volume of water delivered to the field, to be about 37%. This estimate suggests that about 63% of the water delivered to the field is lost as runoff, drainage, or both. This means that in addition to 30% of water wasted in storage and conveyance, about 44% of the total water available at the source is lost as runoff and/or drainage. Wallace (2000) suggests that some of the water "lost" from an irrigated field 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.

2.3 Hydrological Response and Runoff

The primary source of water in rivers and streams is precipitation that flows through the landscape following several different paths (Dune and Leopold, 1979; Smakhtin, 2001). Impacts of surface runoff on the natural and human environment are dramatic and diverse. Estimation of runoff volumes helps predict streamflow and is needed for effective management of water resources including management of floods, water and power generation (Brandes *et al.*, 2005). Over a certain time period, watersheds have different hydrological responses to precipitation inputs due to the different factors that influence surface runoff, base flow, and subsurface flow.

Climatic and geo-physical characteristics of the landscape have a large influence on stream discharge and hydrological responses of watersheds. Howarth and Sefton, (1998) identified the distinguished key basin characteristics impacting hydrological response; they include watershed morphology, soil, land cover and climate. They also explained that 63% of variance in the hydrological response variables.

Flow patterns and velocities of runoff through a landscape are strongly related to the slope and size of the watershed. Smaller watersheds with steeper slopes tend to have faster runoff flows that travel only a short distance before discharging into a lake or stream. This has an important impact on hydrologic response. The faster water flows across the land, the less time is available for infiltration, evapotranspiration, and surface storage (Bo-Jie *et al.,* 2004). This can increase peak stream discharge, while decreasing a stream's lag time.

Hydrological response of watersheds can be analyzed by examining streamflow and its response to different patterns of precipitation in a watershed. Streamflow can be characterized by a large array of different hydrologic indices.

Different indices describe different hydrologic responses of watersheds including runoff. Rainfall-runoff ratios describe the proportions of precipitation that discharge 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).

Several hydrological studies describe the relative magnitude of high and low flows by using different parts of the streamflow duration curve. Some of the magnitude of high flow variables include the QH-10 and QH-20 flow exceedance coefficients (Biggs and Clausen, 2000; Zheng *et al.*, 2007). These variables use the 10 and 20 percent exceedance flows (Q_{10} and Q_{20}) from the flow duration curve divided by the median flow (Q_{50}) (Biggs and Clausen, 2000). The resultant coefficients describe high flows as a proportion of the median flow. Different exceedance values can be used depending on the interest of the flow type. The relative magnitude of low flows are determined in a similar fashion except the lower parts of the flow duration curve are used (Biggs and Clausen, 2000).

Land use has a large effect on water resources and streamflow. Examples of major land use categories include crop land, pasture, forests, and urban land use. Urban use has a dramatic influence on runoff and hydrologic response. Urban areas usually have a larger proportion of precipitation forming into runoff and as a result tend to have faster hydrological responses and decreased lag times, increases in peak flow, reductions of base flow and low flows, and decreases in water quality from increased runoff and effluent discharge (Chang, 2007; Doughtery *et al.*, 2007).

2.4 Land Use and Hydrological Impacts

A growing global population desiring for higher standard of living will increase demand for the extraction of natural resources (DeFries and Eshelman, 2004). This has the inevitable consequence of driving land use change, which is one of main sources of global environmental change.

The effects of anthropogenic land use change have multiple consequences for numerous biophysical systems. In recent times, the main focus on land use change research has been the effects of land use on the atmosphere, climate, as well as impacts to ecosystems and biodiversity (DeFries and Eshelman, 2004). The impacts of land use change on water resources however, could have a more immediate effect on human populations and ecosystem health.

Land use can impact water resources through direct manipulation of surface water flow through the construction of dams, drainage canals, and modification of stream channels, or indirectly by changing the landscape surface, altering land-water interactions (Bo-Jie Fu *et al.,* 2005; DeFries and Eshelman, 2004). Runoff processes can affect water resources in regards to both water flow and water quality.

High rates of runoff have negative impacts on the environment and quality of water resources. Runoff picks up materials in the landscape including sediment, nutrients, and other non-point source pollutants, and transports them down slope, eventually discharging into water bodies such as streams and lakes (Bo-Jie *et al.*, 2004, 2005). Overloading of sediments can choke streams thus altering the natural stream process of erosion and deposition, and disrupting aquatic ecosystems. Similarly, overloading of nutrients particularly phosphorus and nitrogen can also disrupt ecosystem processes and lead to water quality issues affecting the human environment (Bao-quing *et al.*, 2001). Lakes closures due to blue-green algae blooms, eutrophication, and hypoxia are all key symptoms of water bodies overloaded with nutrients.

Land use is one of the key geophysical characteristics affecting the hydrological response of watersheds to precipitation and runoff. Land use can influence the permeability of land surfaces, infiltration rates of the soil, and amount of surface features that can disrupt flow (Bo-Jie *et al.,* 2005). Watershed with steep slopes, low permeability, and few flow obstructing features will tend to have high discharge rates of runoff into streams having a significant effect on streamflow (Dune and Leopold, 1979; Bo-Jie *et al.,* 2005).

One major implication of land use change has been the conversion of natural lands like forest and grassland, into agricultural lands and pastures. This is one of the largest and most historic land use change with a number of eco-hydrological consequences. The disruption of soils and reduction of plant cover increases the flow of runoff and movement of nutrients and sediments from the landscape to aquatic systems (Dune and Leopold, 1979; Chen and Tong, 2002; DeFries and Eshelman, 2004). This effect is exacerbated if land with steep slopes and easily erodible soils are cultivated, and is also a function of the type of agriculture practiced.

Urban land use is another important alteration of the natural landscape. Compared to agriculture, urban land use change is a more recent development and while not as widespread as agriculture it is a more intense alteration of the landscape. Urban areas dramatically increase the area of impervious surfaces such as pavement and buildings. This significantly reduces infiltration rates and surface storage capacity, causing an increase in runoff discharge (Peters and Rose, 2001).

2.5 Distribution and Hydrologic Effects of Small Water Bodies

The detainment of water on the landscape has many beneficial uses for human society. It can be used to generate sources of water supply, manage flooding, and provide a source of recreation. These landscape features have significant environmental and hydrologic effects, and have been identified as a significant feature on every river and watershed worldwide (Bartley *et al.*, 2002). In sections of the landscape above reservoirs the export rates of water, sediment, and nutrients are reduced.

On the downstream portion of the reservoir, there is usually less surface water due to losses from evapo-transpiration, human consumption, and groundwater infiltration. This starves the downstream areas of water, sediment, and nutrients (Bartley *et al.*, 2005). This alteration of hydrology has important impacts on the chemical and physical properties of water as it flows downstream.

The main focus on reservoir impacts has been on larger bodies of water, mostly focusing on reservoirs that are directly connected to stream and rivers. The influences of smaller scale water storage are not as well known. Only recently has the distribution of small water bodies been quantified. Available hydrological databases such as the National Inventory of Dams (NID) in the United States of America do not provide a comprehensive estimation as they tend to overlook water features less than 10,000 m^2 of surface area (Bartley *et al.*, 2002; Buddemeier *et al.*, 2004).

Small water bodies, while outsized by larger reservoir features, 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.*, 2005).

Small water bodies are a significant source of land use change. The distributions of small water bodies are widespread. They are constructed and filled in based on human use of the landscape, management strategies, and natural sedimentation processes (Bartley *et al.*, 2005). They also have a wide variety of uses, which include: small scale water supply, aquatic habitats and recreational uses, and management of runoff and floods in both urban and rural settings. The fact that these features are so abundant and have size dependent hydrological impacts emphasizes the need to better understand their cumulative effects on the landscape.

2.6 Importance of Reservoirs and Dugouts

A reservoir is a man-made lake which is created when a dam is built on a river or a stream. The river or stream water back up behind the dam creating a reservoir which is used for various purposes. The reservoir is equipped with an outlet structure which is constructed with concrete, pipe or concrete pipe. They are mostly constructed for the following purposes

- To hold water for domestic use, agricultural purposes (irrigation) and for industrial use. When water is retained in reservoirs they are made to go through a period of self purification since sedimentation is allowed to take place. The water is then clear to some extent to be used for domestic purposes.
- To hold water to prevent flooding when there is intense rainfall that can cause flooding to a community. Reservoirs commonly used for this purposes are called attenuation reservoirs and are used to prevent flooding of low lying areas. They store water during periods with abnormally high rainfall and gradually release the water during periods of low rainfall.

- To hold water for the purposes of electricity generation and for powering wind mills. The reservoirs for this purpose are equipped with turbines which generate the electricity. Reservoirs can be constructed for secondary purposes as recreation such as sailing, fishing and water skiing (Hagan, 2007).

2.7 Integrated Water Resources Management of the White Volta Basin

Integrated water resources management (IWRM) encompasses water resources as an integral part of the ecosystem and also as natural resources. According to the Global Water Partnership (2006) IWRM is defined as "*the process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*." There are various other definitions of IWRM. The water resource users in a watershed or basin form part of the management of the entire basin. There are various guidelines or principles under the concept of IWRM. The Dublin Principles are generally used as a set of guidelines for IWRM.

2.8 Irrigation and Crop Water Requirements in the Basin

Agriculture is the backbone of most developing countries and Ghana is not an exception. Irrigation technological measures allow more crops to be cultivated all year round with less dependent on rainfall. According to the FAO, Ghana has a renewable water resource of 53.2km^3 (FAO, 2006). Water used for crop production is estimated at 0.25 km^3. This shows a very low rate of irrigation in the country. Irrigation in Ghana is practiced on a small scale basis and is basically informal especially in the White Volta Basin. The cultivable area in Ghana is about 42% of the total area of the country out of which 4.25% is under cultivation (FAO, 2006).

Table 2-1: Existing Irrigation Sites and their Water Requirements in Ghana

Project	Region	Water Sources	Irrigable area (ha)	Crops	Irrigation water requirements (Mm^3)
Asutsuare	G/Accra	Main Volta	660	Rice	17.16
Dawhenya	Accra	Volta	404	Rice	10.5
Tono	U/East	White Volta	2207	Rice/ Vegetables	39.78
Afife	Volta	Agali	880	Rice/ okra	22.88
Vea	U/East	Yaragatanga	850	Rice/ Vegetables	7.14
Botanga	Northern	White Volta	450	Rice/ okra	11.7
Afram plains	Eastern	Volta	101	Groundnut/ Vegetables	0.85
Ashaiman	G/Accra	Main Volta	117	Rice/ okra	3.04
Aveyime	Volta	Volta	63	Rice	1.64
Kpando-Torkor	Volta	Main Volta	40	Okra	0.34
Small schemes.	Northern	White Volta	16	Rice/ Vegetables	0.13
Libga Golinga	Northern	White volta	26	Rice/ Vegetables	0.68

Source: Wiafe, (1997)

3. OVERVIEW OF STUDY AREA

3.1 General Overview.

The Upper East Region (UER) of Ghana is one of the most deprived or poorest regions (GSS, 2005). It is situated in the centre of the Volta Basin in the north-eastern corner of Ghana and is bordered by Burkina Faso to the north and Togo to the eastern part. It has a population of 1,046,545 people according to the 2010 national census and has a population density of 118 inhabitants/ km^2 and a growth rate of 1.2 % (GSS, 2010).

The regional capital is Bolgatanga with other important towns such as Bawku, Navrongo and Paga. The region is made up of 11 districts and has a land size of 8842 km^2 which is approximately 3.4% of the total land mass of Ghana and is predominantly rural (87%) (GSS, 2005).

The UER has the highest elevation of 455m in the northern part and the lowest of 122m in the southern part of the region (Leibe, 2002).

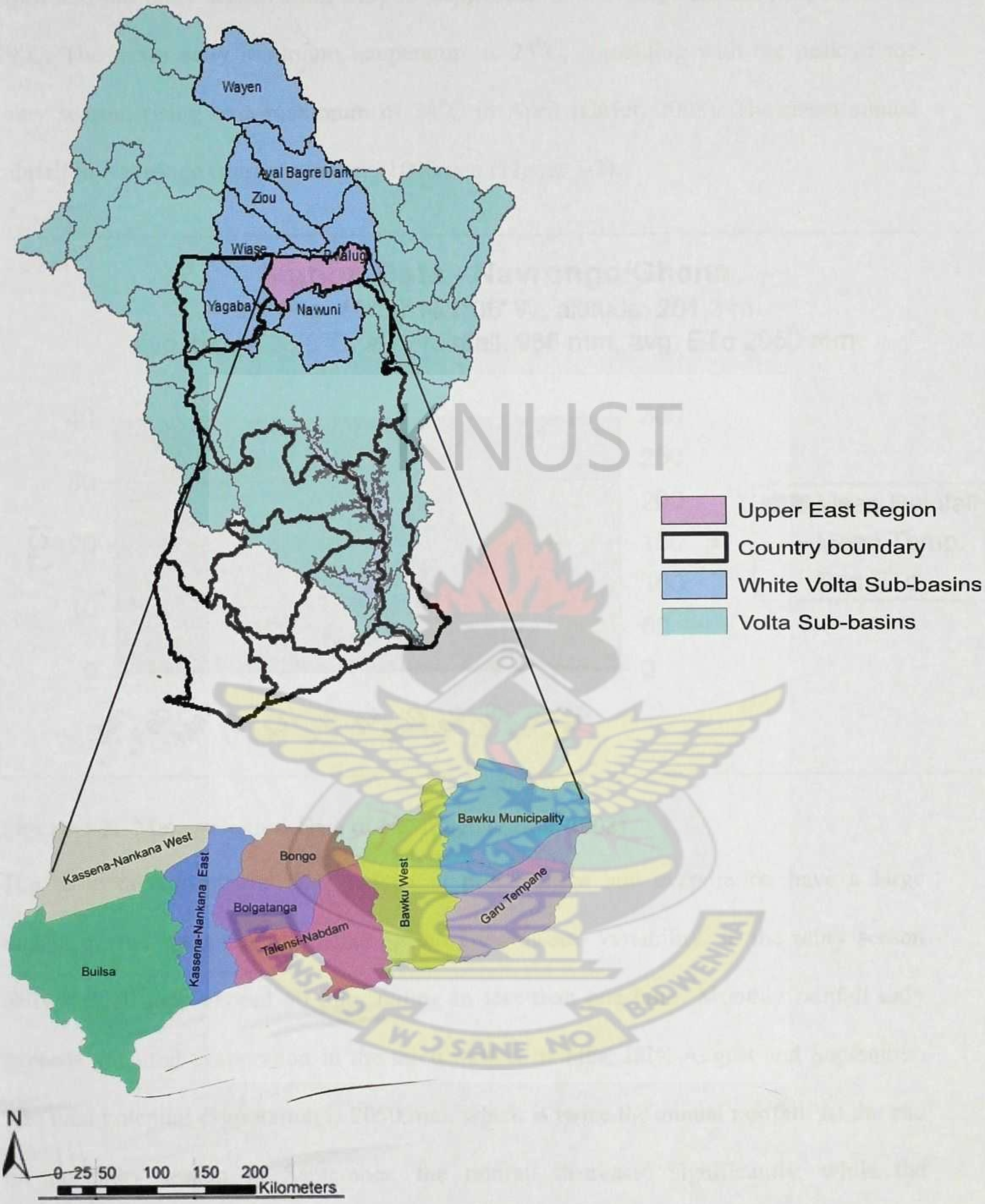


Figure 3-1: Upper East Region in Relation to Ghana and the White Volta Sub-basins

3.2 Climate and Rainfall Patterns

The Upper East Region (UER) falls within a semi-arid tropic climate. This climate is characterized by high temperatures and two distinct seasons, a dry season from October to

April and the rainy season from May to September. The average annual temperature is 29°C. The mean daily minimum temperature is 25°C, coinciding with the peak of the rainy season, rising to a maximum of 34°C in April (GMet, 2008). The mean annual rainfall in Navrongo is approximately 1000 mm (Figure 3-2).

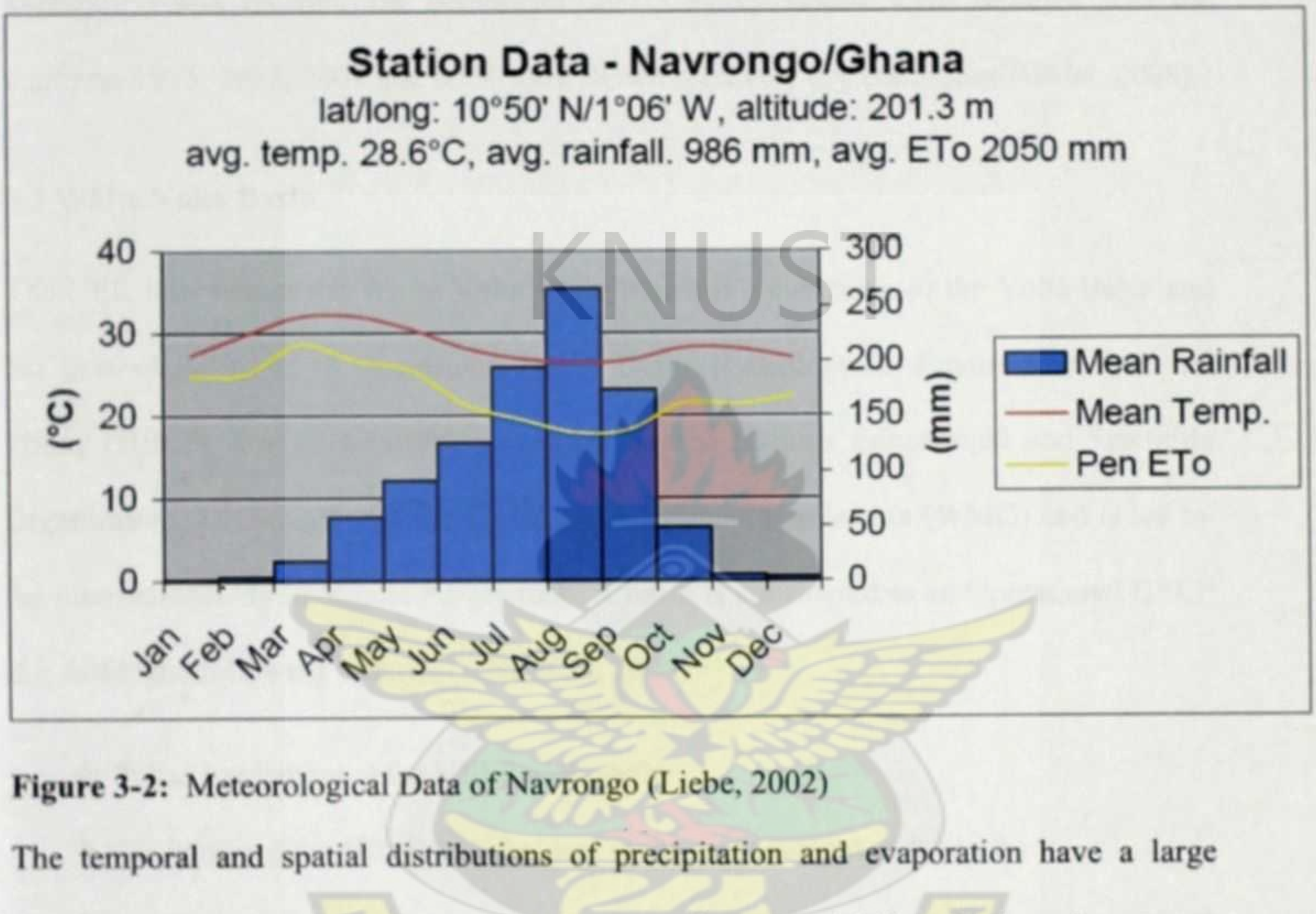


Figure 3-2: Meteorological Data of Navrongo (Liebe, 2002)

The temporal and spatial distributions of precipitation and evaporation have a large impact on the water regime including the groundwater variability. In the rainy season daily rainfall may exceed 50 mm, falling in less than one hour. Monthly rainfall only exceeds potential evaporation in the three wettest months, July, August and September. The total potential evaporation is 2050 mm, which is twice the annual rainfall. At the end of ~~the~~ rainy season in September, the rainfall decreases significantly, while the evaporation increases, leading to a large water deficit. In May, reservoir levels decrease and groundwater wells run dry. The water deficit decreases from May on, at the start of the rainy season (Liebe, 2002).

Remarkable aspects of the sub-tropical climate in West Africa are inter-annual and long-term variability of rainfall (Prathapar, 2000). The 1960s were relatively wet, while the 1970s and 1980s were distinctively drier (Postel, 1993). Also short-term variability can be noticed. The years 1999 and 2003 were exceptionally wet (15-35% above long-term average), while recently (in September 2007) heavy floods were reported. On the contrary, 1995, 1998, 2002 and 2004 have shown relatively dry conditions (GMet, 2008).

3.3 White Volta Basin

The UER falls within the White Volta Basin which is a sub basin of the Volta Basin and has been classified as an Operational HELP Basin. Hydrology for Environment Life and Policy (HELP) is a joint initiative between United Nations Educational and Scientific Organisation (UNESCO) and the World Metrological Organisation (WMO) and is led by the International Hydrological Programme. A basin is considered as an Operational HELP if it fulfils the following criteria; (UNESCO, 2006);

- "It has implemented the HELP philosophy
- Has involved the HELP stakeholders in the management of the basin
- Is substantially functioning across several HELP key issues in an integrated manner;
- Demonstrates an active interface between science and water managers, and society
- Has established mechanisms for unrestricted information and data access and exchange;
- Follows the WMO Resolution 25 on international exchange of hydrological and related data."

It is one of the main tributaries of the Volta River and has a total area of 104,749 km^2.The area in Ghana is 45,804 km^2 and that in Burkina Faso is 58,945 km^2. It is located upstream of the lake Volta in Northern Ghana and southern part of Burkina Faso (UNESCO, 2006). The area of the various tributaries of the White Volta basin and their lengths are shown in Table 3-2.

Table 3-1: Various Tributaries of the White Volta Basin and their Areas and Length (UNESCO, 2006)

Name	**Area (Km^2)**		**Length(km)**
	Ghana only	**Ghana and BF**	
White Volta	49,230		1,140
Tamne	880	106,740	50
Morago	620	1,610	80
Mole	5970		200
Kulpawn	10,600	10,640	320
Sisili	5,180	8,950	310
Red Volta	590	11,370	310
Asibilika	1,520	1,820	100
Agrumatue	1,410	1,790	90
Nasia	5240		180
Nabogo	2960		70

The total annual discharge leaving Burkina Faso through the Red and White Volta Rivers is estimated at 3.7 km³ /year (FAO, 2006). The land is predominantly flat, particularly in the southern part which is 0.1% (Wagner *et al.*, 2002). The White Volta basin has been home to many projects. Among these is the Small Reservoir Project (SRP), the GLOWA Volta project, the Water Resource Commission Climate Change Adaptation Project, the project for Improving Water Governance in the Volta Basin and the CGIAR Challenge Program on Food and Water which are all aimed at improving the livelihood of the growing population in the region through intensive Research work. The White Volta falls within the interior savannah ecological zone. The geologic formation of the basin is Voltain and granite and there is generally low groundwater yield from dug wells and boreholes in the basin between 5.23×10^{-4} to 1.05×10^{-3} m^3/sec and an average depth of 38m (Wiafe, 1997). According to Andah (2005) runoff coefficients are generally low; meaning that direct recharge of aquifers from precipitation is less than 20% across the Basin. This figure implies that less runoff end up as recharge for groundwater. The White Volta River is one of the main tributaries of the Volta River which forms part of the Volta Lake. The Akosombo and Kpong dams use water from the Volta Lake for hydro-power production. Downstream of these dams, there are substantial farming activities which use water from these dams for irrigation practices.

The Volta Lake is by far the largest man-made lake ever to be constructed in the world and is also the largest regulated Lake in the world (Dams under Debate, 2006). The Akosombo Hydro power plant produces 912MW of electricity at its' full capacity whiles the Kpong dam produces 160MW (VRA, 2006). In recent years there has been a significant reduction in the contribution of runoff from the White Volta River and the other rivers in the basin to the main Volta River (Gyau-Boakye, 2000) due to a lot of factors which include exploitation of water resources upstream of the White Volta River. The mean annual flow of the WVR is 9.57 billion m^3.

3.4 Location, Topography and River Network

The part of the White Volta River Basin in Ghana is located between latitudes 8°50'N - 11°05'N and longitudes 0°06'E - 2°50'W. It is bounded to the east by the Oti River Basin, to the west by the Black Volta River Basin and to the south by the Main/Lower Volta sub-basins. Burkina Faso forms its northern boundary.

This area is characterised by fairly low relief with few areas of moderate elevation in the north and east. The mean elevation is about 201.3 m and the highest portion reaches 600m.

Basin (WRC, 2008). The White Volta River and its

the Red Volta (Nazinon) and the Kulpawn/Sissili rivers, take their sources in the ral and north-eastern portions of Burkina Faso.

river first flows south on entering Ghana, turning west to join the Red Volta and inues westwards through the Upper East Region and then turns south, where it is ed by several tributaries, including the Kulpawn/Sissili and Nasia rivers. It continues hwards to Nawuni, flows westwards to Daboya and then southwards again where it is ed by the Mole river before entering the Volta Lake.

