**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY**
**KUMASI, GHANA**

# Assessing the Sustainability of Raw Water Supply in Nawuni River for Tamale Metropolis and Environs



**BY**

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**MASTER OF SCIENCE**

**Water Resources Engineering and Management**

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## DECLARATION

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



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## DEDICATION

*To my brother, Mr. Issah Fuseini*

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## ABSTRACT

Water supply service arguably is the most essential of all public service in Ghana and any obstruction to its delivery threating human survival. A major challenge to water supply is the rapid urbanisation that has increased demand for water in the urban areas; putting pressure on service provider to meet demand of urban dwellers. Perennial water shortages in Tamale is linked to several factors including the inability of the service provider to keep pace with the demand of the rapidly increasing population of the city. Looking forward, this situation could be exacerbated by competing water uses upstream the city supply source and natural climate variation. Assessment of the reliability of water supply to satisfy future demand is therefore crucial in order to plan and make informed decisions towards preventing possible future water crises. This study investigates the sustainability of water supply to Tamale metropolis and environs using Water Evaluation and Planning Model (WEAP). Operating on the basic principle of water balance, WEAP can be applied to municipal as well as agricultural water systems, complex or single catchment system. The assessment was made based on the analyses of the following scenarios: Reference scenario, Scenario 1: High Population and Socio-economic growth, Scenario 2: Intensifying upstream water use and Scenario 3: Extended Dry Climate under above scenarios. The alternative scenarios were then evaluated which aimed at possible future situations up to the year 2035. The model results revealed that, intensifying upstream water use as projected in the study do not have impact on the downstream water availability for sustainable water supply for Tamale Metropolis and environs. However, the assessment based on Scenario 1: High Population and Socioeconomic growth results showed significant value (229 million cubic meter) of Unmet Demand in year 2035 for Urban and rural demand site; indicating that there will be shortage of water in the future if this scenario occurred. Finally, under Scenario 3, where supply and resources data was adjusted using the Water Year Method to see how natural variation in climate data (stream flow, rainfall etc.) affect demand and supply, the results showed that, the water demand will outstrip raw water supply by 2029 when Extended Dry Climate is inherited from scenario 1: High population and Socio-economic growth. In 2030, there is deficit of supply of 10 million cubic meter which increased to 342 million cubic meter in 2035 under Urban and rural demand site. It is therefore recommended to investigate possible options of water storage reservoir to mitigate the effect of extended dry season.

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| | |
|---|---|
| CSIR | Centre for Scientific and Industrial Research |
| CWSA | Community Water and Sanitation Agency |
| DSS | Decision Support System |
| EPA | Environmental Protection Agency |
| FAO | Food and Agriculture Organisation |
| GCM | General Circulation Model |
| GEOR | Ghana Environment Outlook Report |
| GIS | Geographic Information System |
| GoG | Government of Ghana |
| GSS | Ghana Statistical Services |
| GWCL | Ghana Water Company Limited |
| GWP | Global Water Project |
| GWSC | Ghana Water and Sewerage Corporation |
| HSD | Hydrological services Department |
| IBWRD | International Bulletin of Water Resources and Development |
| IPCC | Intergovernmental Panel on Climate Change |
| IWRM | Integrated Water Resources Management |
| MCM | Million Cubic Meter |
| MDGs | Millennium Development Goals |
| NWP | National Water Policy |
| PEST | Parameter Estimation Tool |
| SDGs | Sustainable Development Goals |
| SEI | Stockholm Environment Institute |
| SRs | Small Reservoirs |
| SWC | Southwestern and Coastal |

| | |
|---|---|
| TGICA | Task Group on Data and Scenario Support for Impact and Climate Analysis |
| UN | United Nation |
| UNDP | United Nation Development Programme |
| UNESCO | United Nation Educational Scientific Organisation |
| UNICEF | United Nations Children's Emergency Fund |
| UNSO | United Nations Sudano-Sahelian Office |
| WEAP | Water Evaluation and Planning |
| WHO | World Health Organisation |
| WRC | Water Resources Commission |
| WRI | Water Research Institute |
| WWDR | World Water Development Report |

# CHAPTER 1: INTRODUCTION

## 1.1 Background of the study

Water is the most essential and indispensable resource on earth. Without it, there would be no life (Bigas, 2012). Lack of drinking water, the occurrence of drought or flood exposed people, particularly women and children to water-borne and sanitation-related diseases (NWP, 2007). Previously, water was regarded as a free commodity, - considered unlimited in quantity and available as required (NWP, 2007). Nevertheless, continued growing population, pollution of water bodies and rapid economic development as well as changes in climatic conditions have resulted in stress on the existing water bodies (IBWRD, 2014).