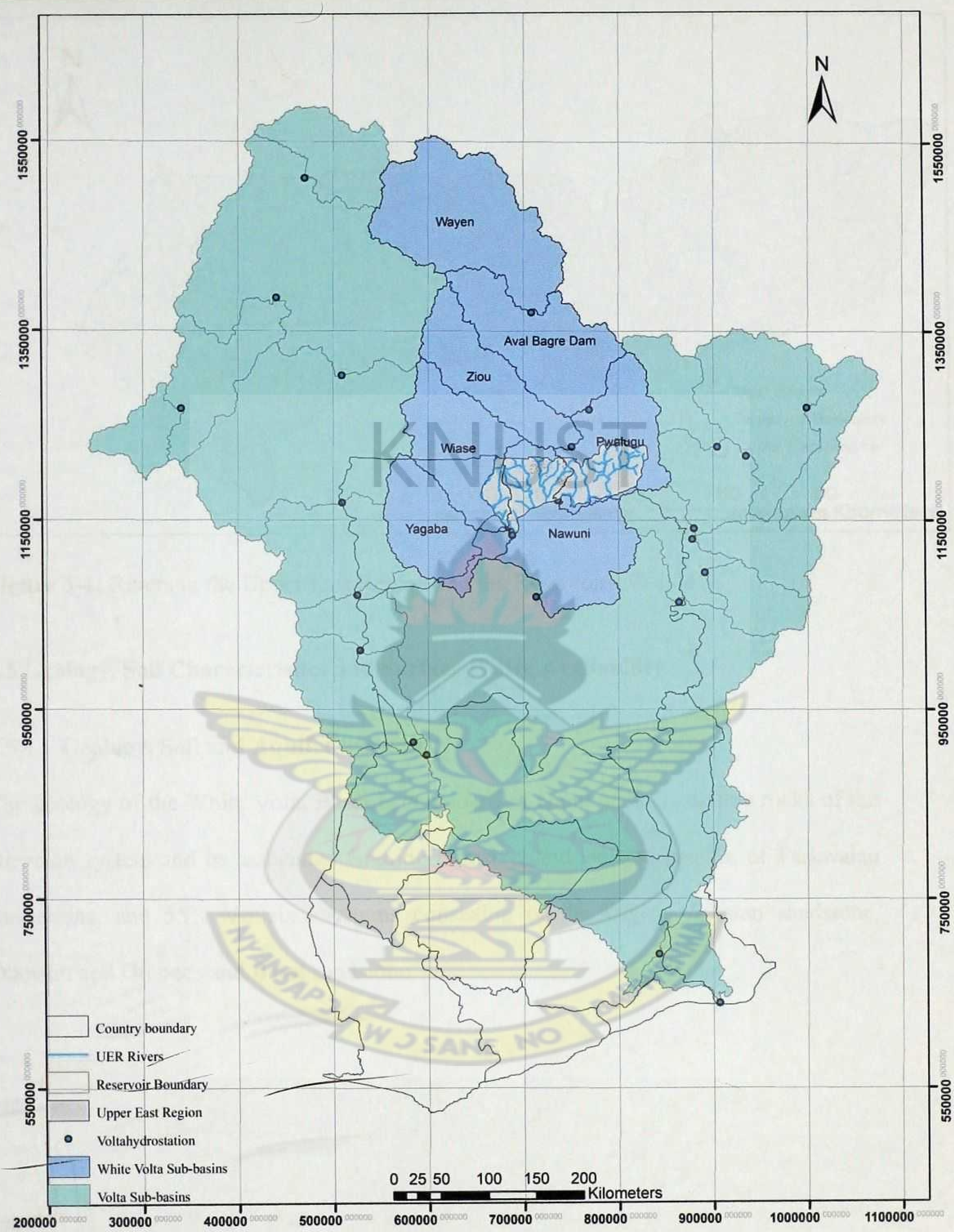


Figure 3-3: Sub-catchments of the White Volta Basin in Relation to the Main Volta Basin.

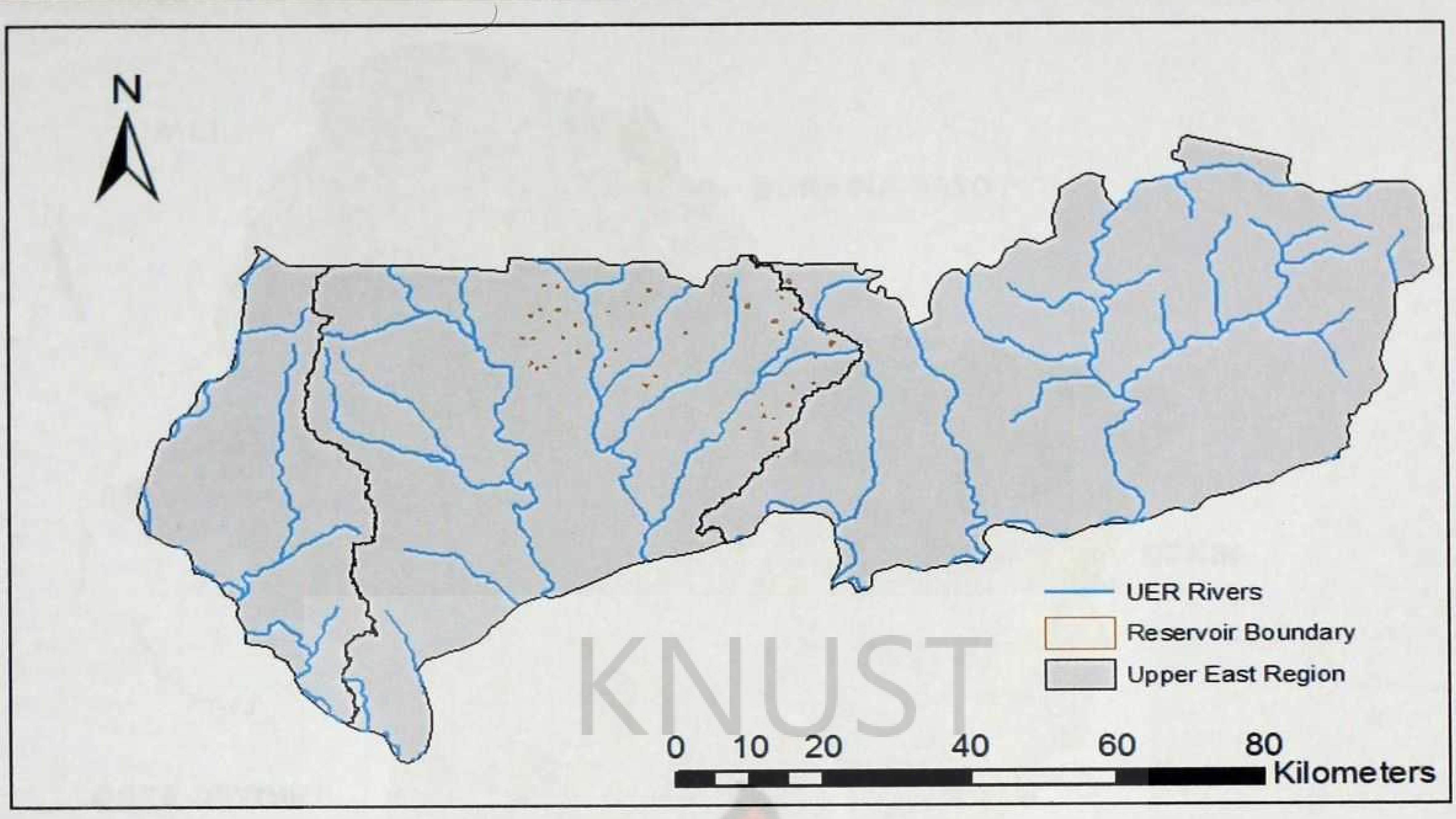


Figure 3-4: Rivers in the Upper East Region and the Reservoirs Visited

3.5 Geology, Soil Characteristics and Surface Water Availability

3.5.1 Geology, Soil and Aquifer Systems

The geology of the White Volta Basin is composed of about 45% crystalline rocks of the Birimian system and its associated Granitic intrusive, and isolated patches of Tarkwaian formations, and 55% Voltaian systems consisting of the Upper Voltaian sandstone, Obosum and Oti beds and Basal sandstone.

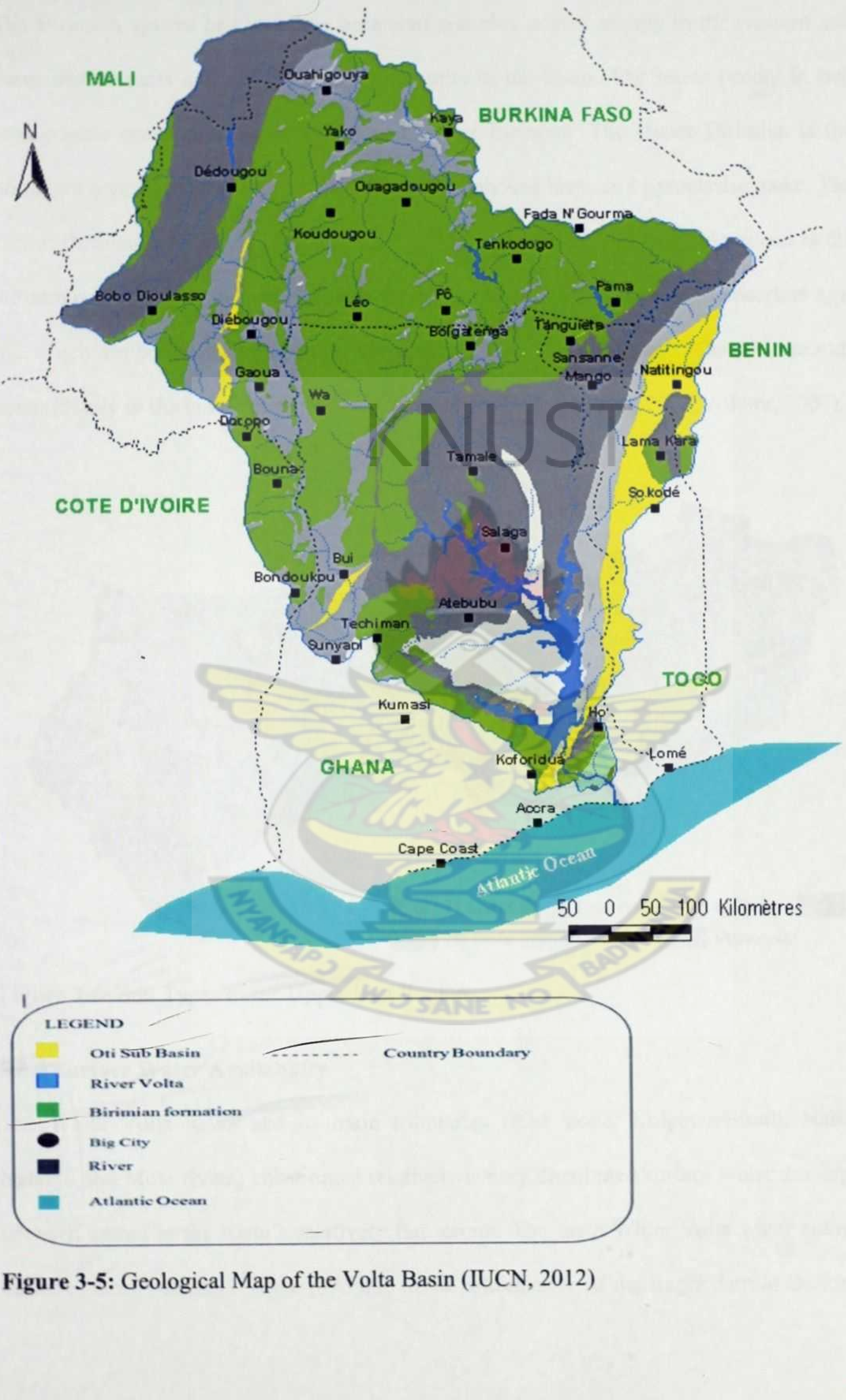


Figure 3-5: Geological Map of the Volta Basin (IUCN, 2012)

The Birimian system or crystalline basement complex occurs mainly in the western and north-eastern parts and are the oldest rock units in the basin. The series occurs in two stratigraphic successions – the Upper and Lower Birimian. The Upper Birimian is the dominant rock formation and consists of metamorphosed lavas and pyroclastic rocks. The Lower Birimian consists of phyllites, schists, tuffs and greywackes, and is dominant in the western part of the basin. The Birimian system is intruded by Granitoids of uncertain age, but which are believed to be of post-Birimian and pre-Tarkwaian age. These Granitoids occur mainly in the northern and western parts of the basin (Martin, 2006; Allaire, 2007).

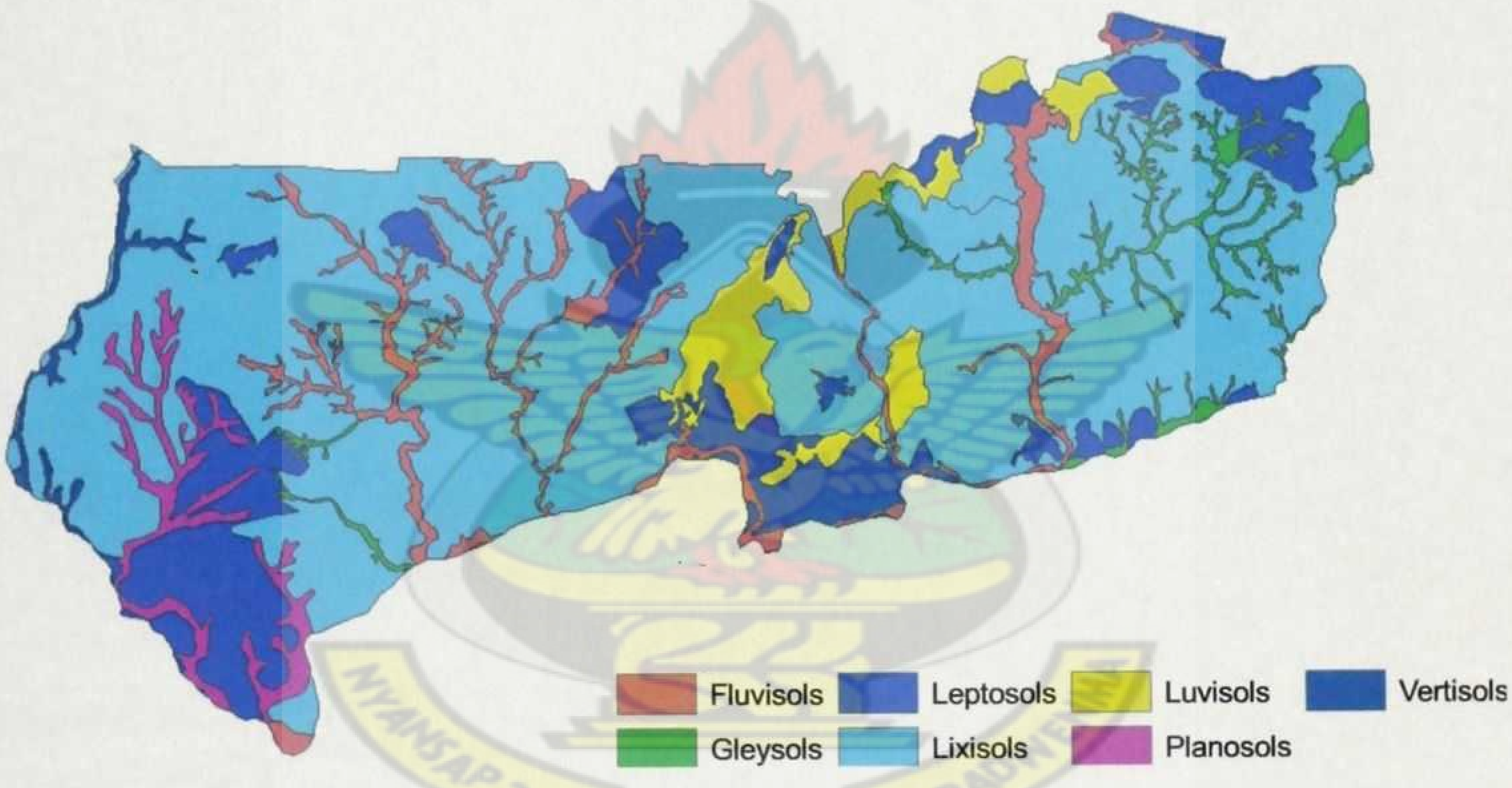


Figure 3-6: Soil Types of the Upper East Region

3.5.2 Surface Water Availability

The White Volta River and its main tributaries (Red Volta, Kulpawn/Sissili, Nasia, Nabogo and Mole rivers) constitute a relatively evenly distributed surface water drainage network nested in the basin's relatively flat terrain. The main White Volta water course became "more perennial" after 1995 due to the introduction of the Bagré dam in Burkina

Faso. However, most of its main tributaries dwindle to hardly any or no flow in the dry season with only pockets of stagnant water remaining (WRC, 2008).

4. METHODOLOGY

The following methods were used to achieve the objectives of the study.

4.1 Desk Study

Related reports and data on impacts of agricultural activities using shallow wells, boreholes, water pumps, hand-dug wells and small reservoirs were studied. Topographical and hydro-geological maps were collected from the Survey Department and research institutions including Water Research Institute, Water Resources Commission, Hydrological Service Department and the Geological Survey Department for review.

4.2 Field Study.

Visits were made to the study area to collect data on perceived impacts from the various farmer groups and the measurement of surface areas of reservoirs in the Basin.

4.3 Data Collection, Verification and Validation

Data was obtained from numerous sources. Meteorological data was obtained from the Ghana Meteorological Agency, Bolgatanga. Stream discharge was obtained from the Hydrological Services department, Bolgatanga and the reservoir inventory data from Irrigation Development Authority, Bolgatanga. Other relevant data obtained for the purposes of the study have been provided in Tables 4-1 and Table 4-2.

Table 4-1: Detailed Steps in Data Acquisition

Data Required	Methodology	Steps taken to obtain Data
Agricultural water use interventions in the basin	❖ Use of questionnaires/ check list (Questionnaire administration) ❖ Focus group discussions	❖ A number of 15 sites were selected across the basin taking into consideration the water use demands of the sites, ❖ For each site, group interactions were organised ❖ A follow-up monitoring was undertaken to observe and confirm or otherwise the interventions used.
Groundwater and Stream flow data	Fieldwork and monitoring for groundwater and secondary data for the flow data from Hydrological Services Department	❖ Data from Ten (10) selected gauge stations was collected from the Hydrological services Department (HSD). ❖ The drawdowns were analysed to determine the extent of Agricultural water interventions used in the Basin
Climate data	Secondary data from Ghana Meteorological Agency	
Crop water demand (Water use in agriculture)	Secondary data from FOA	

Table 4-2: Background of Data Collected

Data Type	Institution	Year acquired
Inventory of small Reservoirs in the Basin	Irrigation Development Authority (IDA) and MoFA	1920- 2010
Stream flow	Hydrological Services Department, Bolgatanga, and Tamale.	1951-2007
Rainfall	Ghana Meteorological Agency (GMet)	1961-2011
Crop water Requirements	MoFA and FOA website	
Water Use Demands	Field survey and observation	
Other related literature	Libraries and the Internet	2000-2011

4.4 Data Acquisition and Processing

- **Data Acquisition;** 'LANDSAT 7 wet season image' was acquired from the Global Visualization Viewer Website. The image was an 8 bands image captured on September 2002 and it was processed to have a better view of all the small water bodies in the Basin.
- **Data Processing;** The downloaded data was extracted and the 8 bands stacked to produce a single image using the ERDAS software. The image was then re-sampled to give it a spatial reference and ensured a standard spatial resolution of all the bands.
- The image was then added to the ArcGIS ArcMap 9.3 for classification and digitization of the water collection system.
- The shape file of the digitized reservoirs was then superimposed onto the rivers shapefile and the reservoirs with hydrological linkage to the streams were noted and used for modelling in the WEAP (Water Evaluation And Planning Tool).

4.5 Catchment Delineation

GIS was used in the determination of the catchments using the spatial analyst tool in ArcGIS version 9.3 and the SRTM 90 was used.

A shape file of the White Volta Basin was created using the Volta shape file. 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 signs 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 watershed

4.6 WEAP MODEL

4.6.1 Introduction and Development of WEAP

Water Evaluation and Planning System (WEAP) is a microcomputer tool for integrated water resources planning (WEAP User guide, 2012). It is easy to use and offers a comprehensive approach to water resources management. Various organizations have been responsible for the development of the WEAP model. The Stockholm Environmental Institute SEI provided primary support and the US Army Corps of Engineers provided funding for the development of the model. A number of agencies were involved in the development of the Model. They include The World Bank, USAID, and the Global Infrastructure Fund of Japan (WEAP User guide, 2012). The model functions on the principle of water balancing. Since the first version of the model was developed in 1990 the model has been applied in a lot of research work. It has been applied primarily in a number of studies concerning;

- Agricultural systems
- Municipal systems
- Single catchments or complex Trans-boundary river systems

4.6.2 Model Structure

The structure of the model is such that, the water resource system is represented in terms of groundwater, reservoirs withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The analyst can choose the level of complexity to meet the requirements of a particular analysis. This customization can also be used to reflect the limits caused by restricted data (Sieber J. *et al.,* 2005). The model consists of five main views: schematic, data, results, scenario explorer and notes.

4.6.2.1 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, reservoirs, groundwater supply, etc can be positioned. This allows for changes and modifications to be made in the area with ease.

4.6.2.2 Data

The data view is where data is entered into the programme. It allows variables and various assumptions to be created using mathematical relationships. Data can also be imported from Excel.

4.6.2.3 Result

Results are easily accessed. Every model output is displayed. This can also be exported to Excel for further modification.

This allows for easy accessibility of key indicators in the model.

4.6.2.4 Note

Notes can be added to the model for documentation of the key assumptions.

4.6.3 Parameterization of WEAP

Data and information that characterize the White Volta basin was processed and organized into formats usable in WEAP. These included hydrological and meteorological data, land cover and land-use, demography and water requirements for various uses.

4.6.3.1 Hydro-meteorological Data

The White Volta basin water year begins in May. Historical data of river flows as observed at various gauges on the White Volta River and meteorological information including rainfall and temperature on monthly time series for the basin were obtained from the Water Resources Commission (WRC), Hydrological Service Department (HSD) and the Ghana Meteorological Agency (GMet). Further, data on relative humidity and cloud cover for the basin was extracted from the TS 2.1 dataset of the Climate Research Unit (CRU) of the University of East Anglia (http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10). The CRU dataset used covered the period 1951 – 2009. There was however, no data on the wind. The default value of 2 as noted in WEAP was used.

4.6.3.2 Land Cover/land use and Projections

Recent works by the WRC in the White Volta basin and the Water Audit carried out by the International Union for Conservation of Nature in collaboration with the Volta Basin Authority revealed land cover/use in the basin is characterized broadly by grassland, rain-fed cropped areas, forests, and human settlement. Satellite imagery information was assessed for the land-use/cover and was projected to 2040. A linear regression was assumed to exist between the years (1981/94, 2004/6 and 2040) under consideration.woodlandtures area reduced from 2051.4 Km2 to 1780 Km2, neglecting owing to population growth**Water Resource Base**

In WEAP, water resource for exploitation is derived from precipitation which is injected into the model through a catchment object represented by a **'green dot'**. This is a simplified hydrologic model, for which satisfying the hydrologic cycle is paramount. Thus the precipitation contributes to runoff, groundwater recharge, evapo-transpiration and storage, where existent while meeting the respective water demands of the various uses.

4.6.3.4 Water Requirements and Demands

Generally, WEAP presents water use as "demand site" represented by a **'red dot'**. Thus water use and for that matter, water requirements were assessed for various needs in the basin. Four consumptive uses have been considered for the White Volta basin notably:

- Domestic water requirements for key towns and cities;
- Livestock water requirements;

- Irrigation activities and developments; and
- Industrial/Mining water requirement.

4.6.3.5 Demography and Domestic Water Requirements

A number of key towns and cities were identified and represented in the model to reflect water resources development of the White Volta basin. An attempt was made to represent in each sub-catchment at least a town and/or city.

For water requirements per capita, there exist variations in rural and urban demands. The baseline report from the hydrogeological assessment project (HAP) of the northern regions of Ghana from the Water Resources Commission indicated 85 lit/day and 55 lit/day for urban and rural settings respectively in 2010. Reconciling these figures with abstractions from rivers and groundwater sources revealed a rather low per capita water consumption varying from 18 lit/day in rural areas to 55 lit/day in urban settings around the 1960s. A linear forecast expression available in WEAP was employed to characterize the per capita water consumption per year for the simulation period.

4.6.3.6 Livestock Water Requirements

Data on livestock population was sourced from the draft report of the Water Audit Update of the Volta Basin carried out by the International Union for Conservation of Nature (2012). The tropical livestock unit (TLU) was applied to the livestock population and the water requirements were assessed. The data was projected for the period under consideration, year 2040.

4.6.3.7 Irrigation Water Requirements

A number of irrigation schemes exist in the basin for which operations are expected to grow and expand in the future. Specific to this is the Tono, Vea, Botanga and Lybga irrigation schemes at Kasena/ Nankana, Bongo, Savelugu and Nantong Districts respectively. However, the volume abstracted as per the water rights granted by WRC in 2010 was 11 Mm^3. This value was kept constant over the simulation period. The irrigation development schemes were projected based on reference scenario.

4.6.4 Priority for Water Allocation

A semi-distributed approach is employed for the WEAP modelling where water allocation as per sub-catchment is treated in isolation. For all practical purposes, an upstream catchment is served first, relative to a downstream catchment. To this end, WEAP automatically assigns priority to each of the demands represented in the schematic view. Water allocation is somewhat "discriminatory" among various uses in a given catchment. The parameter with this behaviour is the "demand priority" which ranges from 1 to 99. It is represented in parenthesis at the end the demand name. Thus water demand with priority "1" will be served first, and so on, whereas 99 will be served last.

In Ghana, and for the sub-catchment under study, domestic water needs are served first, followed by livestock and agricultural water demands, hydropower and then industry.

In the projected scenarios, and for all practical considerations, environmental flow of 0.05 m^3/s is given the highest priority with domestic water demands for a given catchment, thus satisfied first.

Table 4-3: Demand Priority for Water Uses

Demand	Demand Priority
Domestic water demand	1
Minimum flow	1
Livestock use	2
Hydropower production	3
Irrigation water demand	4
Storage (dams)	5

4.6.5 Calibration

The WEAP was calibrated to determine values of a set of key parameters which represent somewhat the physical characteristics of the catchments following 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 were from 1971 to 2010.

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

$$1-\frac{\sum_{i=1}^{N}(Q_{obs.i}-Q_{est.i})^2}{\sum_{i=1}^{N}(Q_{obs.i}-Q_{obs.ave})^2}$$

Where Q is a variable representing the river flows and N is the number of observations on monthly time step. The subscripts "obs", "est" and "ave" denote observed flows, flows estimated by the model and the average of the N observed values for Q, respectively. 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.

In the case where some of the observed gauge readings had quality problems, the calibration resorted to balancing the hydrologic cycle elements for the catchments. Thus river flows were estimated to range between 10.5% to 16% of volume of annual rainfall, 71% to 76% volume contributed to evapo-transpiration whiles the rest went for groundwater recharge. In sub-catchments with storage reservoirs, about 1% went for storage relative to annual precipitation volumes.

Water allocation for various uses has been digitized as per each sub-catchment in the White Volta basin.

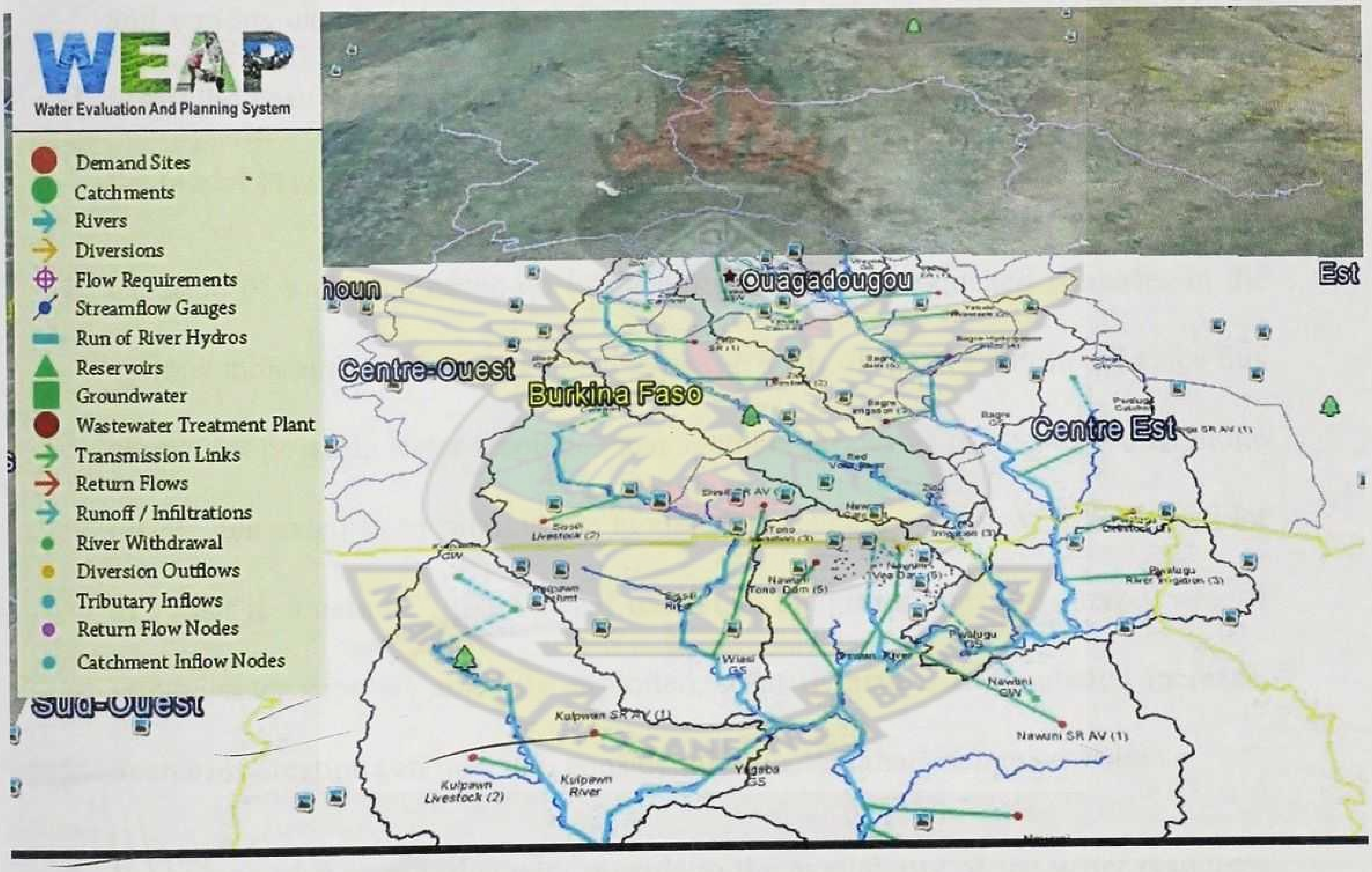


Figure 4-1: Schematic View of Water Allocation in the White Volta basin

4.7 MODELLING

4.7.1 Modelling Process of WEAP

The modelling of a watershed using the WEAP consists of the following steps (Sieber *et al.*, 2005).

- Definition of the study area and time frame. The setting up of the time frame includes the last year of scenario creation and the initial year of application.
- Creation of the Current Account which is more or less the existing water resources situation of the study area. Under the current account available water resources and various existing demand nodes are specified. This is very important since it forms the basis of the whole modelling process. This 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 various indicators. This forms the core or the heart of the WEAP model since this 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 can help the water resources planner in decision making.

4.7.2 Input Data

A GIS based vector layer of the area of UER of Ghana and the whole of the Volta Basin was obtained from the Volta Basin Starter Kit (2006). The kit was compiled by the International Water Management Institute (IWMI) and the Challenge Program on Water and Food. The Starter kit also provided information on the runoff data and a range of other useful information. The year chosen for the current account was 2010. The runoff data for the year 2010 was obtained from the starter kit and other sources. Boundaries of the UER area were set using the raster layer of the whole Volta Basin which was also obtained from the Basin Starter Kit. Streams in the area were redrawn by using the drag and drop button of the river button on the WEAP model. Data on the water use and areas of irrigation was obtained from the study conducted on water use and irrigation of some selected areas of the UER of Ghana (Faulkner *et al*., 2008).

4.7.3 Minimum Flow

A minimum flow of 0.05 m^3/s was assumed to flow through the rivers and streams to meet environmental requirements of each sub-catchment.

4.7.4 Assumptions Made

In the modelling of the reservoirs in the study area, some assumptions were made regarding some of the input data. The runoff data obtained was only on some selected stations from various towns in the whole basin. For streams with no gauge stations their runoff data were deduced from the neighbouring stations. This was done by taking into consideration the catchment area of the stream. Concerning water use in the region, it was assumed that the water use for domestic purposes, irrigation and livestock production were very critical and were satisfied first.

With regards to the areas of irrigated land in the various towns, it was assumed that the land sizes were the same as 9ha for good functioning reservoirs (SR3) and that for medium reservoirs (SR2) and poorly functional reservoirs (SR1) was set to be 2.5 ha and 1 respectively. The assumption was used because poor functional reservoirs with high seepage losses will not have enough water for irrigating more than 2.5ha of land. Consequently, good and better functioning reservoirs will have quite a good area under irrigation. The rate of water use varied from one reservoir to the other depending on the type of crops cultivated (crop water required).

4.7.5 Development of Scenarios

Following the calibration of the model, the framework becomes the reference to build scenarios. This section focuses on development of scenarios to assess the effects of climate variability and change and the increase in the number of small reservoirs on water availability, allocation and which portion(s) in the basin is/are likely to experience water stress in the future, including projected development(s). Scenarios have been developed over a 30-year period with the year 2010 as "base" or "current" year of simulations and running through to 2040.

4.7.5.1 Scenario 1; Increase in the Number of Small Reservoirs

The increase in the number of small reservoirs could be considered a business as usual scenario where there are more reservoirs constructed and more irrigated lands exploited. The impact on the runoff would be achieved by increasing the number of reservoirs in accordance with expected population growth over a period of time. An average growth rate in terms of reservoir development was computed for each of the four catchments. These growth rates were then used in the respective key assumptions for the catchments against the number of reservoirs recorded in the reference scenario. This gave results for the increase in number of reservoir scenario.

4.7.5.2 Scenario 2; Increase in irrigated Land/Increase in Demand

The effect of an increase in irrigated land and a corresponding increase in quantity of water use was applied to find out how they impacted on the runoff. According to the International Fund for Agricultural Development (IFAD) report, for there to be a significant growth in the Basic Need Income (BNI) for smallholder irrigation, the existing areas of irrigated lands which are below 1.6 ha should be increased to 2.4 ha (FAO-IFAD,2006). In the creation of this scenario, the irrigated areas were increased from 9 ha for every SR1 type reservoir to 13 ha. For SR3 and SR2 type reservoirs the increase was from 1.0 ha to 2.0 ha and 2.5 ha to 5 ha respectively.

4.7.5.3 Development of Scenarios Under Climate Change

This section focuses on scenarios to assess the effects of climate variability and change on water availability and exploitation including projected development(s). Scenarios were developed over a 30-year period with the year 2010 as "base" or "current year" of simulations.

According to the *Intergovernmental Panel on Climate Change (*IPCC), climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) ~~by~~ changes that persists for an extended period, usually decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. A report on the meeting of the *IPCC in 2007* indicated increasing temperature trends in the West African sub-region but no consensus was reached on the expected changes in the precipitation pattern and trends over space and time, whether a decrease or an increase relative to historical record.

A temperature anomaly curve of temperature records of Navrongo meteorological station in the Nawuni catchment and near the Sissili, Pwalugu and Kulpawn catchments reveal about 0.1–0.7°C change in mean annual temperatures from 1990 to 2010. Thus in the coming years over the simulation period, it is projected that the temperature would experience about 1°C rise in the said basins. For our consideration in this study, three scenarios would be looked at over the period and are as follows:

- Reference scenario- uses historical monthly data as input towards 2040.
- Drier climate change scenario where displacement of the CRU grid by 1° shifts the grid from north to south relative to the reference location over the Sissili-Kulpawn sub-basin. The CRU grid is 0.5° X 0.5°.
- Wetter climate change scenario where displacement of the CRU grid by 1° shifts the grid from south to north relative to the reference location over the Sissili-Kulpawn sub-basin.

5 RESULTS AND DISCUSSION

5.1 Surface Water Availability

The White Volta River and its main tributaries (Red Volta, Kulpawn/Sissili, Nasia, Nabogo and Mole rivers) constitute a relatively evenly distributed surface water drainage network nested in the basin's relative flat terrain. The main White Volta water course became "more perennial" after 1995 due to the introduction of the Bagré dam in Burkina Faso. However, most of its main tributaries dwindle to hardly any or no flow in the dry season with only pockets of stagnant water remaining (WRC, 2008).

The mean runoff in the White Volta is estimated at 11.5 billion m^3 from figure 5-1. The driest and wettest months are March and September, respectively. Monthly flows in Yarugu (upstream), Pwalugu (Mid-stream) and Nawuni (downstream) were used to assess the runoff from the basin within Ghana.

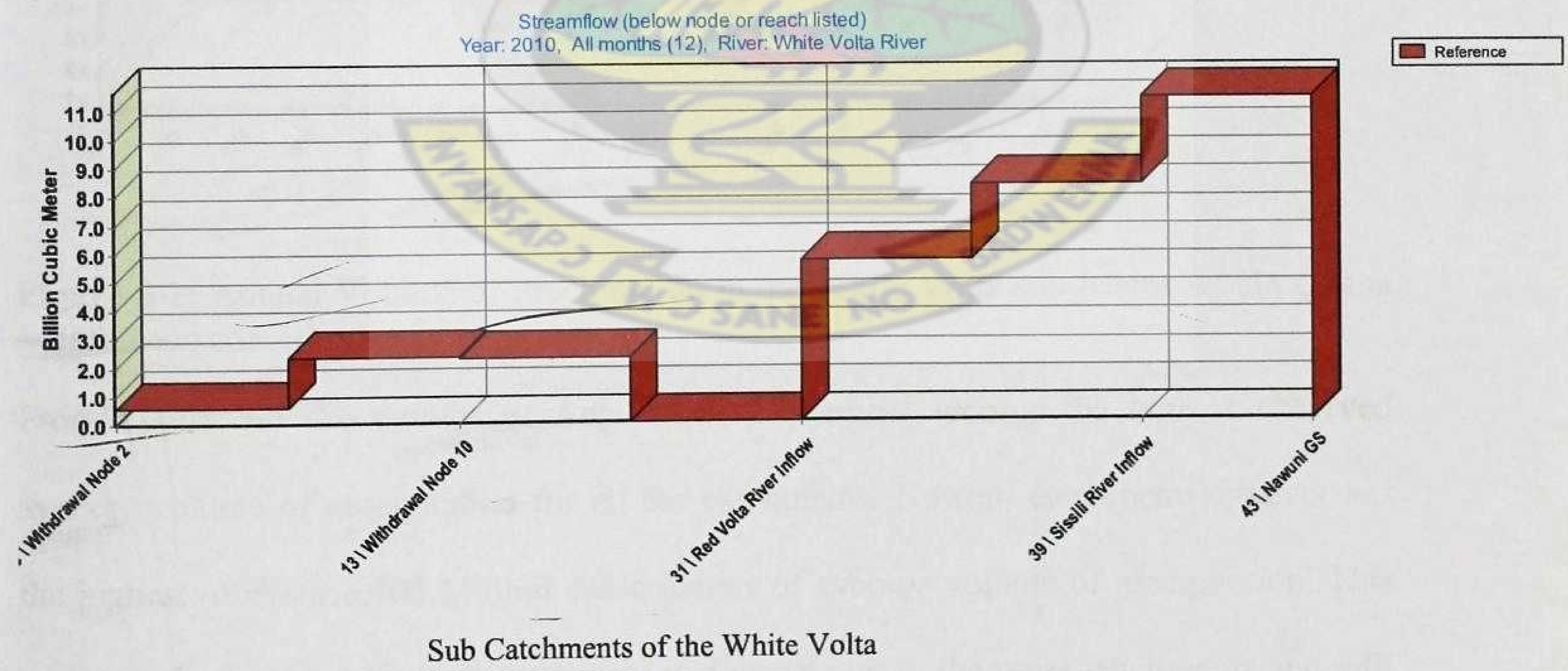


Figure 5-1: Chart of Stream Flow for Streams in the UER in million m^3

WEAP gave out the volume of water available for exploitation from the "inputted" monthly precipitation data. Following, the monthly volume of water was aggregated within WEAP to present the annual perspective of water resource in the basin. For all three scenarios, the annual precipitation is characterized by wet, normal and dry years with the climate change under drier scenario being more pronounced. For the entire Basin within Ghana, it is expected that annual volume precipitation levels will range from 7 billion m^3 in a dry year under drier climate change scenario to about 22 billion m^3 under wetter conditions as shown in Figure 5-2.

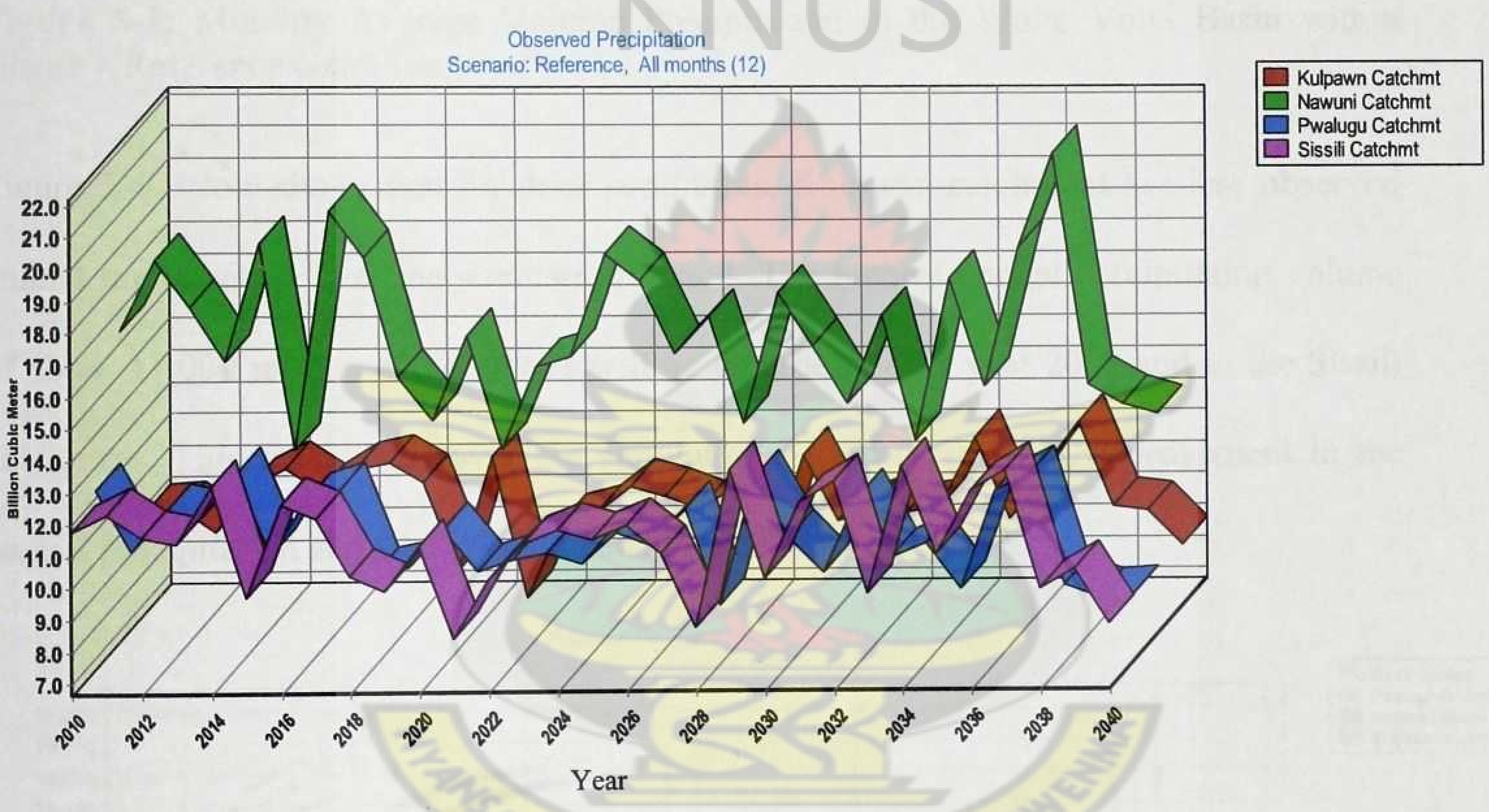


Figure 5-2: Annual Volume of Precipitation in the White Volta sub-basins within Ghana – Reference condition

From Figure 5-3 the months of August and September records the highest observed average volume of precipitation for all the catchments. Nawuni catchment however has the highest of about 3,400 Million cubic meters of average volume of precipitation. This is due to the fact that Nawuni catchment is downstream to the other catchments and will therefore take into consideration volumes of precipitation from the three catchments that are upstream.

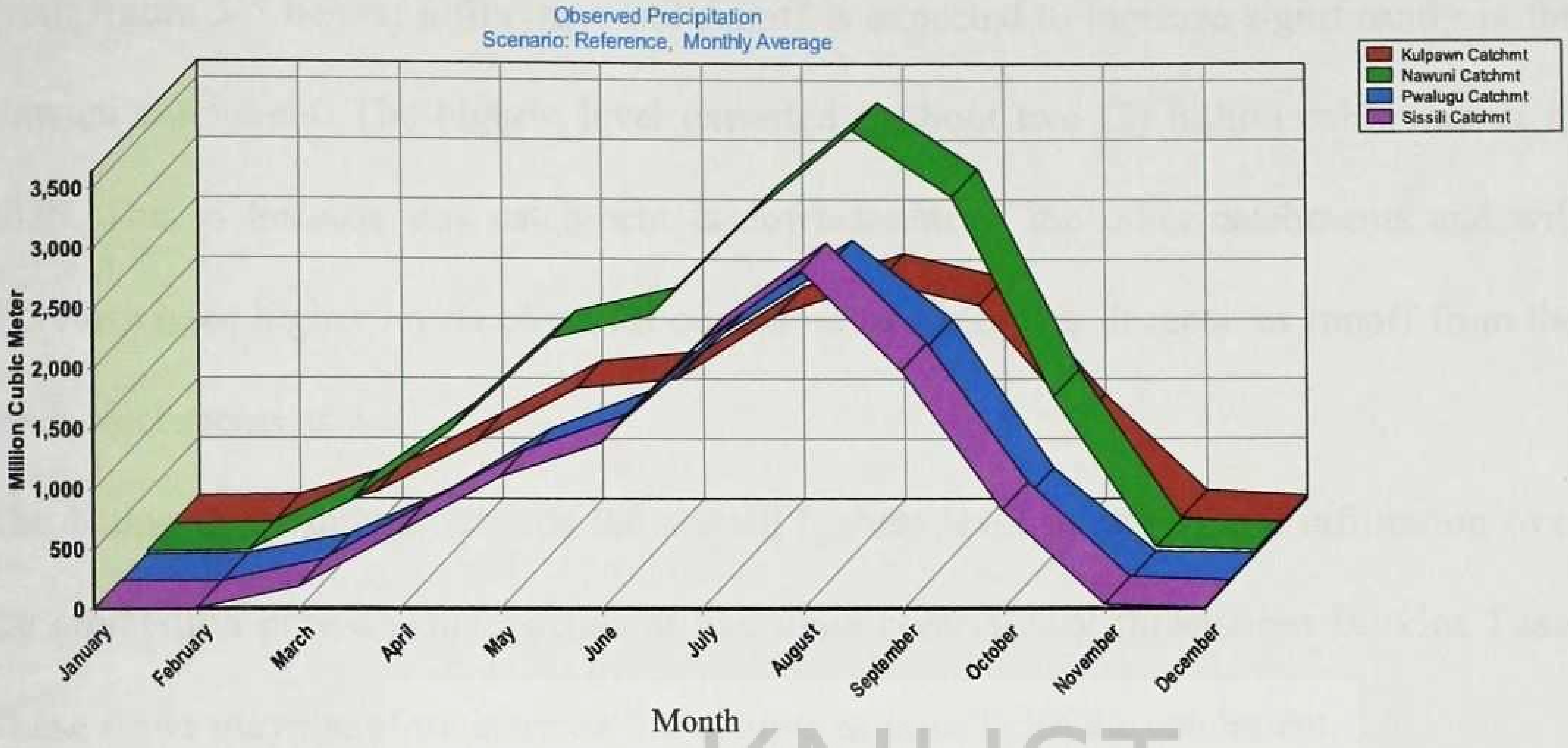


Figure 5-3: Monthly Average Volume Precipitation in the White Volta Basin within Ghana – Reference condition

Figure 5-4 below shows that for drier conditions, Kulpwan catchment has less observed annual precipitation over the simulation period. The highest annual precipitation volume of about 17,000 million cubic meters will be recorded in the year 2039 and in the Sissili catchment. This means that over the simulation period there is an improvement in the annual precipitation across the Sissili catchment.

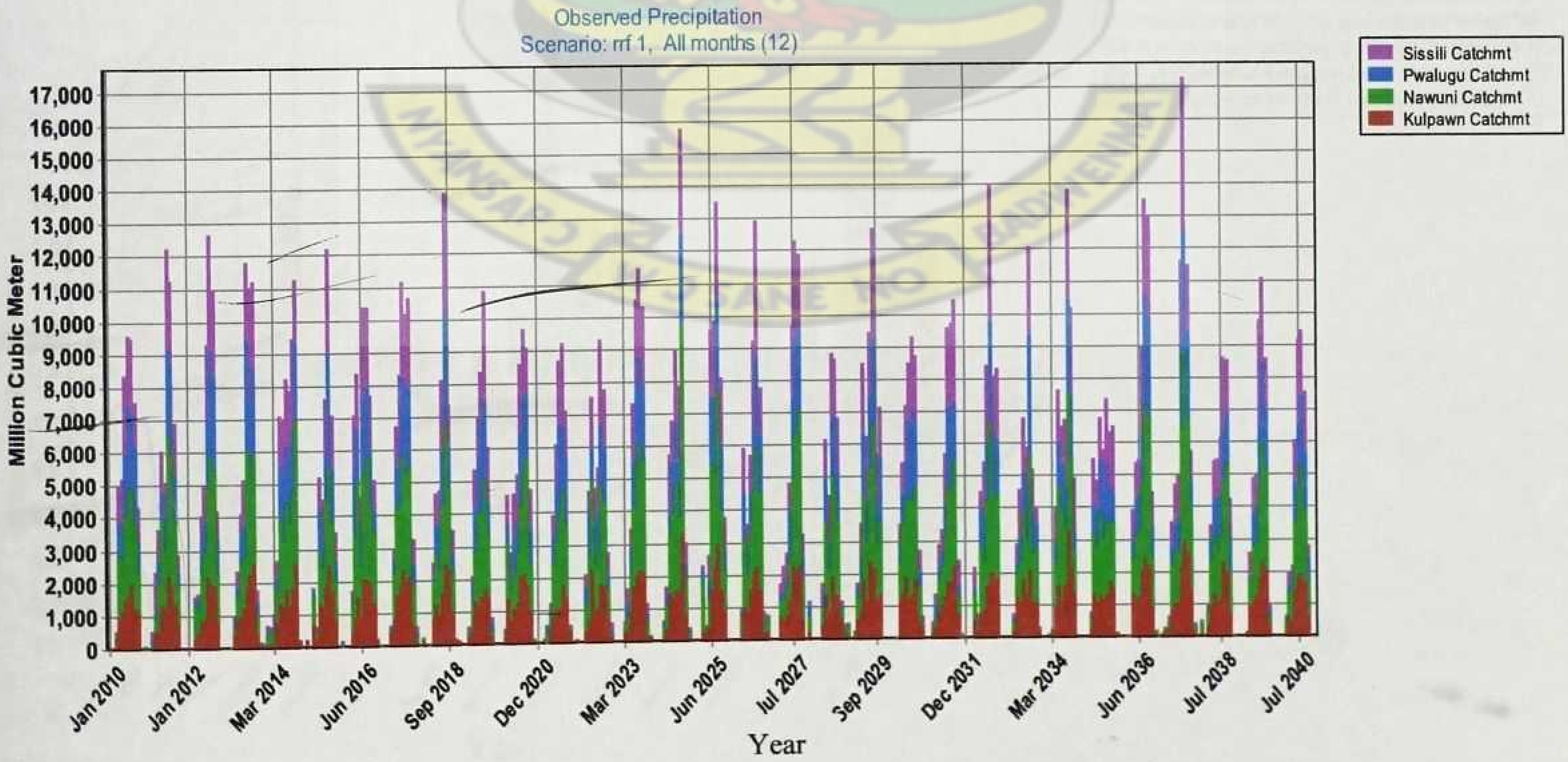


Figure 5-4: Annual Precipitation in the White Volta Basin within Ghana – Drier Condition

From figure 5-5 below, infiltration and runoff is expected to increase significantly in the Nawuni catchment. The highest level expected is about two (2) billion cubic meters in 2028. This is because this catchment is downstream of the other catchments and will therefore have higher levels of runoff compared to the others. It receives runoff from the other catchments as well.

The Kulpawn catchment records the second highest level of runoff and infiltration over the simulation period. This catchment has some contributory flows from Burkina Faso. These flows may therefore increase the volume of runoff into the catchment.

There was no significant runoff/infiltration from the catchments to groundwater. This is because for a scenario of increase in the development of small reservoirs, it is expected that the reservoirs will reduce the volume of flow into the river and hence impacting negatively on the hydrology of the catchment.

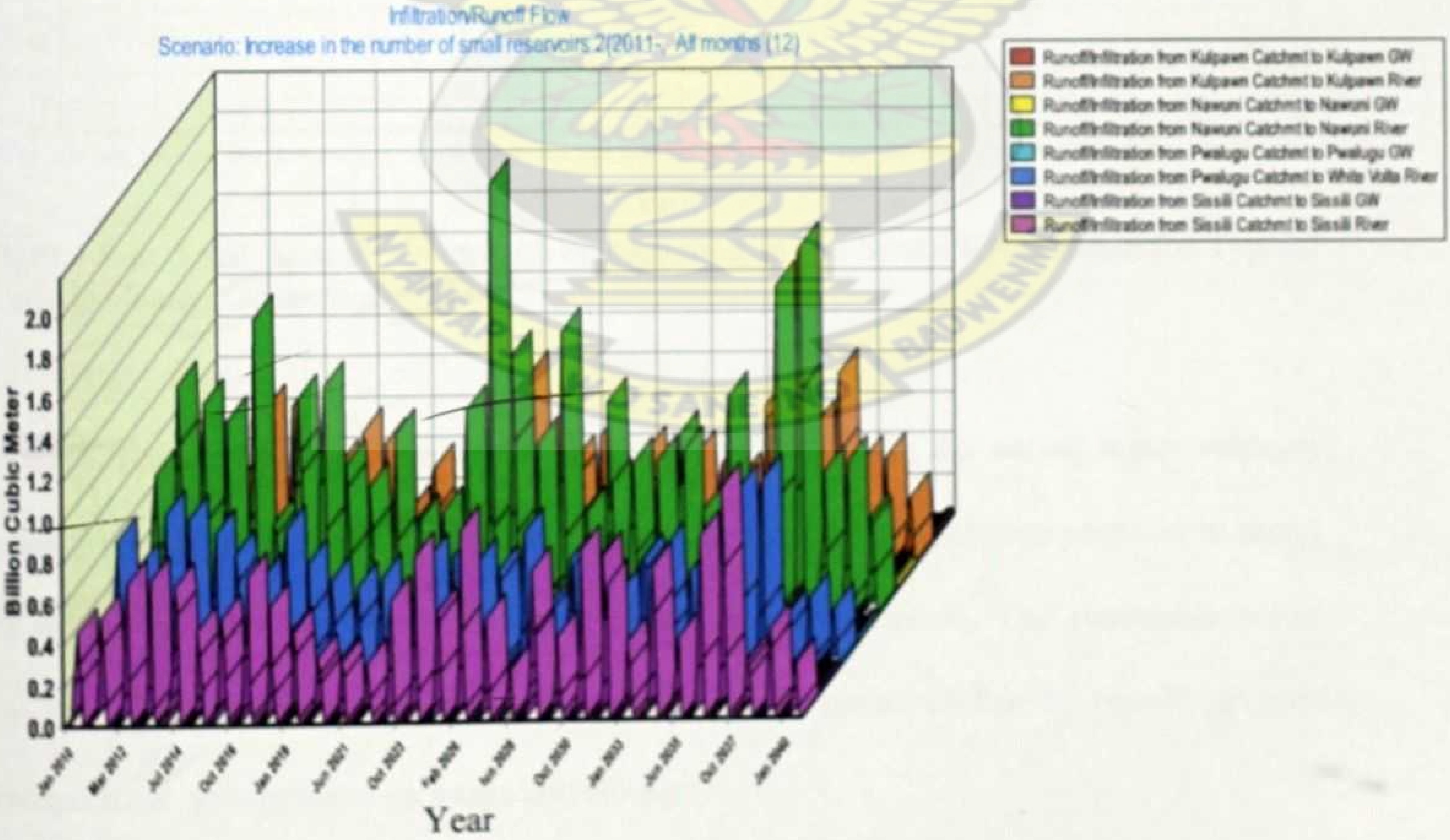


Figure 5-5: Runoff/Infiltration Generated in the White Volta Sub-basins within Ghana – Climate Drier Condition and Increase in Number of Reservoirs

From Figure 5-6, WEAP gave out the volume of water available for exploitation from the "inputted" monthly precipitation data. Following, the monthly volume of water was aggregated within WEAP to present the annual perspective of water resource in the basin. For all three scenarios, the annual precipitation is characterized by wet, normal and dry years with the climate change under drier scenario being more pronounced. In the Sissili River Basin, it is expected that precipitation levels will range from 7 billion m^3 in a dry year under drier climate change scenario to about 14 billion m^3 under wetter conditions.

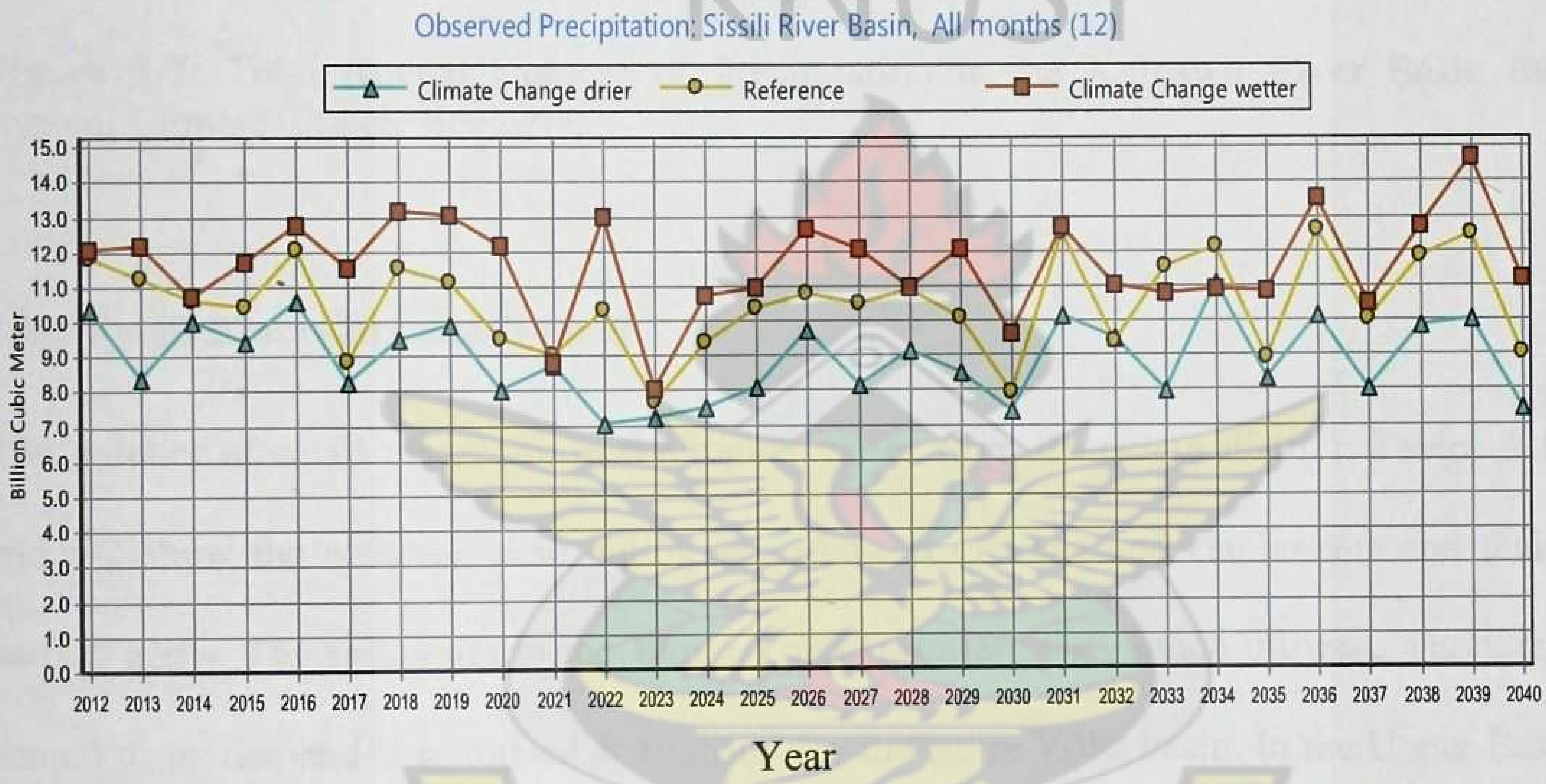


Figure 5-6: Total Annual Volume of Precipitation in the Sissili River Basin for Typical Climate Change Scenarios

In the Kulpawn river basin as shown in Figure 5-7, however, the annual water volumes range from about 6 billion m^3 in a dry year under drier climate change scenario to about 12 billion m^3 in a wet year of wetter climate change scenario. The renewable water volume will satisfy the hydrologic cycle through contributions to runoff, evapo-transpiration, groundwater recharge and storage.

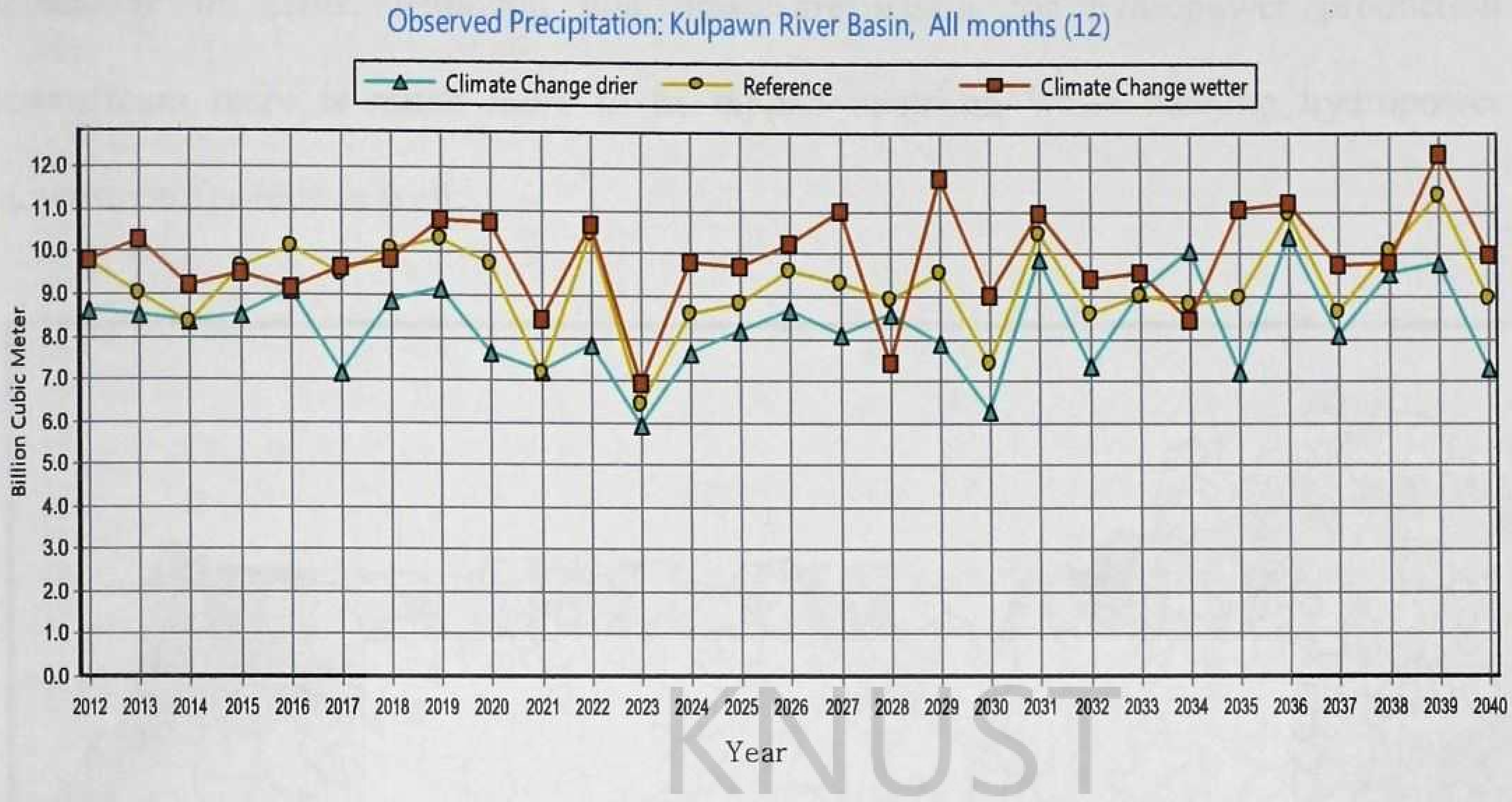


Figure 5-7: Total Annual Volume of Precipitation in the Kulpawn River Basin for Typical Climate Change Scenarios

5.2 Small Reservoirs and Dugouts

The number of small reservoirs in the region varies from district to district. Tables 5-1 and 5-2 show the reservoir distribution according to districts and catchments and their surface areas. The reservoirs in the White Volta Basin are very much utilized. The total annual water demand is estimated at 102Mm^3 for the entire Volta basin. In the Upper East Region of Ghana in the White 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.

The late 1980s and early 1990s marked the evolution of reservoirs in the basin; and reservoirs are still being constructed. This period (1990-2009) is referred to in this study as a post-impact period since the reservoirs cause hydrological alterations in the basin as shown in the chart (5-10 and 5-12). Period (1952-1989) before the construction of the small reservoirs is called a pre-impact period. From the figure above it is evident that a large quantity of water flows to the Volta Lake untapped before the evolution of a greater percentage of dams. Although this flows are useful for hydropower production downstream there is much more to be tapped upstream while meeting hydropower (downstream) needs as well.

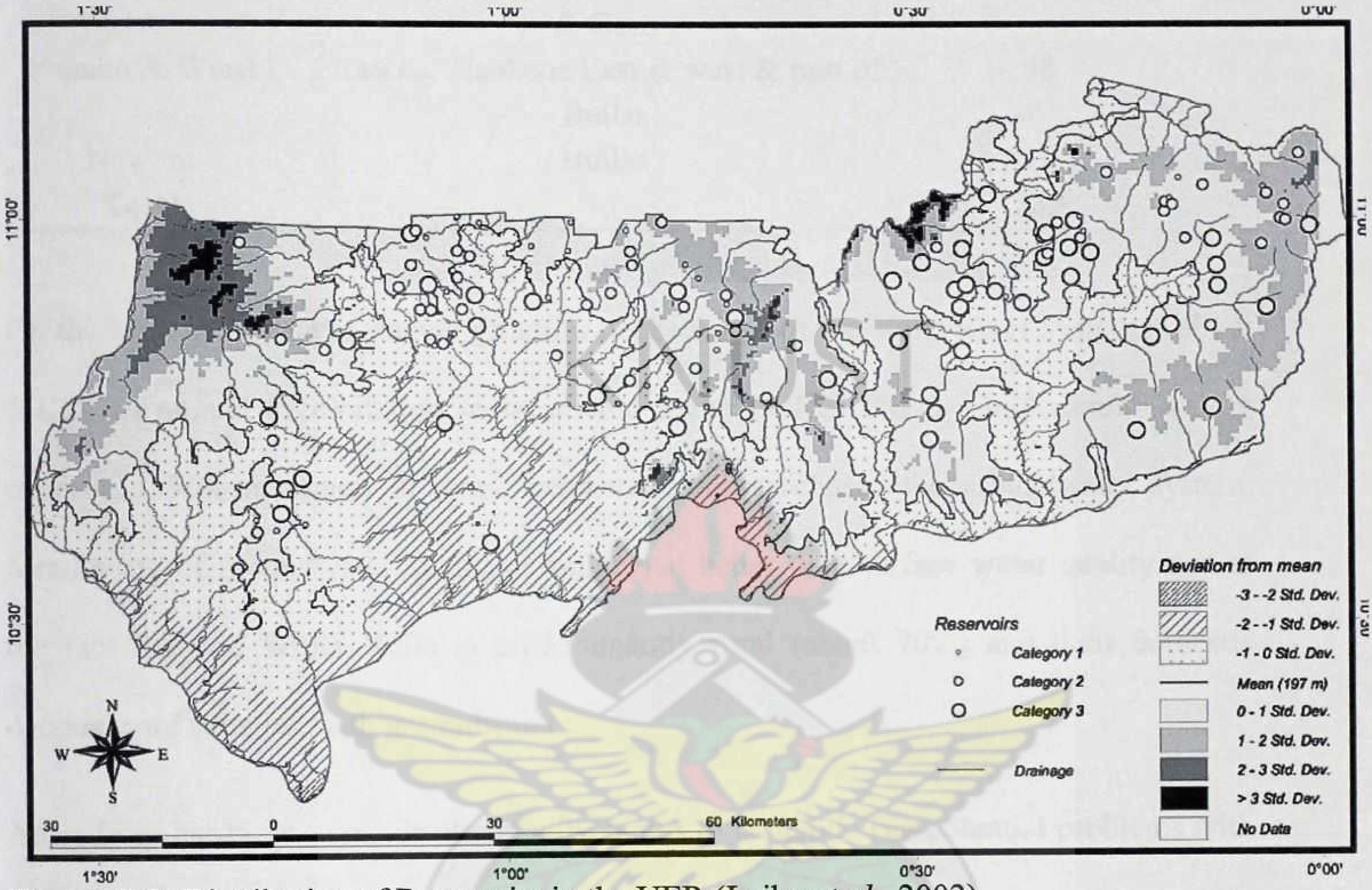


Figure 5-8: Distribution of Reservoirs in the UER (Leibe *et al.*, 2002)

The number of reservoirs in the region varies from district to district. Table 5-1 shows the reservoir distribution according to districts and their surface areas. The Kasena/ Nankana district has the highest number of small reservoirs with a total area of 2277.35ha.

Table 5-1: Reservoir Distribution According to Districts and their Surface Areas

District	No. of SR	Total Area (Ha)
Bolgatanga & Talensi Nabdam	30	205.94
Kasena/ Nankana East & West	81	2277.35
Bawku West	17	187.65
Bawku Municipal, Binduri & Garu	67	632.94
Builsa	27	149.76
Bongo	17	549.2
TOTAL	**239**	**4002.84**

Table 5-2: **Inventory of Small Reservoirs Per Catchment in the Basin**

Catchment	Districts Under catchment	No. of Reservoirs
Pwalugu	Bolga, Talensi, Bongo, & Nabdam	47
Yarugu	Bawku West, Bawku municipal, Binduri & Garu	84
Yagaba & Wiasi	Kasena/ Nankana East & west & part of Builsa	98
Nawuni	Builsa	10
Total		**239**

On the average, the mean annual groundwater recharge of the Volta River system is about 5-12% of annual precipitation in weathered rocks (WRC, 2011). Only rainfall values exceeding 380mm/annum in these weathered rocks recharge the groundwater system. Monitoring of groundwater quality is somewhat better than surface water quality due to the fact that the White Volta is predominantly rural (about 70%) and their domestic demands are satisfied with groundwater.

Apart from hardness, groundwater quality seems to be good. The potential problems with groundwater are largely fluoride excesses and iodine deficiencies (i.e. less than 0.005 mg/l) (WRC, 2011).

Three (3) stations, namely Yarugu, Pwalugu and Nawuni were selected to represent the upstream, midstream and downstream of the basin in Ghana, respectively. Figure 5-9 to 5-12 shows the flows for July and September and the monthly minimum flows in the basin fixed as the 25 percentile flow for Pwalugu.

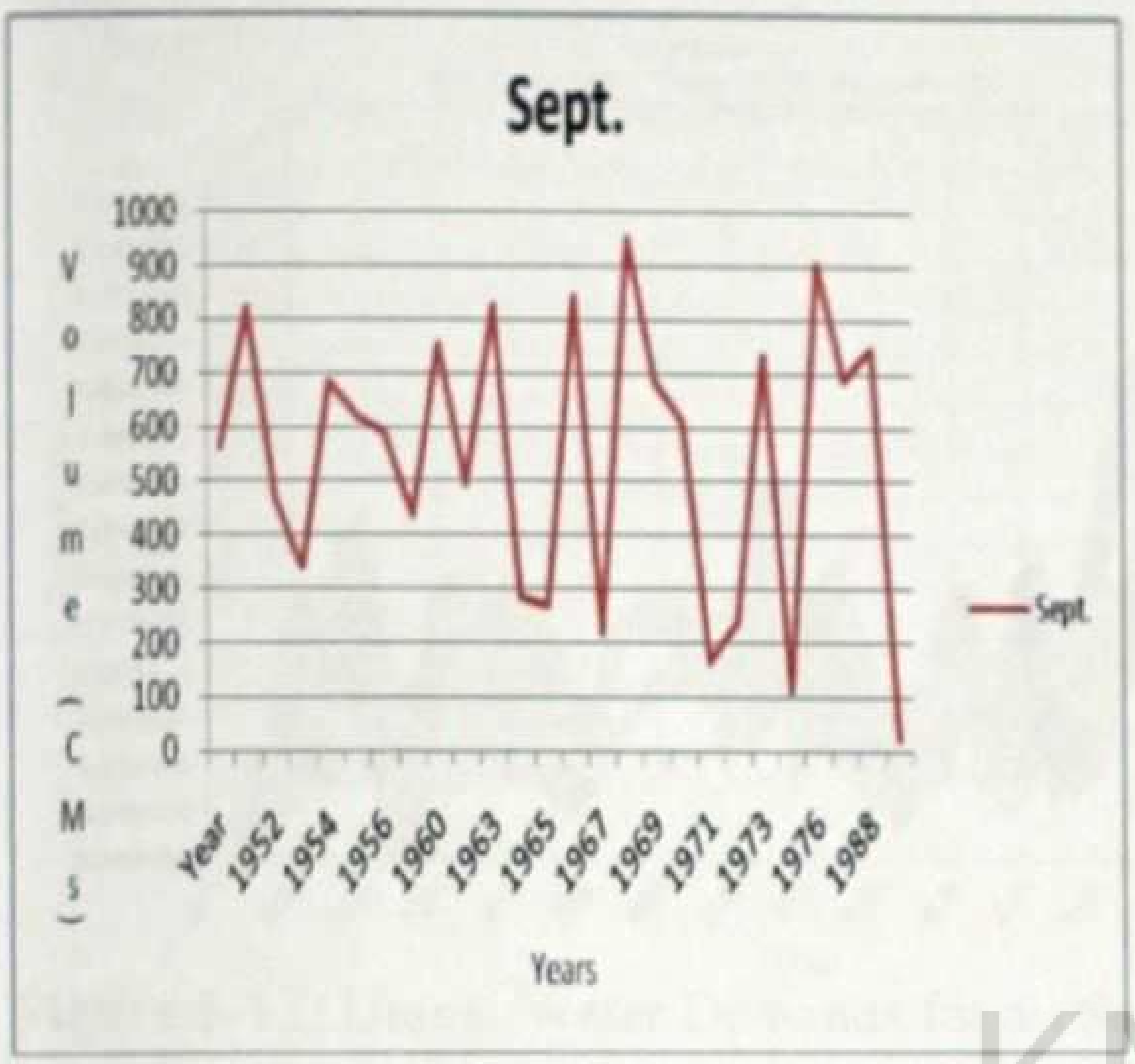


Figure 5-9: Pre-Impact Flows for Pwalugu (1951-1990) for September

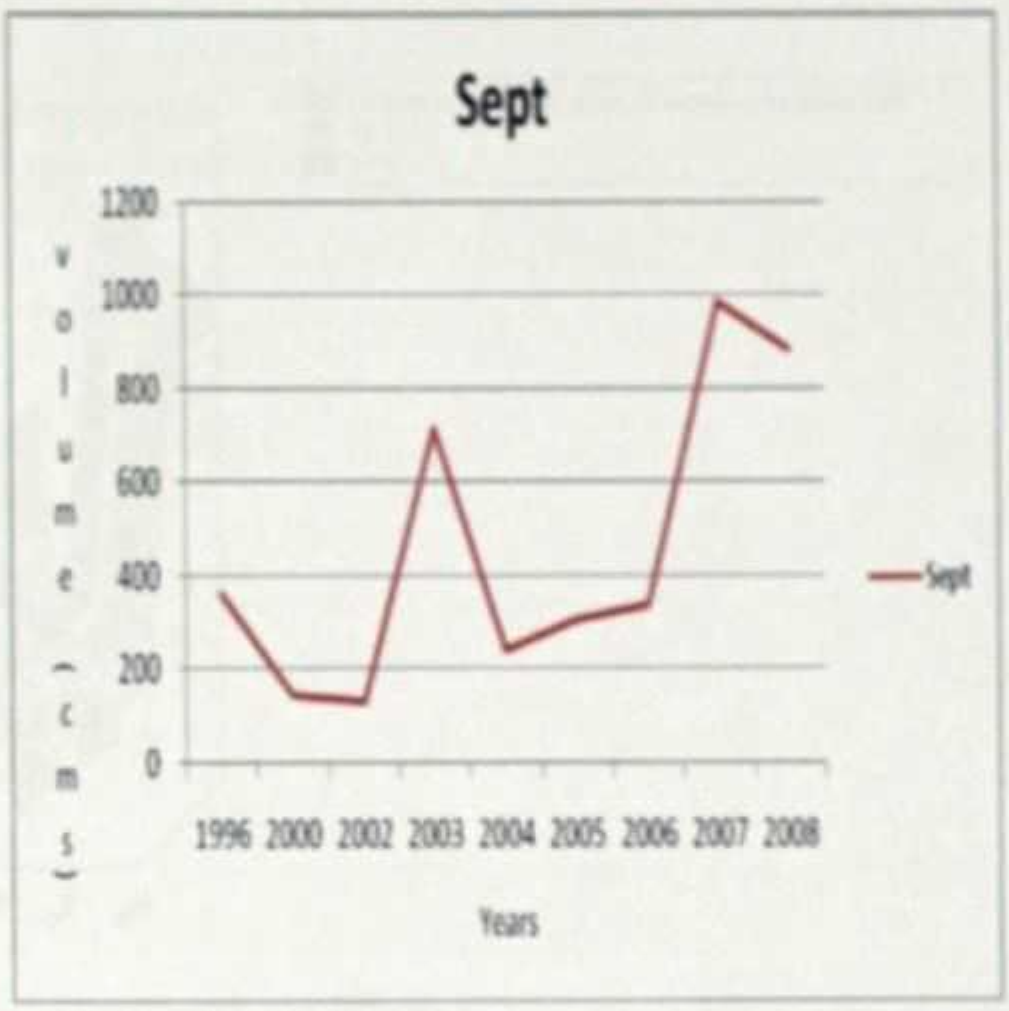


Figure 5-10: Post-Impact Flows for Pwalugu (1991-2008) for September

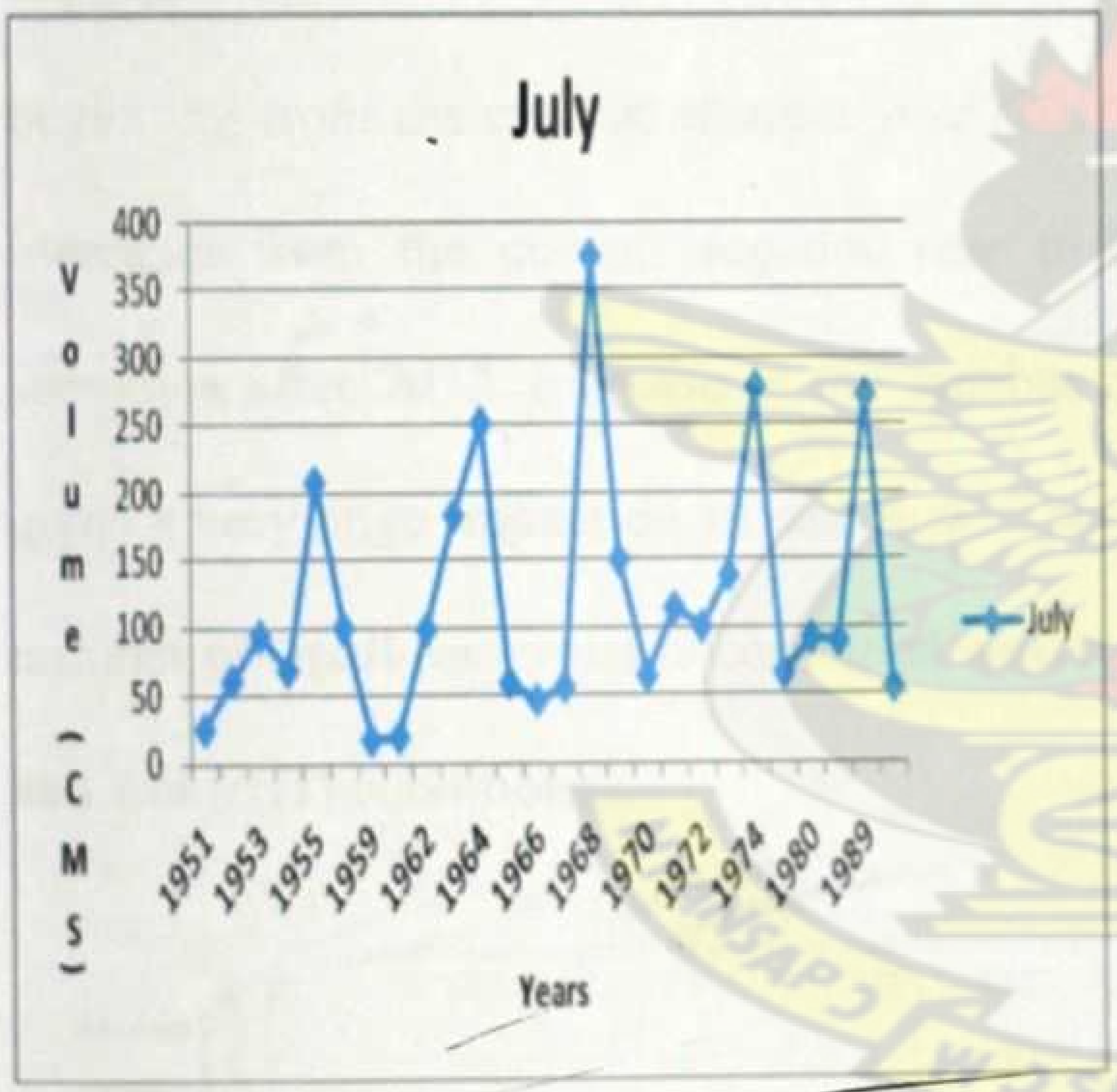


Figure 5-11: Pre-Impact Flows for Pwalugu (1951-1990) for July

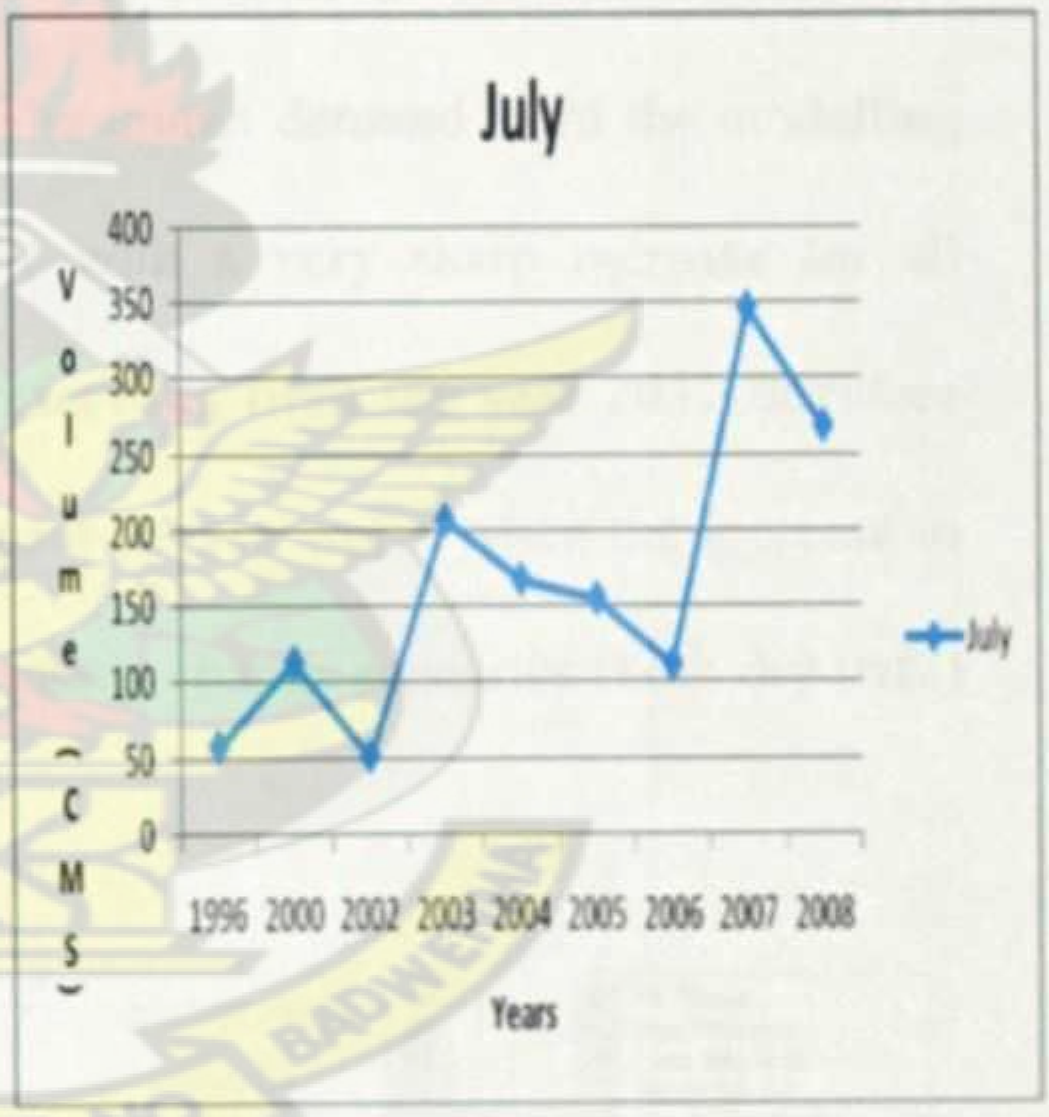


Figure 5-12: Post-Impact Flows for Pwalugu (1991-2008) for July

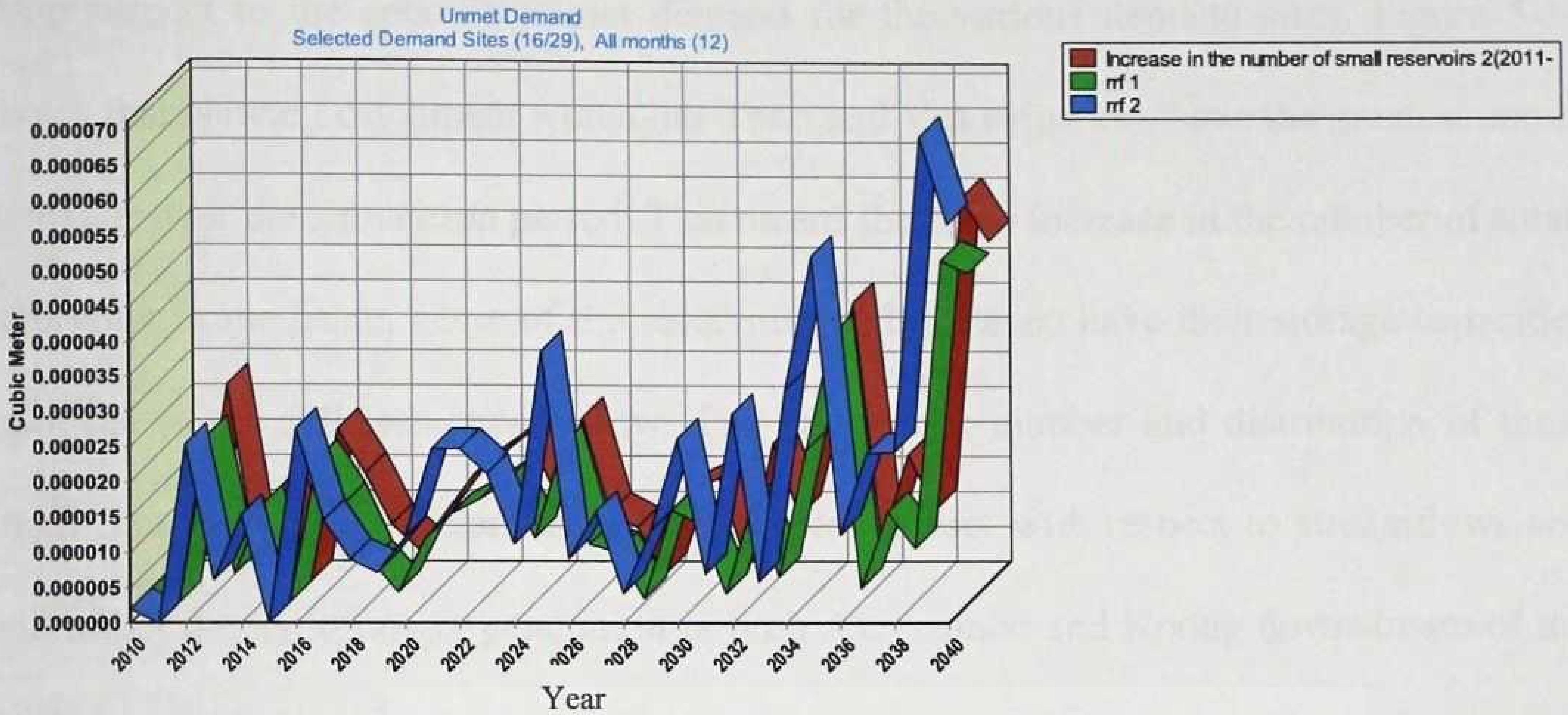


Figure 5-13: Unmet Water Demands for all Scenarios and all Years

It is shown in Figure 5-13 that water in the Ghana portion of the basin is already experiencing some unmet demands particularly with respect to the small reservoirs beginning from the current account year (2010). The unmet demand from the modelling increases from the current account year to 2031 with a very sharp increase for all scenarios after 2032. Increase in the number of reservoirs from the year 2031 therefore gives a very huge impact on stream flow. The impact is even worse when the increase in number of small reservoirs is combined with the climate change scenarios (both dry (rrf2) and wet (rrf1) conditions).

Figure 5-14: Unmet Water Demands for all Demand Sites and all Years

With respect to the specific unmet demand for the various demand sites, Figure 5-14 shows that Nawuni catchment which has Tono and Vea irrigation, have the greatest unmet demands over the simulation period. This means that with increase in the number of small reservoirs in the basin, some of the reservoirs will not even have their storage capacities achieved to the full less stream flow. The increase in number and distribution of these small reservoirs in the Basin has a hydrological impact with respect to streamflows and will affect the hydropower generation in both Akososmbo and Kpong downstream of the Basin.

The impact is significant in Nawuni catchment because Nawuni is downstream of the other catchments and so any development regarding water harvesting by reservoirs upstream will adversely affect the streamflows downstream catchment as it is observed in Nawuni.

There are however less unmet demand for Kulpawn livestock and small reservoirs and pwalugu livestock, irrigation and small reservoirs. Both Kulpawn catchment and Nawuni catchment are largely dependent on flows outside Ghana.

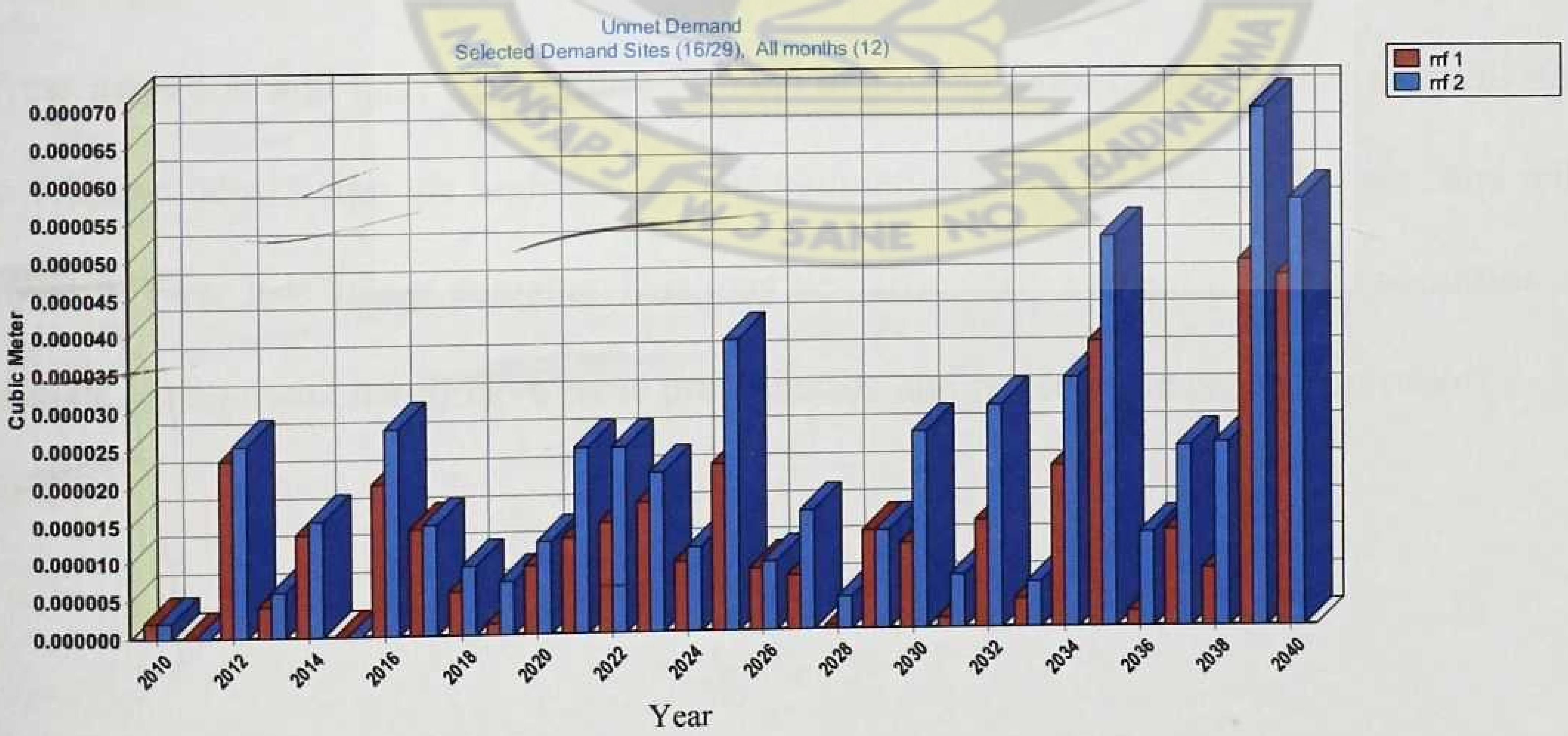


Figure 5-15: Unmet Water Demands for Climate Change and Reference Scenarios and all Years. (Legend details: rrf1 means climate change wet scenario and rrf2 means climate change dry scenario).

With the advent of climate change of an increase in temperature by 1°C, Figure 5-15 shows that the impact is not really different from the business as usual scenario (reference). The climate change scenario may either result in more water or less water, the impact of which may neutralize resulting in almost the same impact as the reference scenario.

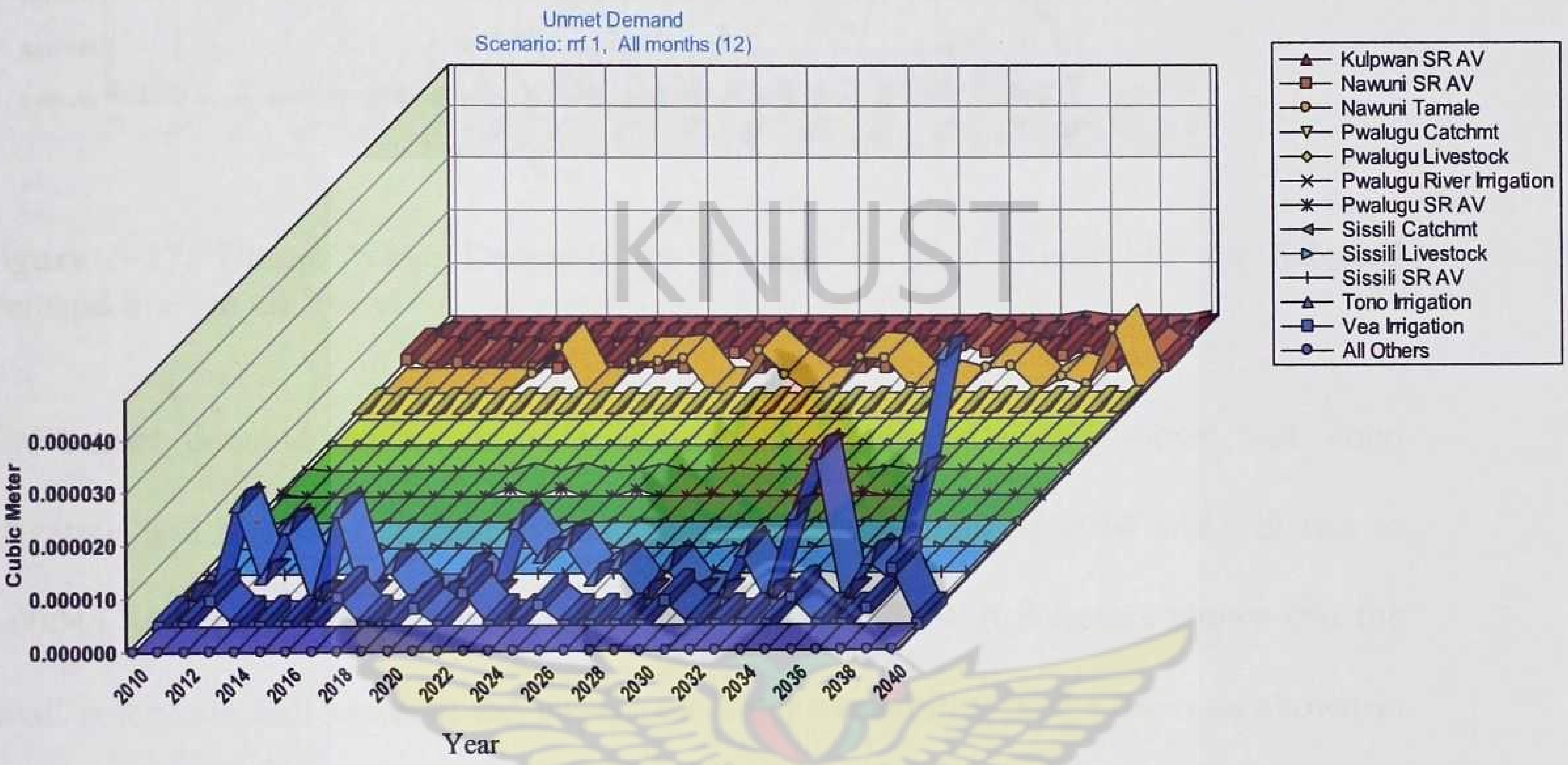


Figure 5-16: Unmet Water Demands for Climate Change Scenarios for Selected Demand Sites and all Years

From Figure 5-16 above, the unmet demand for the climate change scenario shows that Tono irrigation will have high unmet demand beginning from the year 2025 and will rise to 0.00045 Mm^3 being the highest over the simulation in 2038. The small reservoirs will however have less unmet demand. This may be particularly evident in wetter scenarios of climate change which will have more precipitation and hence more catchment runoff.

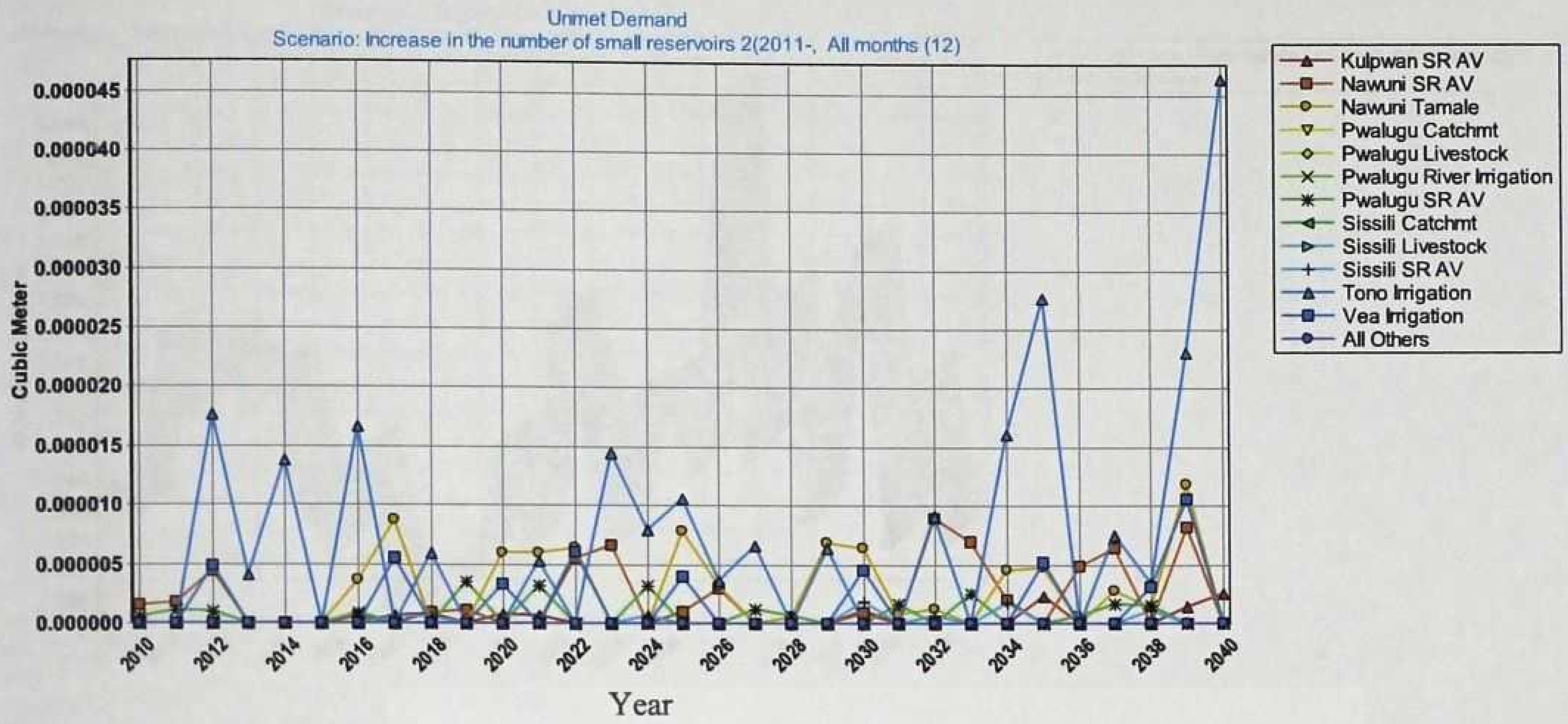


Figure 5-17: Unmet Water Demands for Increase in Small Reservoirs for Selected Demand Sites in all Years

The unmet demand for the more reservoir development scenario shows that Tono irrigation will have high unmet demand beginning from the year 2014 and will rise to 0.00045 Mm^3 being the highest over the simulation in 2039. It therefore shows that the small reservoirs will increase the impact on water availability in the basin as shown in Figure 5-17. The small reservoirs themselves are however experiencing less unmet demand over the simulation period.

5.3 Simulated Results for Stream Flow Under Increase in Number of small Reservoirs

The results for the stream flow under this scenario (Figure 5-18 below) showed very low reduction of runoff downstream of the White Volta River. However the reduction was slightly significant in the stream flow between 2017 and 2028 within the simulation period.

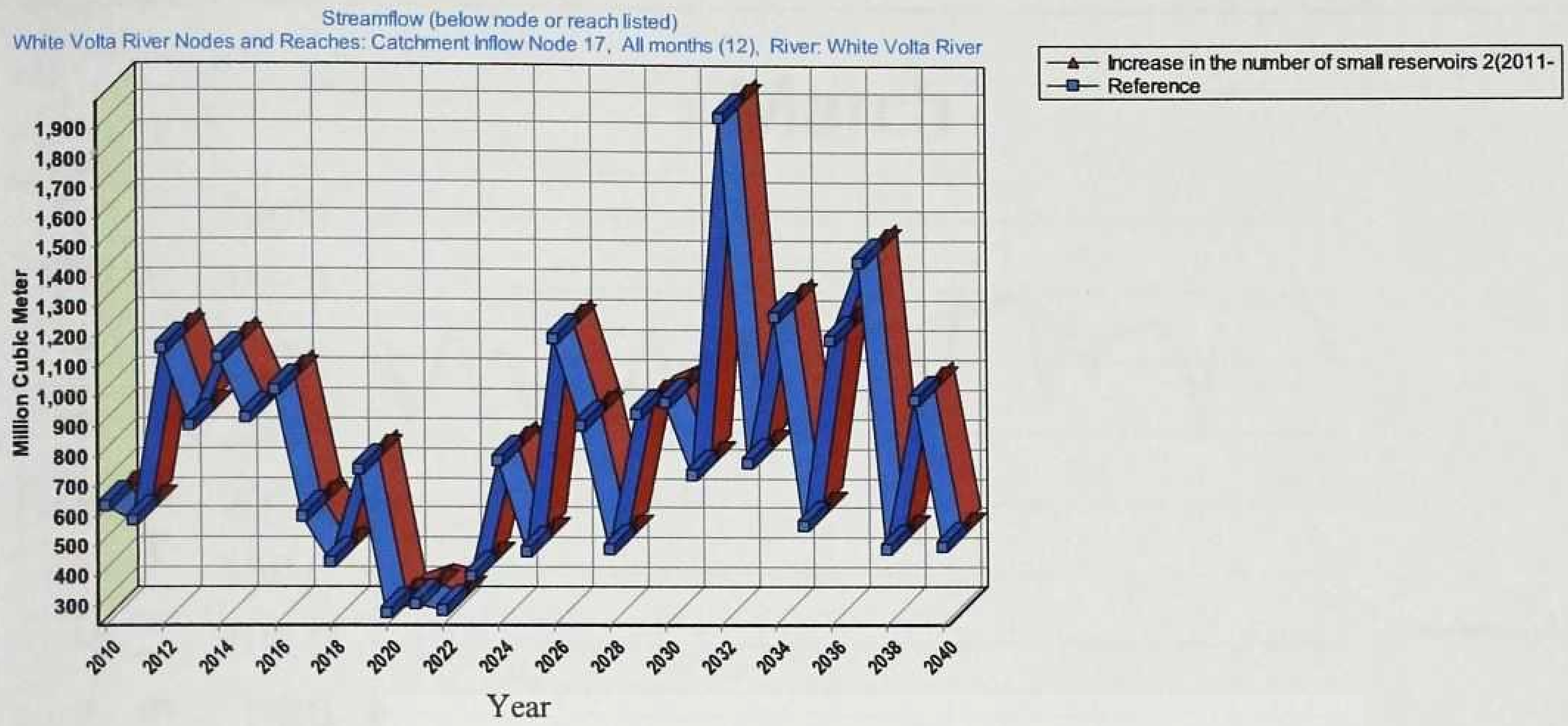


Figure 5-18: Stream Flow for Increase in Number of Reservoirs Scenario

5.4 Potential Evaporation of Reservoirs in the UER

The monthly potential evaporation in the Basin and the volume area relationship are shown in the Figures (5-19 - 5-23) below. The net monthly potential evaporation was recorded over a period of forty years. The minimum and maximum evaporation was compared with the Meteorological station data of Navrongo.

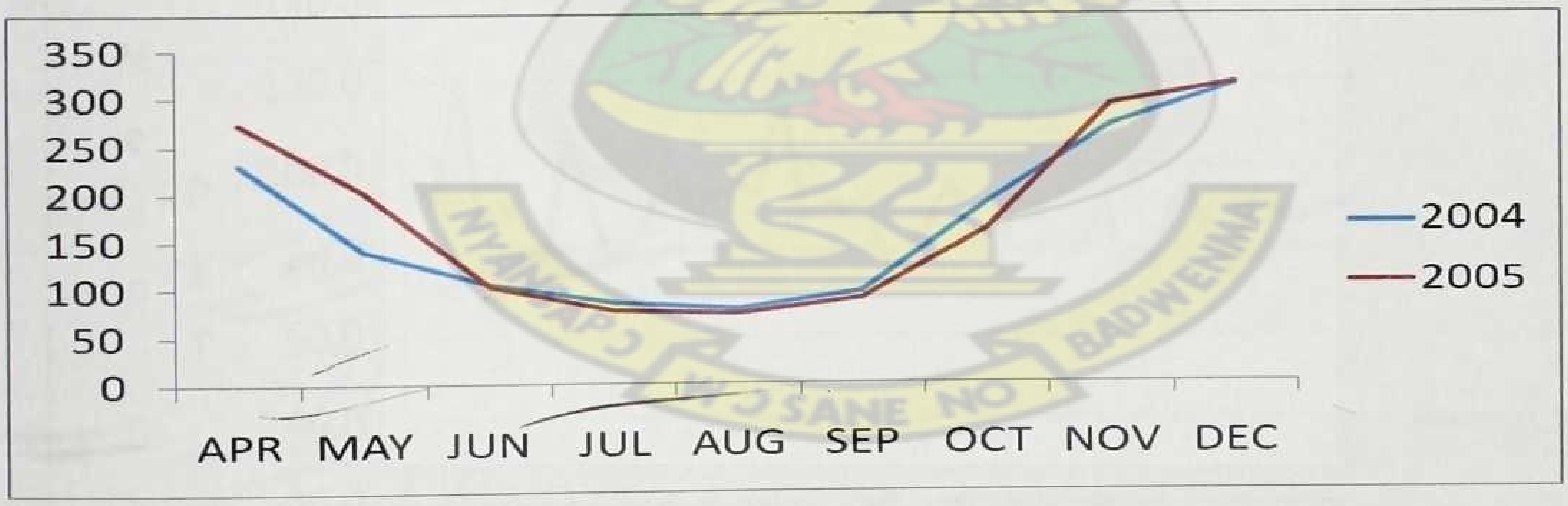


Figure 5-19: **Potential Evapotranspiration (mm) for Manga**

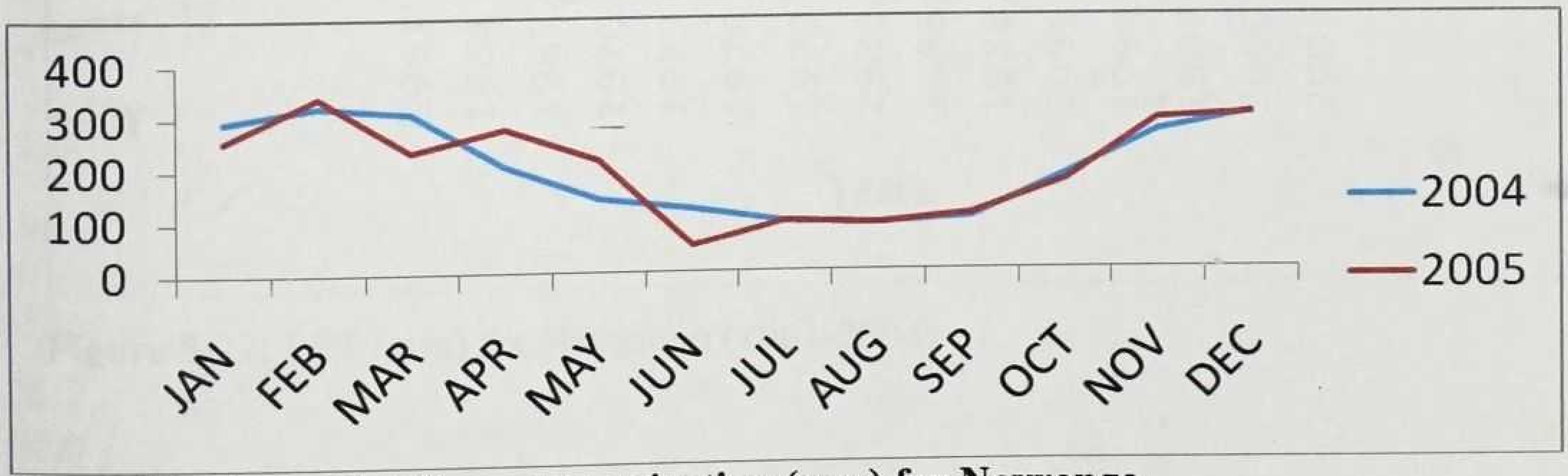


Figure 5-20: **Potential Evapotranspiration (mm) for Navrongo**

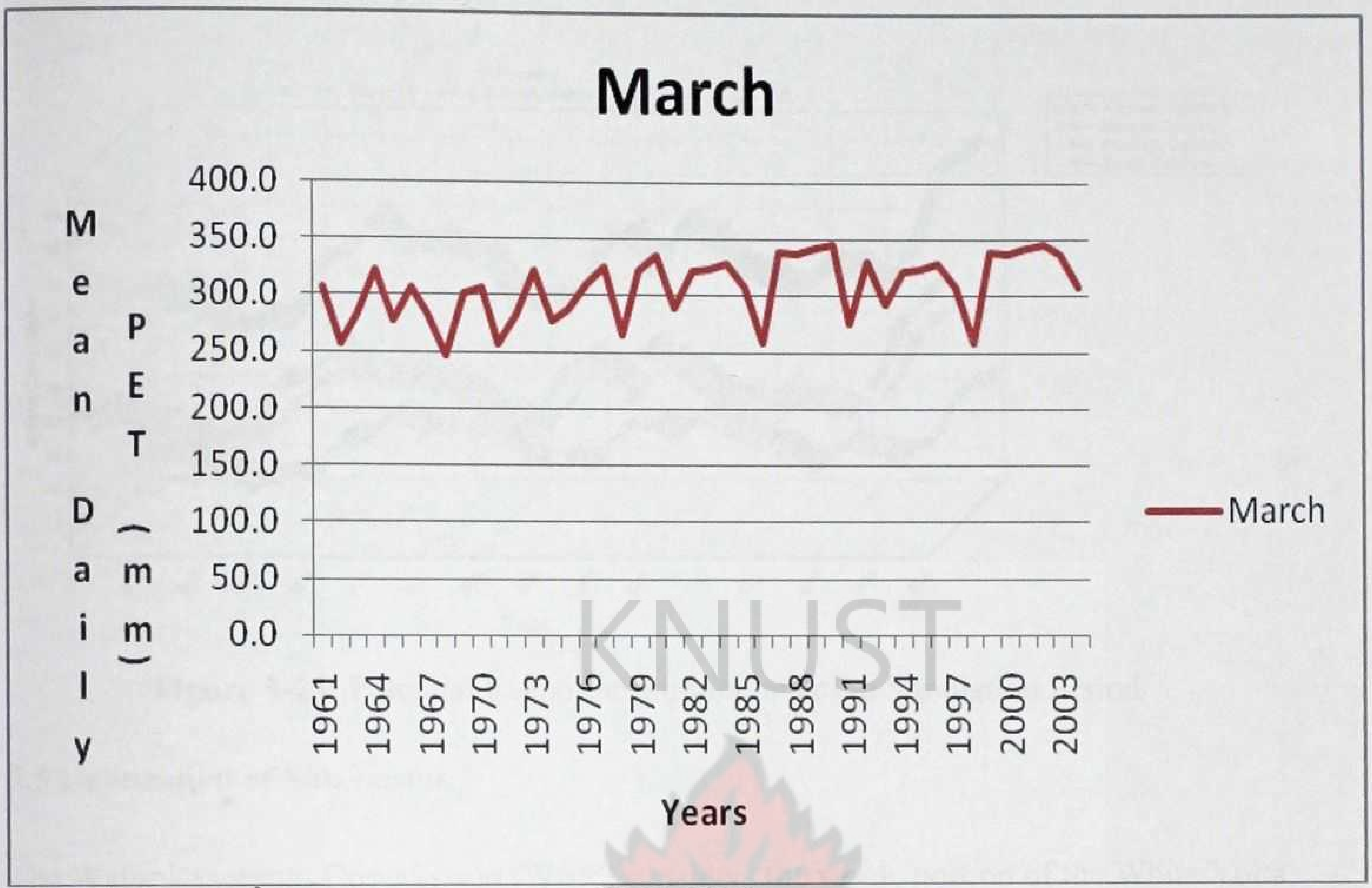


Figure 5-21: PET (mm) for Navrongo (1961-2004)

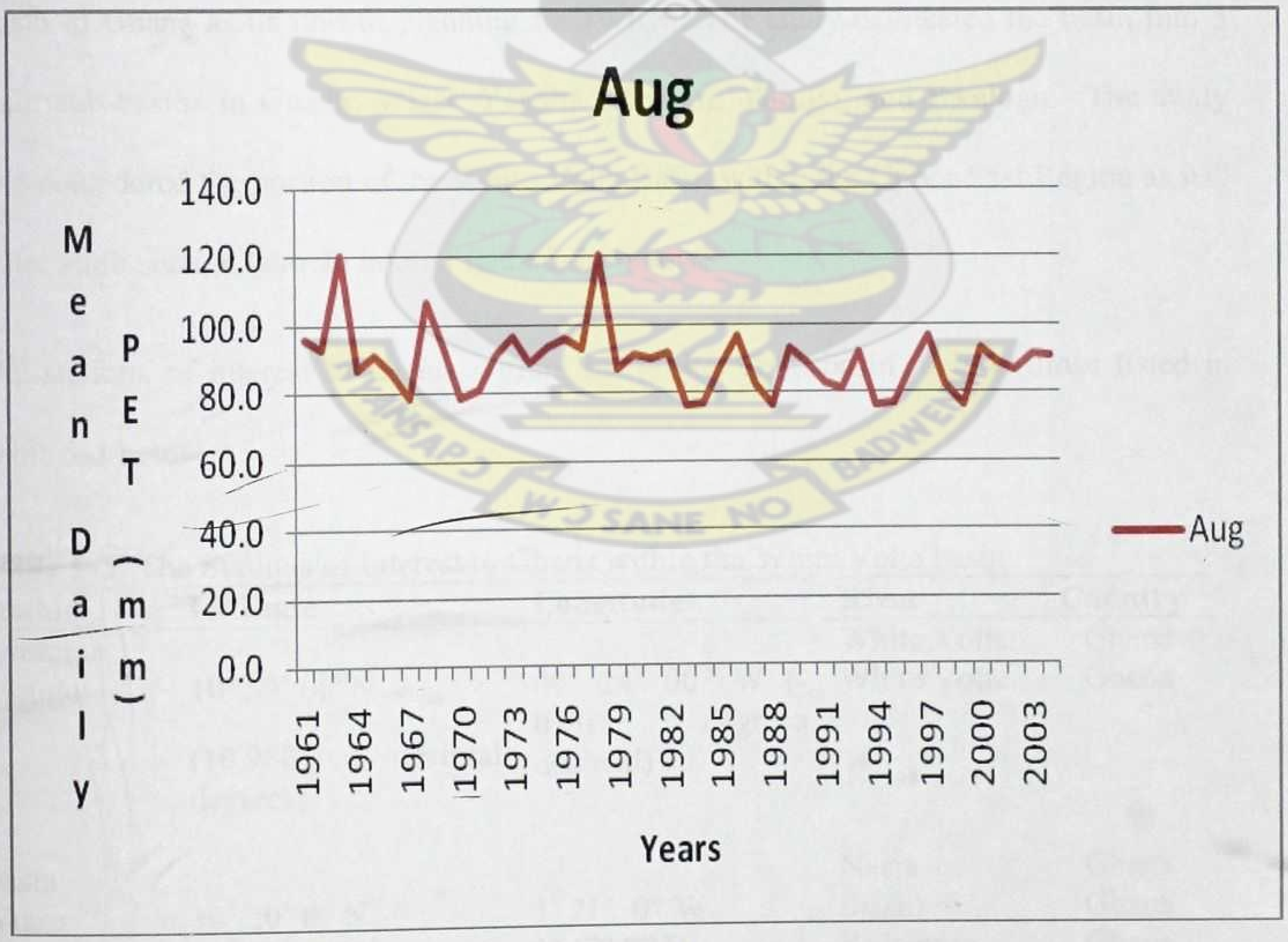


Figure 5-22: PET (mm) for Navrongo (1961-2004)

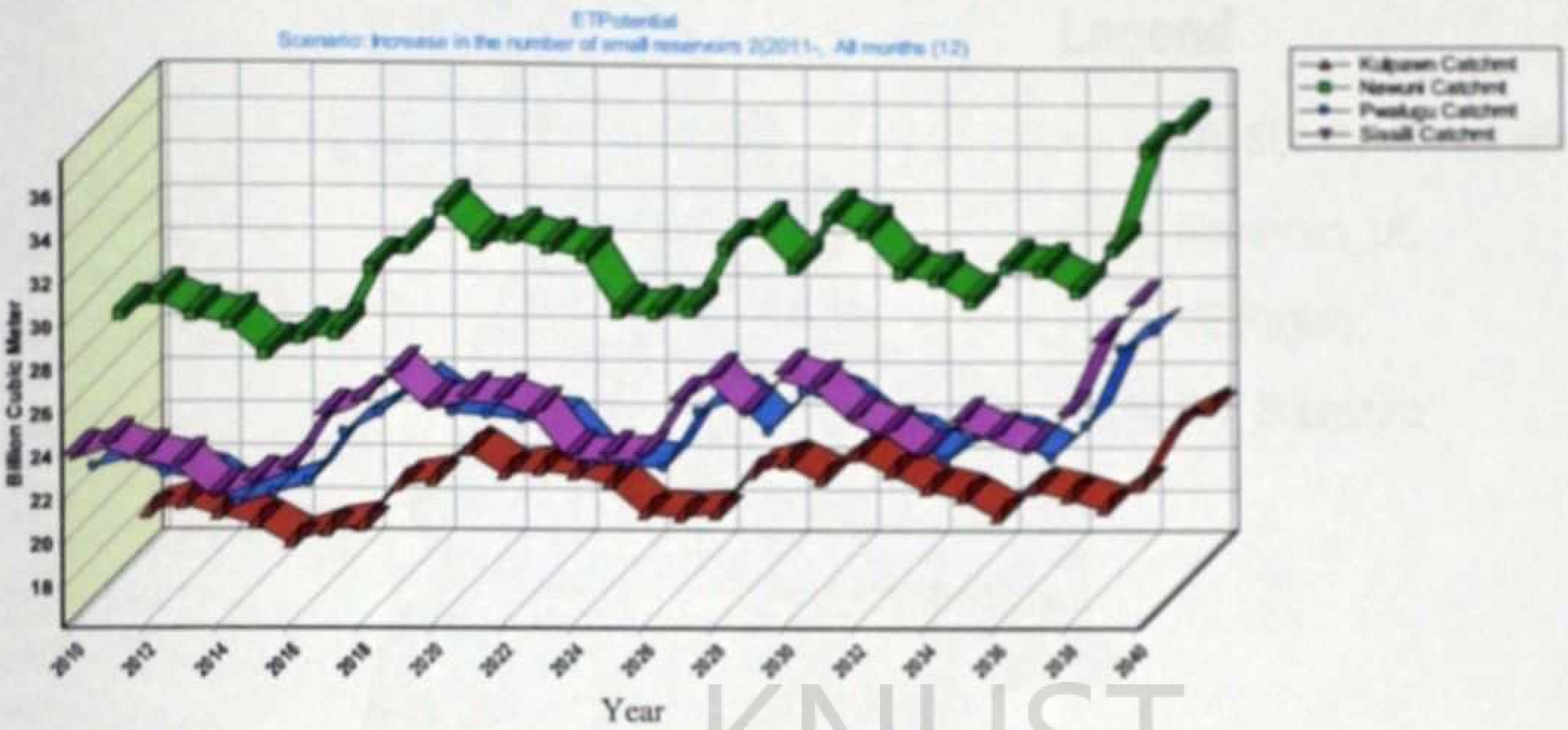


Figure 5-23: Potential Evapotranspiration over the Simulation Period

5.5 Delineation of Sub-basins

The Water Resources Commission (WRC) considers the whole portion of the White Volta Basin in Ghana as its unit of planning for IWRM. The study delineated the basin into 5 main sub-basins in Ghana; Wiasi, Yagaba, Nawuni, Yarugu, and Pwalugu. The study also considered the portion of the White Volta Basin within the Upper East Region as its" water audit section (shown in the Figure 5-24 below).

The stations of interest to Ghana within the White Volta basin include those listed in Table 5-3 below.

Table 5-3: The Stations of Interest to Ghana within the White Volta basin

Station	Latitude	Longitude	River	Country
Pwalugu			White Volta	Ghana
Yarugu	10° 59' 00"N (10.980 decimal degrees)	00° 24' 00" W (-0.40 degrees decimal)	White Volta	Ghana
Nasia			Nasia	Ghana
Wiase	10° 20' 0" N	1° 21' 0" W	Sissili	Ghana
Yagaba	10° 15' 0" N	1° 17' 0" W	Kulpawn	Ghana

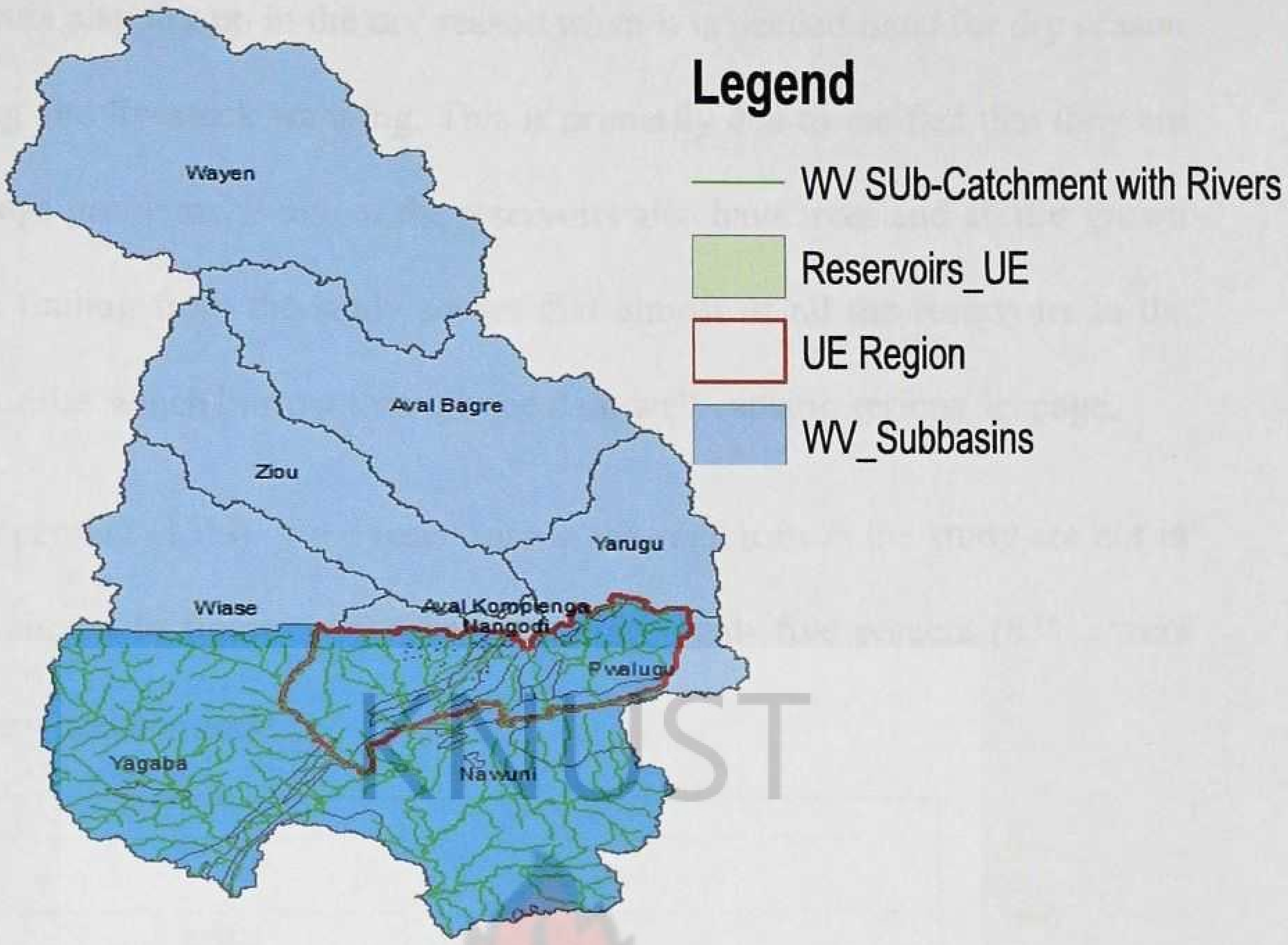


Figure 5-24: Upper East Region within the White Volta Sub-catchments

5.6 Conditions of Dams and Dugouts

There are about 239 small reservoirs and dugouts in the Ghana portion of the White Volta basin. Distribution in the sub-basins is given in Tables 5-1 and 5-2.

Communities in the White Volta are supplied with water from boreholes for their water needs. However, management mechanisms are operational through monthly levy and contributions from members who patronize the facility for the purpose of maintenance.

Some communities have been provided with Small Reservoirs or Dugouts. However, few of the small reservoirs and dug-outs are used for intensive large scale irrigation. These intensive irrigation schemes are concentrated in the Bawku and Kasena/Nankana areas and are usually carried out downstream of these facilities. Other facilities however do have farming activities upstream of the reservoir. This phenomenon was observed in areas of facilities with broken down canals or without canals.

Most of these dugouts also dry up in the dry season when it is needed most for dry season vegetable gardening and livestock watering. This is primarily due to the fact that they are silted or have seepage problems. Some of the reservoirs also have trees and shrubs grown on the banks. One finding from the study shows that almost or all the reservoirs in the Basin contain crocodiles which burrow through the dam wall causing serious seepage.

Essentially, fifteen percent (15%) of the reservoirs in the region from the study are not in good condition as shown in figure 5-25. The remaining eight- five percent (85%) were either seen to be very good or good.

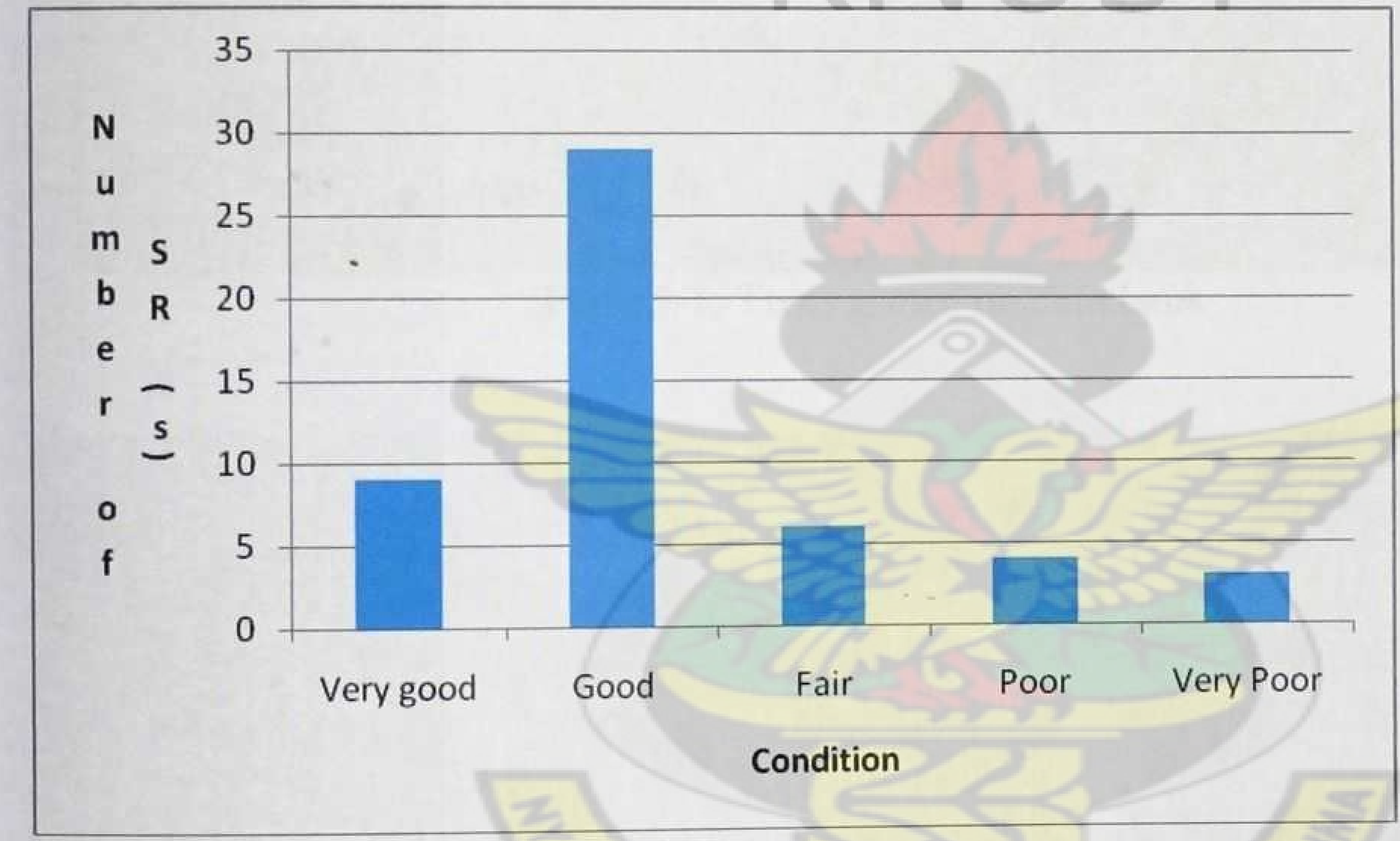


Figure 5-25: Conditions of small Reservoirs in the White Volta basin

Desilting in most cases is not carried out by community members because they claim it is difficult and requires heavy equipments. This may explain why there was no attempt to desilt the fifteen percent of reservoirs that were not in good condition. The plates below (5-1 and 5-2) depicts the state of some of the fifteen percent reservoirs in the region from the study.

Plate 5-1: Trees grown on dam bank

Plate 5-2: Trees and serious siltation

5.7 Cropping Patterns in Sub-catchments

Common Crops grown are mostly cereals like Millet, Maize, Guinea corn and rice in the rainy season and mostly vegetables including tomatoes, pepper and onions in the dry season. The yields of these crops are low because of poor soil fertility with most farmers now going into dry season farming. Women are also most often given the poor lands in terms of soil fertility to farm on. This discrimination does not promote gender equity and poverty alleviation among women and household food security, in general.

The rainfall pattern is becoming more and more erratic and poses a major challenge in the basin as most farmers do rain-fed farming. This contributes to the low yields especially for the early millet and maize. There is the need therefore to put in modern technologies towards efficient and productive irrigation where farmers could make up for their losses.

Dry season crop production in the Upper East region seems to be increasing. However, there is no corresponding increase in yields. So there is intensification of farming without necessarily improving productivity. This does not encourage the young folks in the communities to engage in active farming.

5.8 Landuse and Management of Sub-Catchments

The Upper East region is one of the regions in the northern part of the country that has a peculiar traditional role of men as heads of families. This therefore puts them at a vantage position with regards to access to land for farming. Generally Lands are managed by the Tindanas' and individually owed in most parts of the Basin. Access to lands for farming is therefore authorized by these family heads. By the cultural setting, men mostly take the very arable lands including lands close to water bodies and valley areas. This increases the rate of sediment transport to the water bodies as well as filling up of valley areas due to the bad farming practices adopted.

5.9 Water Use and Conservation

Irrigation water for farms is mostly with buckets and ropes or watering cans. Reservoirs with functional canals are however used in the good category of reservoirs. The use of buckets and ropes is not very efficient and also tiresome when large areas of lands are to be irrigated. Other attendant problems including high cost of fuel for water pumps was also revealed. Rehabilitating and including canals to the reservoirs could go a long way to solve those problems.

For most of the reservoirs visited, water use in those communities is managed by committees mostly the WATSAN or WUA. This is however done with some support from the Ministry of Food and agriculture and some local organisation such as ZOVFA, CSRC and the Presbyterian agric stations.

6 CONCLUSIONS AND RECOMMENDATION

6.1 Conclusion

The development of reservoirs has the potential to increase water harvesting and storage towards ensuring adequate supply of water throughout the year.

In the Upper East Region of Ghana where there is a higher incidence of poverty, small reservoirs are a major component of the people's farming activities with over two hundred and thirty- nine of such reservoirs dotted across the length and breadth of the region. The development of agricultural water management intervention activities through irrigation such as the creation of small reservoirs is one of the means of storing water that can contribute significantly to food production. About eighty-five percent (85%) of reservoirs from the study are in good condition and are therefore supporting agricultural production through dry season irrigation in the area.

The aim of the study was to assess the hydrological impact of Agricultural Water management intervention activities that have become a dominant phenomenon in the White Volta Basin so as to go a long way to enhance, or otherwise, any further Agricultural Water development in the Basin. From the results obtained for all the scenarios created, small reservoirs in the UER are already impacting on the hydrology of the catchments that they are concentrated. The impact though relatively low for climate change (rrf1 and rrf2) and the reference scenarios, is more significant for the scenario of increase in the development of these small reservoirs over the simulation period. The creation of more reservoirs increases the demand sites and therefore reduces the volume of flow into the Volta River.

Both Tono and Vea irrigation schemes in the Nawuni catchment will be hard hit interms of unmet water demands especially from the year 2032 to 2040.

There is however good flow for the Kulpawn and the Pwalugu catchments especially the Pwalugu on White Volta due to the flows contributed from Burkina Faso as a result of the Bagri dam hydropower generation. There are less unmet water demands from these two catchments. The flows from these two catchments can be channelled into other uses especially when a hydropower plant is built on the Pwalugu site of the White Volta since it will still contribute to flow downstream to support both the Akosombo and Kpong hydropower plants.

The WEAP Model was a very good tool for this thesis and can be used as a very good planning tool in water resources planning and management. It offered a wide range of possibilities to be analysed under the scenarios creation.

6.2 Recommendation

- In view of the current conditions of the reservoirs in the region, it is recommended that the various water user groups managing the reservoirs in the communities are strengthened to enhance the management of the reservoirs.
- Further development of reservoirs should be coordinated and targeted at improving the existing ones through desilting, reduction in farm lands close to the reservoirs and controlling the presence of crocodiles especially to reduce seepage and hence increase storage rather than constructing new reservoirs.
- There is the need for a study on the actual cause of seepage in the reservoirs and a detailed relationship between groundwater recharge and streamflow established especially for arid zones.

REFERENCES

Andah, W. E.I., van de Giesen, N. and Biney, C. A. (2005). *Water, Climate, Food, and Environment in the Volta Basin Contribution to the project ADAPT Adaptation strategies to changing environments* [Online][Available on http://www.weap21.org/index.asp?doc=05] [Cited on December 2006].

Annor, F. (2012). “*Diagnostic Study of the Black Volta Basin in Ghana”. 33- 145.*

Annor, F.O., van de Giesen, N., Liebe, J., van de Zaag, P., Tilmant, A, and Odai, S.N. (2009). *“Delineation of small reservoirs using radar imagery in a semi-arid environment: A case study in the upper east region of Ghana”.* Physics and Chemistry of the Earth. 34 (2009) 309–315

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: 21-36.

Bartley, J.D., Buddemeier, R.W and Smith, S.V. (2005). *The Role of Impoundments in the Sediment Budget of the Conterminous United States.* Geomorphology 71: 99- 111.

Bao-quing, S. and Chengqing, Y. (2001). Multipond Systems; A Sustainable Way to Control Diffuse Phosphorous Pollution. *Ambio* 30(6): 369-375.

Bennett, A.J. (2000). Environmental consequences of increasing production: some current perspectives. Agric. Ecosys. Environ. 82, 89–95.

Bigss, B.J.F. and Clausen, B. (2000). Flow *Variables for Ecological Studies in Temperate Streams: Groupings Based on Covariance. Journal of Hydrology* 237: 184-197.

Fu, B.J., Wen-Wu, Z., Li-Ding, C., Zhan-Feng and Liu,Yi-He Lu. (2005). Ecohydrological *Effects of Landscape Pattern Change*. Landscape Ecological Engineering 1: 25-32.

Bouwer, H, (2002a). *Artificial recharge of groundwater: hydrogeology and engineering.* Hydrogeol. J. 10, 121–142.

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, R. W. and Robert, W. (2004). "*Detection and Characterization of Small Water Bodies". A Final Technical Report for the NASA-EPSCoR/KTech- funded project, "Landscape-Scale Detection and Classification of Small Water Bodies: Temporal Integration of Diverse Types of Data.*

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

Chen, W. and Tong, S. T. Y. (2002). *Modeling the relationship between land use and surface water quality*. University of Cincinnati, Cincinnati, USA.

DeFries, R. and Eshelman, K.N (2004). *Land-use and Hydrologic Processes: a major Focus for the Future.* Hydrological Processes 18: 2183-2186.

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.

Dune, T, and Luna, B. L. (1978). *Water in Environmental Planning*. New York: W.H. Freeman and Company.

Faulkner, J W., Steenhuis, T., van de Giesen, N., Andreini, M., and Liebe, J. R. (2008). "*Water use and productivity of two small reservoir irrigation schemes in Ghana's upper east region".*

Fu, B. J., Meng, Q. H., Zhang, Q J., Zhao, W. W., and Bo-jie, F. (2004). *Effects of Land-use Pattern Change on Rainfall-Runoff and Runoff-Sediment relations: A Case Study in Zichang Watershed of the Loess Plateau of China. Journal of* Environmental Sciences 16(3): 436-442.

Geoff, K. and Droogers, P. (2000). *Comparing Estimates of Actual Evapotranspiration from Satelites, Hydrological Models, and Field Data: A case study from western Turkey.*

Ghana Statistical Services, (2005). *Ghana Living Standards Survey Report of the Fifth Round (GLSS 5).*

Ghana Statistical Services, (2010). *Population and Housing Census.*

Gyau-Boakye, P. and Tumbulto, J.W. (1999). "*The Volta Lake and declining rainfall and streamflows in the Volta River Basin*". Environment, Development and Sustainability 2 (2000): 1-10.

Hagan, I. (2007). *Modelling the Impact of Small Reservoirs in the Upper East Region of Ghana.*

Sieber, J., Swartz, C. and Huber-Lee, A. (2005). *WEAP User guide* Stockholm Environmental Institute.

International Union for Nature Conservation (IUCN-BRAO) (2012, Water Audit of the Volta Basin Update Report.

Laube, W., Awo, M., and Schraven, B. (2008). "*Erratic Rains and Erratic Markets: Environmental change, economic globalisation and the expansion of shallow groundwater irrigation in West Africa*". Centre for Development Research, University of Bonn, Germany.

Liebe, J. N., van de Giesen, N., and Andreini, M. (2005). *Estimation of small reservoir storage capacities in a semi-arid environment A case study in the Upper East Region of Ghana.*[Online] Available from www.smallreservoirs.org [Cited November 2006].

Liebe, J. (2002). "*Estimation of Water Storage Capacity and Evaporation Losses of Small Reservoirs in the Upper East region of Ghana*". Master Thesis, Faculty of Mathemetics and Natural Science, University of Bonn, Germany.

Martin, N. (2006). "*Development of a water balance for the Atankwidi catchment, West Africa – A case study of groundwater recharge in a semi-arid climate*". Doctoral thesis, University of Göttingen, Germany.

Martin, N. and van de Giesen, N. (2005). *"Spatial distribution of groundwater production and development potential in the Volta River Basin of Ghana and Burkina Faso".* Water international, 30(2): 239-249.

Longbucco, N. J. (2010). *"Impacts of Small Water Bodies on the Hydrological Response of Small Agricultural Watersheds".*

Pimentel, D., Bailey, O., Kim, P., Mullaney, E., Calabrese, J., Walman, L., Nelson, F., and Yao, X. (1999). *Will limits of the earth's resources control human numbers?* Environ. Sustainability Dev. 1, 19–39.

Postel, S. (1993). Water and agriculture. In: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's FreshWater Resources. Oxford University Press, Oxford, UK, pp. 56–66.

Prathapar, S.A. (2000). Water shortages in the 21st Century. In: Cadman, H. (Ed.). The Food and Environment Tightrope. Australian Centre for International Agricultural Research, Canberra, Australia, pp. 125–133.

Qadir, M., Boers, T. M., Schubert, S., Ghafoor, A., and Murtaza, G. (2003). *"Agricultural water management in water-starved countries: challenges and opportunities".* Wageningen, Netherlands, pp. 165-185.

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

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

Tyler, S.W., Chapman, J.B., Conrad, S.H., Hammermeister, D.P., Blout, D.O., Miller, J.J., Sully, M.J., and Ginanni, J.M. (1996). *Soil-water flux in the southern Great Basin, United States: temporal and spatial variations over the last 120,000 years.* Water Resour. Res. 32, 1481–1499.

Van de Giesen, N., Martin, A., van Edig, A., and Vlek, P. (2001). "*Competition for water resources of the Volta Basin*". IAHS Publication 268: 199-205, IAHS Press, Wallingford, England.

Van den Berg, J. (2008). *Exploring shallow groundwater irrigation: Current status and future application - a case study in the Atankwidi catchment, Ghana*. MSc. Thesis, Delft University of Technology, Delft, Netherlands. 1-32.

Volta River Authority, (2006). *Powering Development in Ghana and West Africa: Business Opportunities & Investment Brochure.*

Wallace, J.S. (2000). *Increasing agricultural water use efficiency to meet future food production*. Agric. Ecosyst. Environ. 82, 105–119.

Water Resources Commission, (2008). "*White Volta River Basin Integrated Water Resources Management Plan*".

Water Resources Commission, (2011). "*Water Resources Atlas of the northern regions of Ghana* ".

Wiafe, K. (1997). *Irrigation, Volta Basin Starter Kit July, 2006 Compiled by Drechsel, P., Barry, B., Bahri, A. and Andah W. E. I.*

World Conservation Union (IUCN), (2007). "*Water Audit of the Volta Basin, Revised edition*".

Zheng, H., Zhang, L., Liu, C., Shao, Q., and Fukushima, Y. (2007). *Changes in Stream Flow Regime in Headwater Catchments of the Yellow River Basin in the 1950s*. ~~Journal~~ of Hydrology 21: 886-893.

Internet Sources

Climate Research Unit (CRU), University of East Anglia http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10.

FAO Coporate document Respository[Online] [Available on www.fao.org] [Cited in December 2006]

GVP Report, (2007) {http://www.glowa-volta.de}

Small Reservoir Project. [Online] [Available on http://www.smallreservoirs.org/] [Cited on December 2006]

APPENDIX 1

Yarugu

The reconstituted flow is from 1953 to 2005 a period of 43 years. The mean annual flow is 229.16 m^3/sec with a co-efficient of variation of …..

	TABLE: WATER AVAILABILITY SCENARIOS AT YARUGU ON THE WHITE VOLTA IN M^3/S											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**ANNUAL**
Curr. Act. 2005	18.21	30.01	27.49	27.52	37.86	105.22	119.57	195.58	216.79	61.71	37.18	33.96	75.93
10%	2.97	0.23	0.16	1.14	2.68	12.82	45.20	38.67	41.68	24.88	14.99	3.43	50.66
25%	11.65	9.83	9.06	10.82	16.21	38.87	70.08	153.04	196.72	73.33	29.64	16.56	102.14
Mean	22.64	22.86	21.76	23.91	32.05	82.74	238.50	494.65	1031.08	581.13	97.16	30.75	229.16
75%	36.81	35.90	32.17	35.31	47.88	134.87	395.60	794.34	1711.98	975.49	159.29	48.81	355.01
90%	40.45	43.23	38.39	41.70	54.48	151.44	466.09	881.03	1922.96	1102.65	172.87	53.61	393.48

Pwalugu

Data constituted covers the 45 year period (1951-2005). The estimated annual mean over the period is 101.54m^3/sec with a co-efficient of variation of 0.44.

	TABLE: WATER AVAILABILITY SCENARIOS AT PWALUGU ON THE WHITE VOLTA IN M^3/S											
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	ANNUAL
Cur.acut.05	16.51	31.92	29.08	28.92	42.02	131.59	155.30	254.38	304.38	82.95	45.62	37.70	96.70
10%	0	0	0	0	0	0	20.07	125.45	132.6	38.40	0	0	26.38
1st Quartile(25%)	0	0	0	0	0	3.77	46.20	217.64	241.19	61.03	3.737	0	47.80
MEAN	3.49	3.81	4.94	6.10	18.76	38.82	100.22	339.97	485.89	170.33	22.56	5.83	101.54
3rd Quartile(75%)	0.60	0.00	0.06	2.82	31.40	58.47	139.43	434.02	700.54	221.81	34.25	5.07	135.71
90%	14.89	13.16	22.48	20.77	53.77	97.22	204.07	601.90	824.04	345.35	52.54	24.20	165.29

Nawuni

	TABLE: WATER AVAILABILITY SCENARIOS AT NAWUNI ON THE WHITE VOLTA IN M^3/S												
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**ANNUAL**
Cur.Act. 05	**35.83**	**50.11**	**55.68**	**51.82**	**56.71**	**168.40**	**280.15**	**368.26**	**816.99**	**271.25**	**141.06**	**66.77**	**196.92**
10%	**5.22**	**2.77**	**2.04**	**1.93**	**3.81**	**18.27**	**70.51**	**240.46**	**349.72**	**167.93**	**32.45**	**10.32**	**75.45**
Lower Quartile(25%)	**6.32**	**4.17**	**3.11**	**3.13**	**6.62**	**34.45**	**98.84**	**412.31**	**856.65**	**295.74**	**43.28**	**13.24**	**148.15**
MEAN	**22.31**	**17.92**	**17.72**	**19.76**	**31.51**	**86.59**	**191.30**	**603.78**	**1166.45**	**566.34**	**88.67**	**32.64**	**240.28**
Upper Quartile(75%)	**35.79**	**26.51**	**21.00**	**27.55**	**55.20**	**105.61**	**255.19**	**785.49**	**1513.79**	**743.93**	**112.60**	**50.33**	**311.08**
90%	**54.18**	**52.92**	**56.18**	**58.20**	**69.15**	**166.25**	**352.65**	**987.32**	**1797.47**	**993.83**	**162.76**	**70.26**	**384.08**

The data completed covers 1951 – 2005. The 45 year mean annual flow is 240.28m^3/sec with a co-efficient of variation of 0.39.

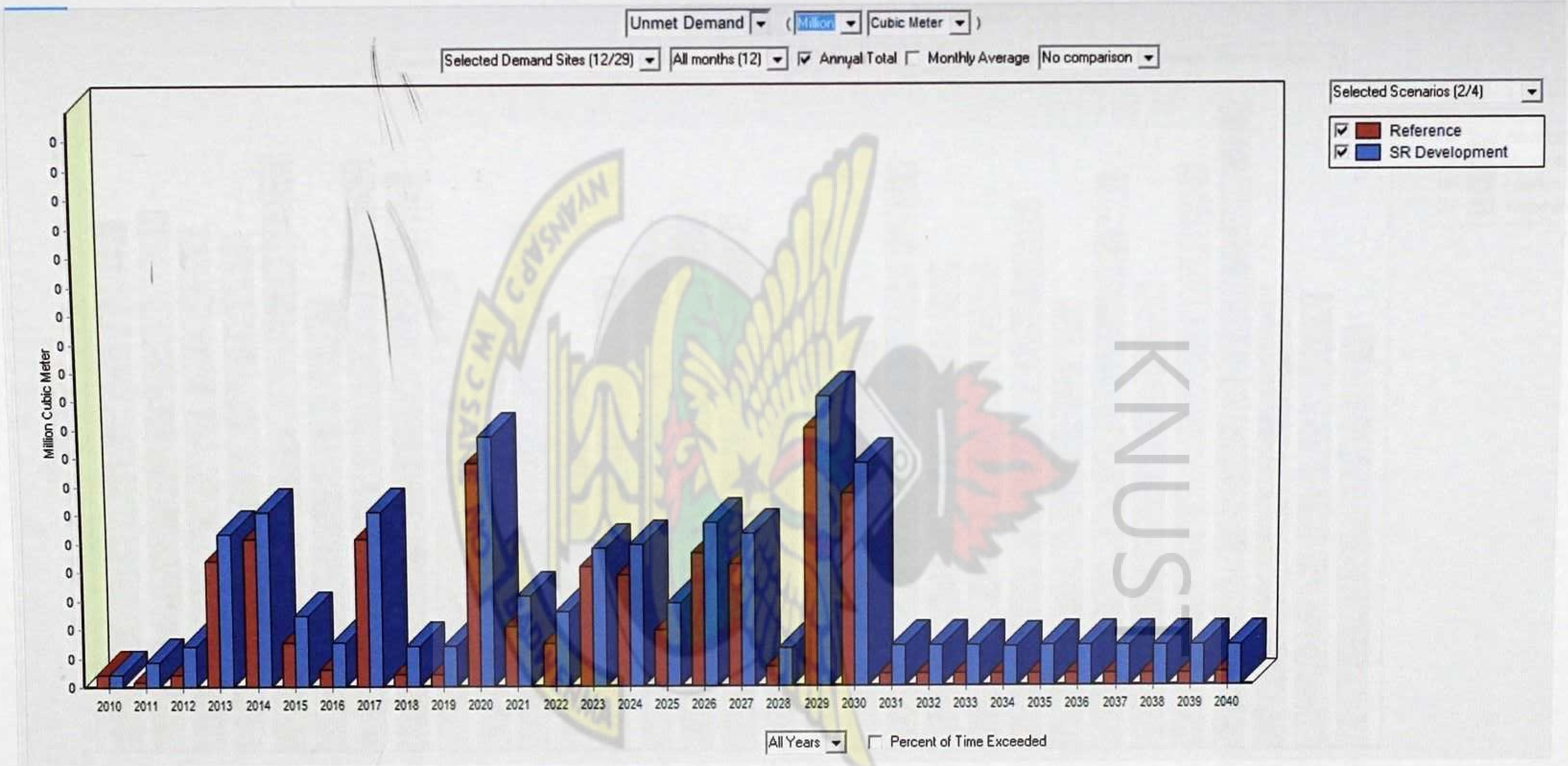
Small Reservoirs (SR) Measurements

FID_SR	Quality measurement	LAT	LONG	Y_PROJ	X_PROJ	Area [m]	Area [ha]	Perimeter
135	good	10.93721	-0.97128	1209781	721715.2	20636	2.06	667
319	very good	10.76872	-0.79178	1191277	741476.9	12016	1.20	458
318	good	10.85986	-0.72055	1201418	749193.8	49844	4.98	1346
317	fair	10.95499	-0.78673	1211891	741878.9	24690	2.47	682
315	good	10.93219	-0.95724	1209237	723253.6	21705	2.17	974
313	very good	10.94413	-0.77994	1210694	742630	22820	2.28	790
312	good	10.94106	-0.84499	1210304	735520.5	61158	6.12	1105
311	good	10.92771	-0.82356	1208843	737873.6	204390	20.44	2529
310	good	10.77171	-0.8029	1191599	740257.8	51994	5.20	1444
244	good	10.71426	-0.78736	1185254	742003.3	30375	3.04	878
236	poor	10.74107	-0.79293	1188217	741372.7	151648	15.16	2417
231	fair	10.75478	-0.82806	1189706	737518.4	84474	8.45	1279
219	fair	10.81868	-0.94908	1196685	724231.5	105218	10.52	1984
217	good	10.82891	-0.93766	1197825	725472.2	56524	5.65	1110
214	very poor	10.84274	-1.08834	1199248	708982.9	46716	4.67	1284
212	good	10.85866	-1.06497	1201024	711527.4	27137	2.71	995

211	very poor	10.88501	-1.10379	1203912	707265.1	64431	6.44	1075
199	good	10.78603	-0.7714	1193208	743692.5	132764	13.28	2023
198	good	10.78774	-0.80646	1193369	739855.9	28260	2.83	884
194	good	10.81505	-0.76959	1196421	743866.7	38933	3.89	1406
193	very good	10.82	-0.74223	1196990	746856.2	19627	1.96	799
189	poor	10.84581	-1.07611	1199595	710319.1	41205	4.12	919
186	good	10.84634	-1.00124	1199706	718506.4	58597	5.86	1155
185	very poor	10.84805	-1.09307	1199831	708462	64934	6.49	1796
179	very good	10.85923	-0.74098	1201332	746960.1	31764	3.18	1499
176	good	10.86481	-1.03637	1201725	714651	104912	10.49	1608
175	very good	10.8696	-0.98751	1202290	719990.4	29581	2.96	930
171	good	10.87709	-0.71631	1203329	749644.2	226525	22.65	3027
170	very good	10.88634	-1.09062	1204068	708704.2	71667	7.17	1543
169	good	10.8887	-1.05445	1204355	712656.5	61157	6.12	1207
166	good	10.89284	-0.78236	1205017	742406.9	59372	5.94	1358
164	good	10.89413	-0.89944	1205069	729602.8	92408	9.24	1521
163	fair	10.89475	-0.96916	1205086	721978.8	173021	17.30	2374
161	very good	10.8936	-0.72868	1205145	748276.8	19701	1.97	737
159	good	10.90122	-0.94716	1205817	724379.9	48600	4.86	1295
158	poor	10.90713	-1.03806	1206405	714436.4	118270	11.83	1711

157	fair	10.90571	-0.73171	1206483	747935.3	74384	7.44	1681
155	good	10.9083	-1.07253	1206511	710666.4	34899	3.49	888
154	good	10.91154	-0.78763	1207082	741815.6	170483	17.05	1991
148	good	10.91661	-1.0942	1207415	708290.8	65555	6.56	1390
144	good	10.92407	-0.99824	1208308	718776.9	14131	1.41	628
141	good	10.92536	-1.05831	1208408	712208.5	119372	11.94	2188
139	very good	10.92537	-1.08045	1208394	709787.8	35137	3.51	1073
138	fair	10.92563	-0.76538	1208660	744237.5	46990	4.70	1147
129	good	10.95572	-0.94504	1211849	724569.9	87672	8.77	1758
127	very good	10.96133	-1.06147	1212385	711838.2	60325	6.03	1396
125	good	10.96042	-0.84862	1212443	735107.8	30345	3.03	774
123	good	10.96324	-1.07478	1212588	710382	50500	5.05	1200
120	good	10.96616	-0.77355	1213138	743311.4	181592	18.16	2715

Results of Unmet Demand for Increase in Number of Reservoirs and the Reference Scenario



Unmet Demand (Million Cubic Meter)

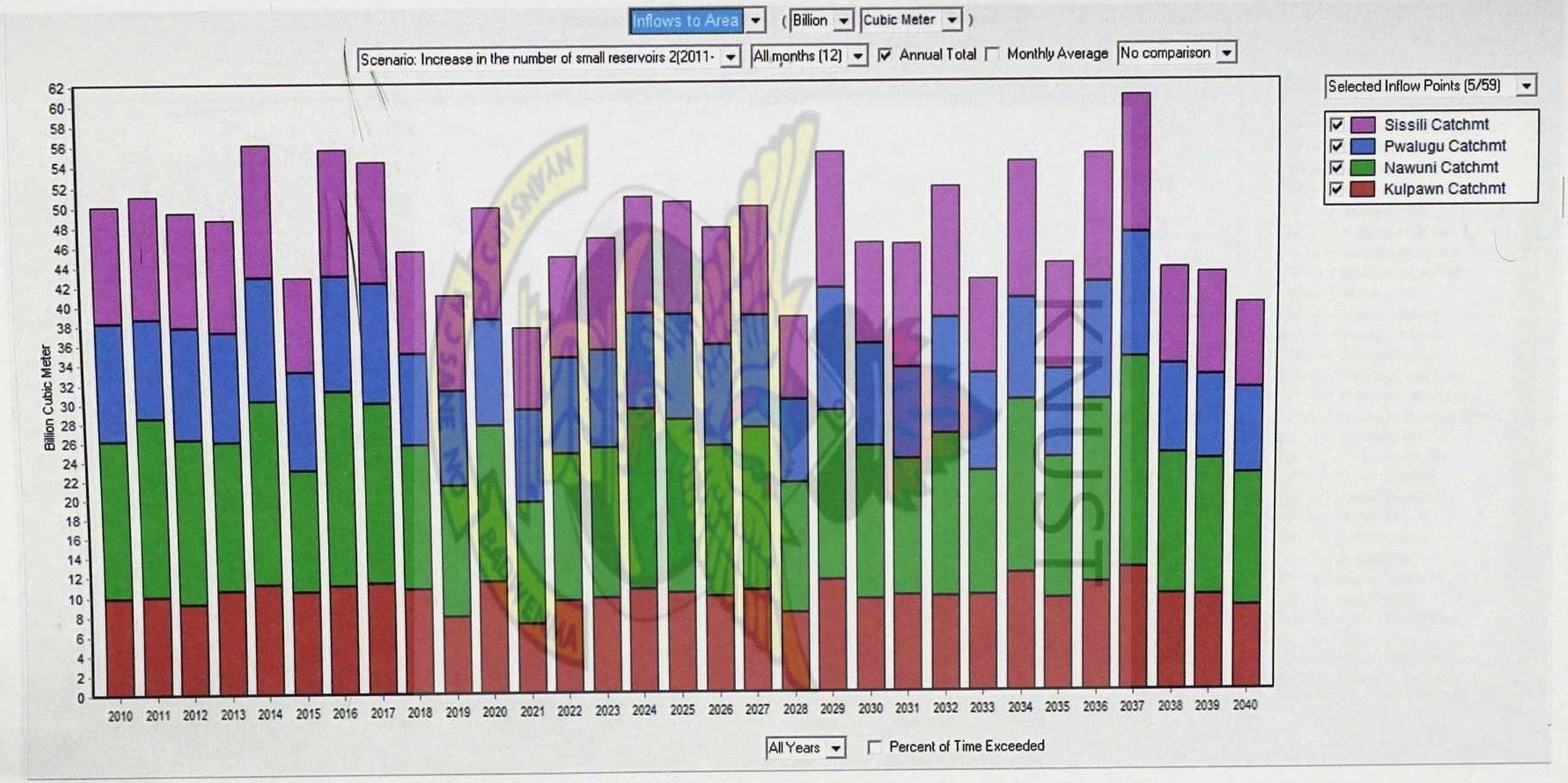
Selected Demand Sites (12/29) | All months (12) | ☑ Annual Total ☐ Monthly Average | No comparison

Selected Scenarios (2/4)

☑ Reference
☑ SR Development

All Years ☐ Percent of Time Exceeded

Results of Inflows into Areas for all Catchments



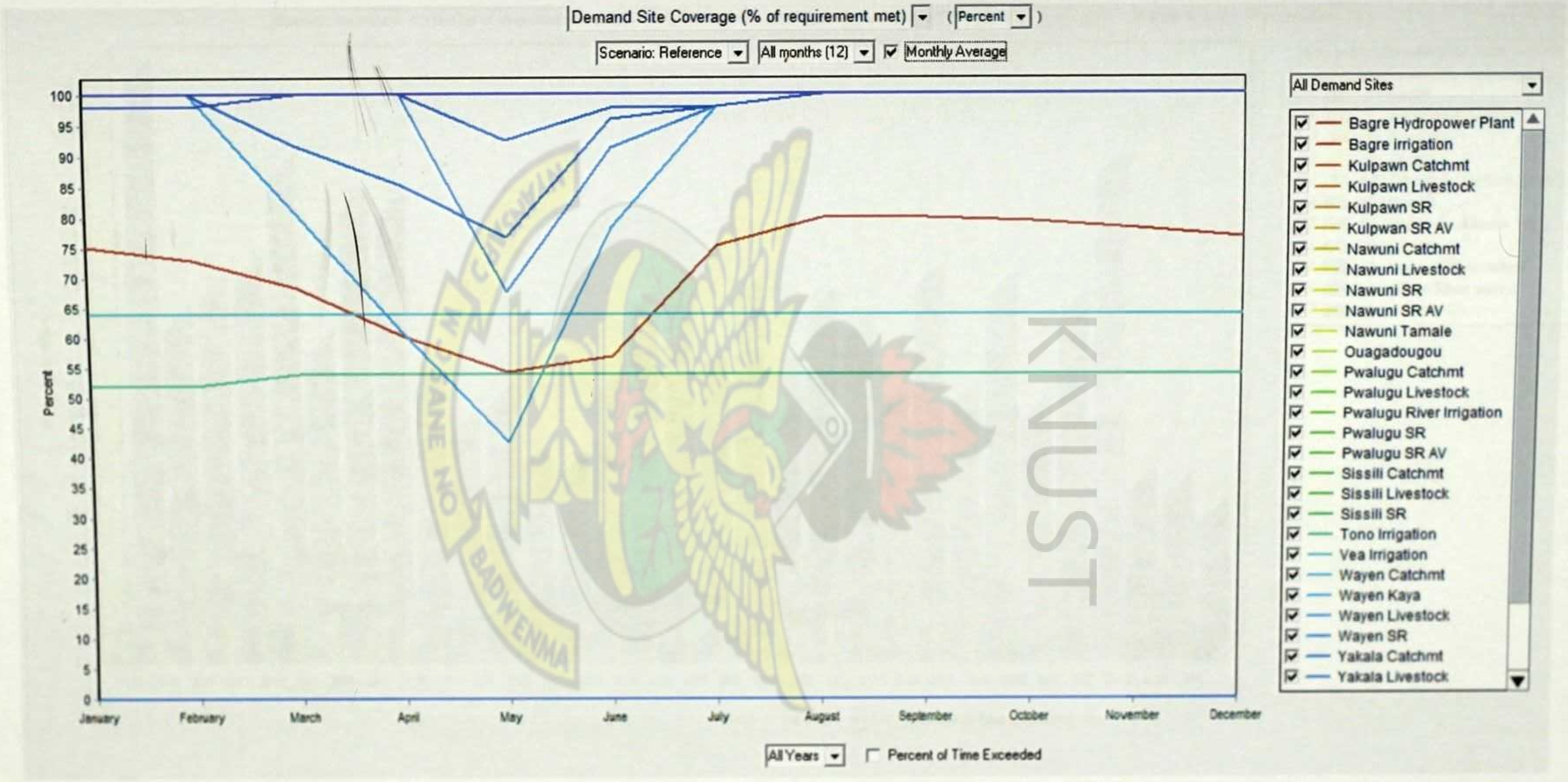
Inflows to Area ▾ (Billion ▾ Cubic Meter ▾)

Scenario: Increase in the number of small reservoirs 2(2011- ▾ All months (12) ▾ ☑ Annual Total ☐ Monthly Average No comparison ▾

Selected Inflow Points (5/59) ▾

All Years ▾ ☐ Percent of Time Exceeded

Results of Demand Site Coverage for all Demand Sites in the Reference Scenario

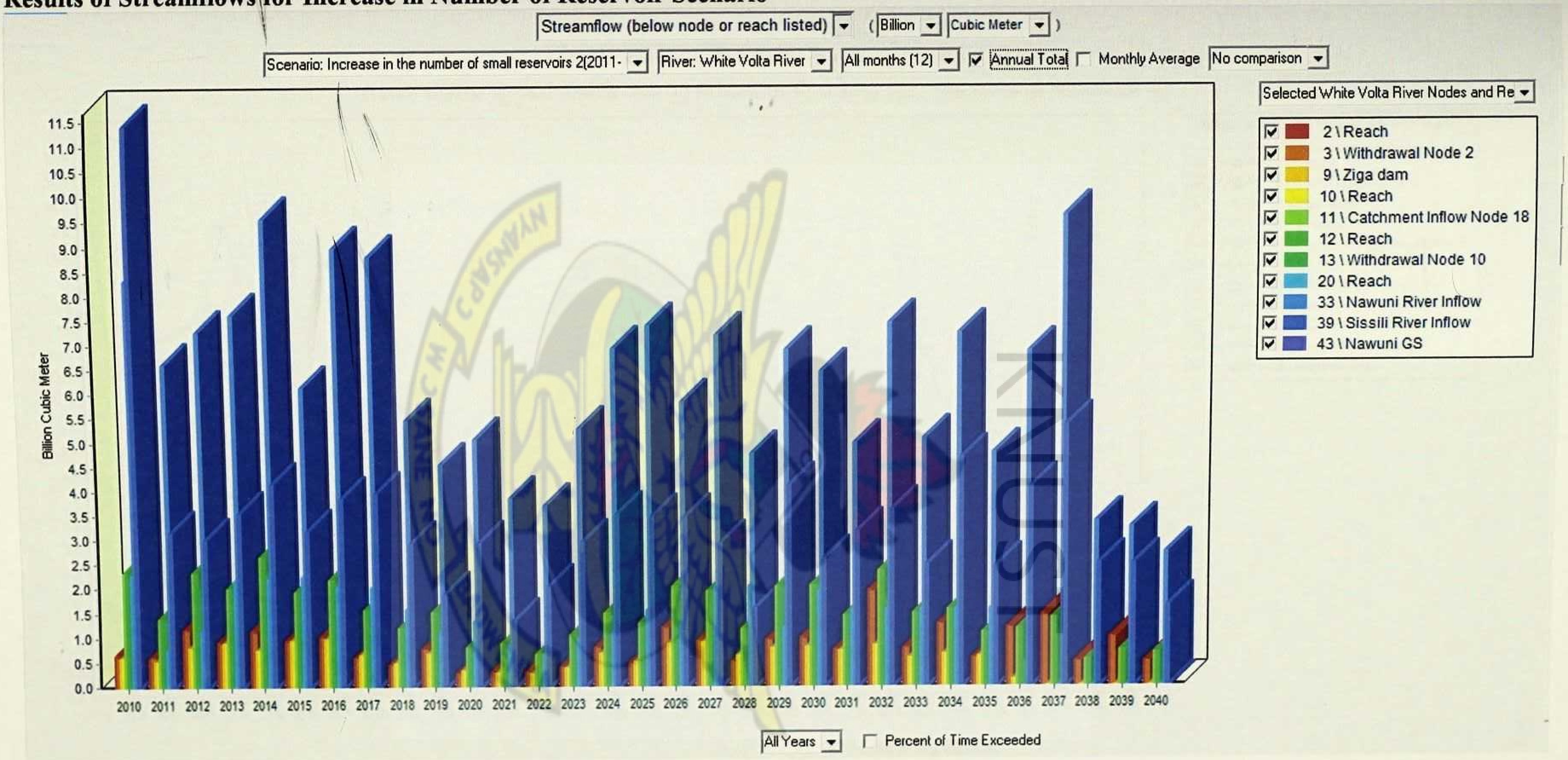


Demand Site Coverage (% of requirement met) ▾ (Percent ▾)

Scenario: Reference ▾ All months (12) ▾ ☑ Monthly Average

All Years ▾ ☐ Percent of Time Exceeded

Results of Streamflows for Increase in Number of Reservoir Scenario



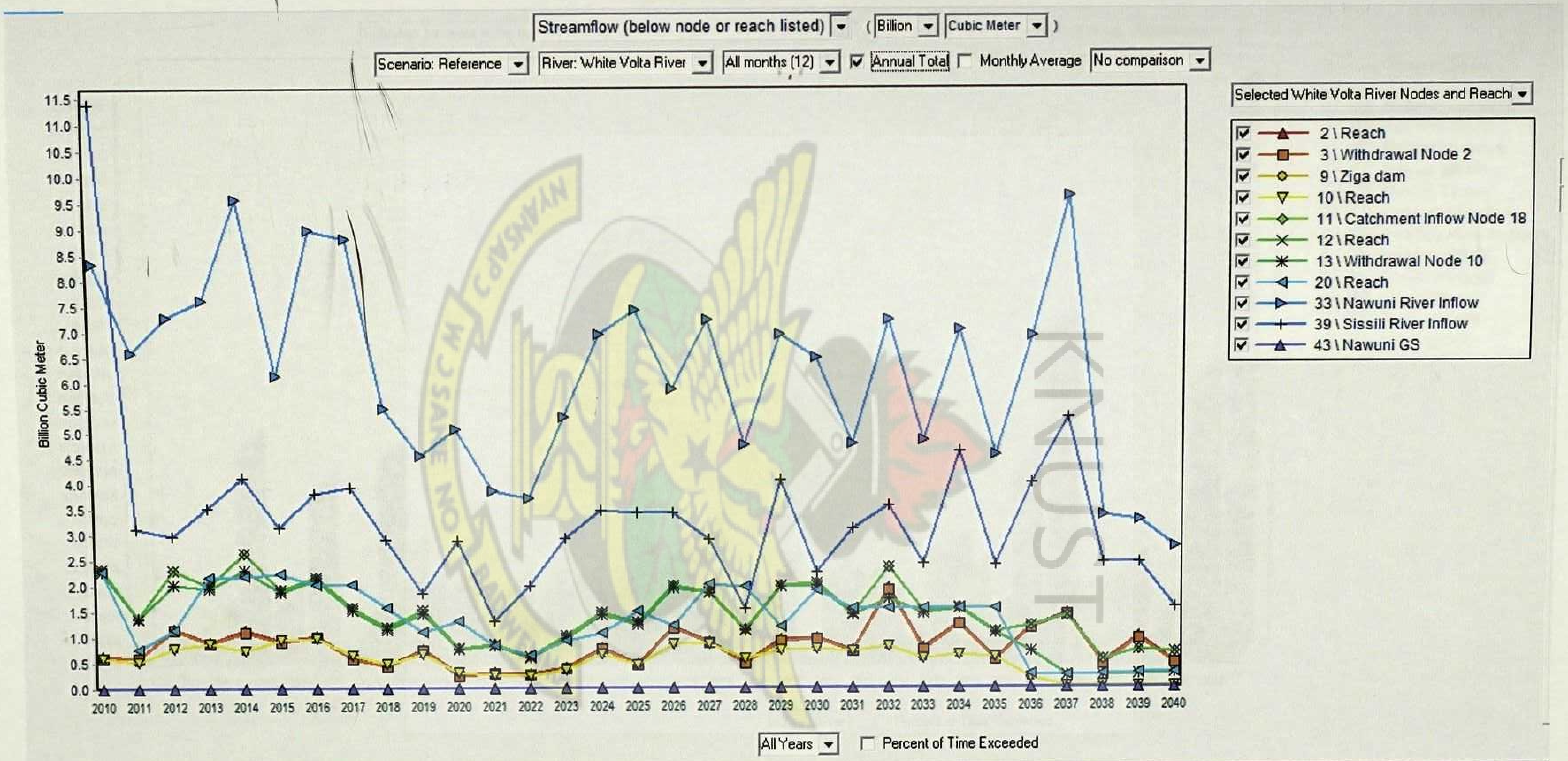
Streamflow (below node or reach listed) (Billion Cubic Meter)

Scenario: Increase in the number of small reservoirs 2(2011- | River: White Volta River | All months (12) | ☑ Annual Total | ☐ Monthly Average | No comparison

Selected White Volta River Nodes and Re

All Years | ☐ Percent of Time Exceeded

Results of Streamflows for Reference Scenario



Streamflow (below node or reach listed) (Billion Cubic Meter)

Scenario: Reference

River: White Volta River

All months (12)

☑ Annual Total

☐ Monthly Average

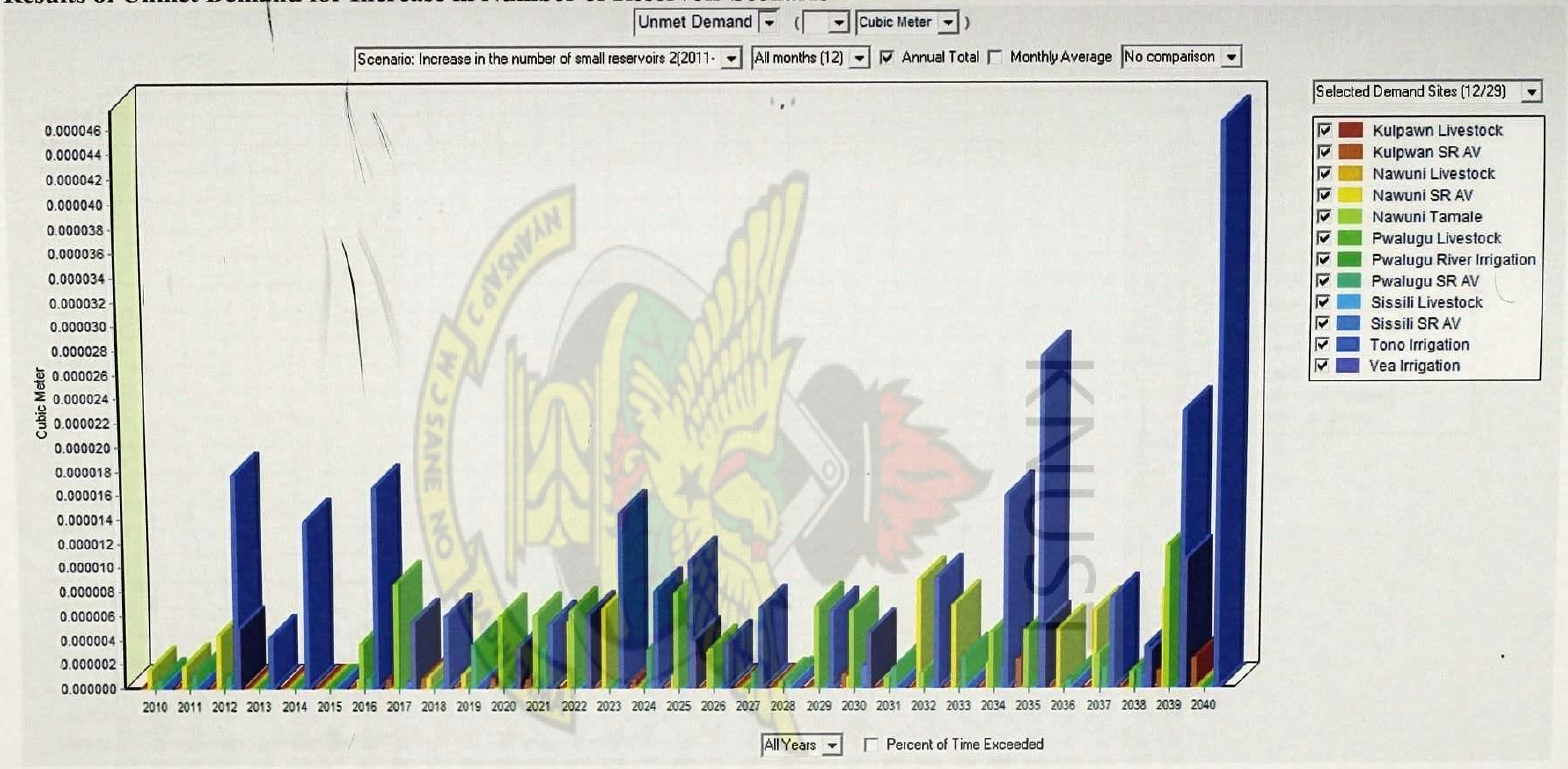
No comparison

Selected White Volta River Nodes and Reach

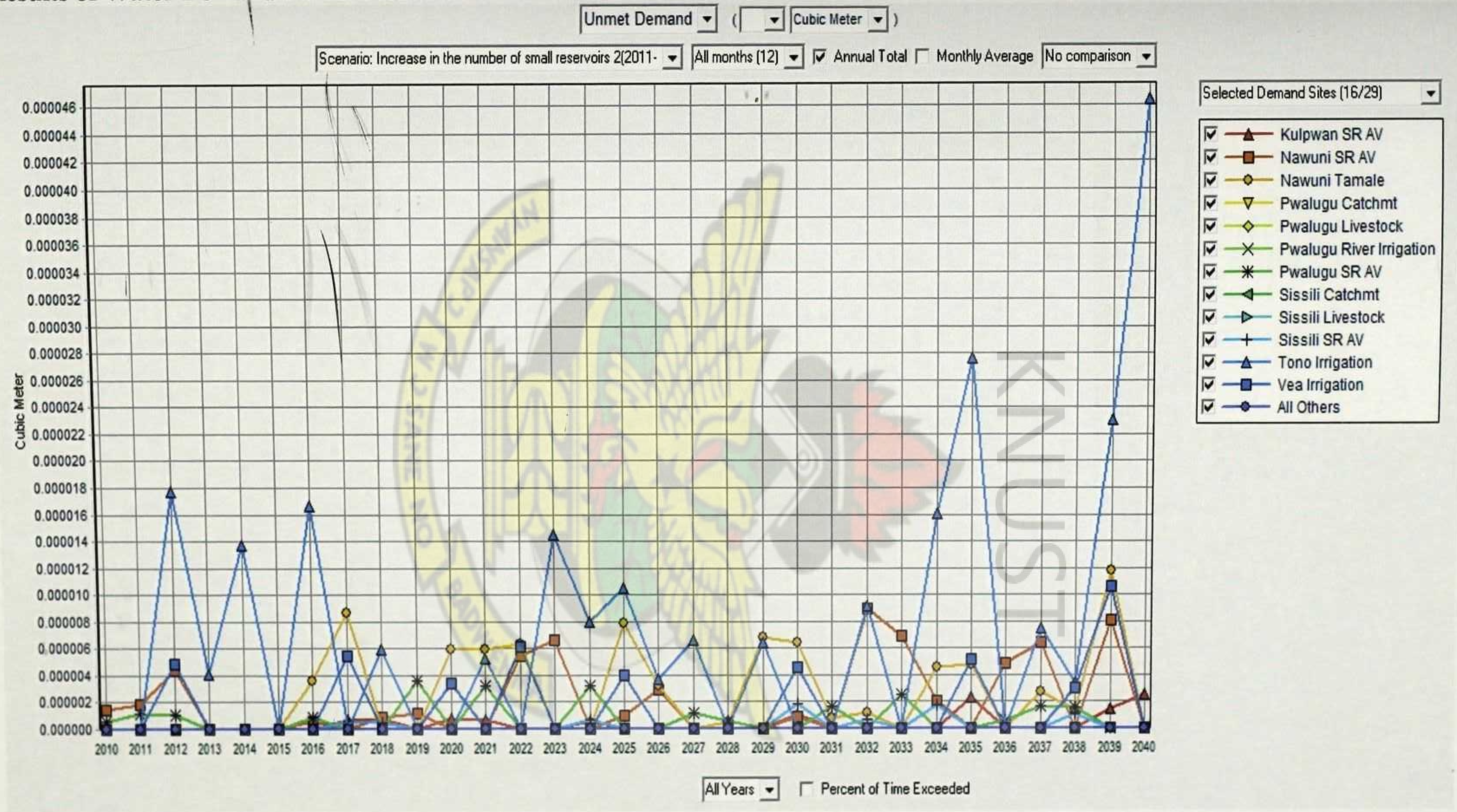
All Years

☐ Percent of Time Exceeded

Results of Unmet Demand for Increase in Number of Reservoir Scenario



Results of Water Demand for all Scenarios in all Demand Site and Catchments



Unmet Demand ▾ (▾ Cubic Meter ▾)

Scenario: Increase in the number of small reservoirs 2(2011- ▾ All months (12) ▾ ☑ Annual Total ☐ Monthly Average No comparison ▾

Selected Demand Sites (16/29) ▾

☑ Kulpwan SR AV
☑ Nawuni SR AV
☑ Nawuni Tamale
☑ Pwalugu Catchmt
☑ Pwalugu Livestock
☑ Pwalugu River Irrigation
☑ Pwalugu SR AV
☑ Sissili Catchmt
☑ Sissili Livestock
☑ Sissili SR AV
☑ Tono Irrigation
☑ Vea Irrigation
☑ All Others

All Years ▾ ☐ Percent of Time Exceeded