Water demand for domestic is driven to a large extent by the population growth and the industrial demand by the expansion of industries for socio-economic development (van Drunen *et al.,* 2006). As the economy grows, people„s income increase and in turn lead to changes in lifestyle. This is often accompanied by an increased in water consumption. In addition, as life expectancy continues to increase the population can grow at rate faster than it is sensible to the environment. Thus; too many people, too little water, water in the wrong place and in the wrong amounts (De Villiers, 2000). This creates a problem, as is the case in many areas throughout the world currently struggling with a decrease in fresh water.

Though Ghana can conveniently be described as having abundant freshwater resources (NWP, 2007), per capita available fresh water in the country is declining. In 1955, the per capita available fresh water declined from 9,204 $m^3$ to 3,529 $m^3$ in 1990 (Karikari, 1996). This is projected to further decline to 1,400 $m^3$ by 2025 (Asare, 2004). Besides, it is expected by the World Water Project that six countries in West Africa, including Burkina - Faso and Ghana - may be short of water by 2025 due to the expected increase in population (Asare, 2004). The annual population growth rate in Ghana is 2.5 % (Ghana Statistical Service, 2012), along with urbanization, as well as socio - economic growth implies an increase in future demand for water. The concerns raised in the above necessitate study on the future availability of the diminishing resource for sustainable planning and management.

The direct impact of economic and population growth is not the only reason for concern when it comes to future fresh water scarcity, however - climate change impact on the future water availability is also crucial. There is a significant impact of climate change on the weather pattern, precipitation and hydrological cycle, affecting availability of surface water, as well as soil moisture and groundwater recharge (UNESCO, 2006). It has been predicted with high confidence (scale of confidence of 8 out of 10) that climate change will exacerbate the water stress situation in some countries (Bates *et al., 2008*); while introducing water stress to countries that do not experience it (Boko *et al.,* 2007). Global Water security is therefore emerging as one of the highest priorities on the development agenda, as evidenced by some of the efforts being made to assess the current state of the resource.

In addition, Volta River and its tributaries, which are an important source of water for inhabitants of six riparian states including Ghana (Biney, 2010), are under severe stress due to competing demands on the resources by riparian states and poor climatic conditions (Mul, *et al.,* 2015). Population growth of Ghana and Burkina Faso that cover the largest proportion of the basin has resulted in larger abstraction of water to meet the increasing demand (McCartney *et al.*, 2012). Also there is variability in both spatial and temporal distribution of rainfall causing high variation in streamflow over the Basin (Mul *et al.,* 2015). The effect of this is that most streamflow, especially in the northern parts of the basin, occur in only a few months of the year with little or no flow for much of the year (Amisigo *et al*., 2005).

## 1.2 Problem statement

Perennial water crisis is not alien to the people of Tamale, the capital of Northern Ghana. The Metropolis has been confronted with the issue of acute shortage of water since 1974 (Edmond, 2012). This is attributed to frequent breakdown of equipment and most importantly, the inability of service provider to keep pace with the demand of the rapidly increasing population of the city. Unfortunately this situation is likely to continue into future. White Volta at Nawuni (Nawuni River), the only source of portable water for Tamale Metropolis and environs is under threat. Its depth has reduced dramatically (Benice, 2010), which threatens the capacity of the river to deliver the volume of water required to meet demand in future. This also reduces the volume of water in the river to feed the Akosombo Dam, the main source of hydroelectric power in the country.

Also, studies conducted into the potential impacts of climate change on hydrology in the Volta basin using a variety of methods and computer models highlighted the sensitivity of river flow to rainfall fluctuations (McCartney *et al*., 2012); which has likely impact on the available water resource to meet future demand of the increasing population of the City. Ghana Water Company Limited (GWCL) supply water from Nawuni River to about 500,000 people spread across the Tamale Metropolis and four districts (Kumbung, Tolung, Savulugu and Sagnarigu) with the residents of Tamale metropolis being the largest clientele. Tamale is the third largest city in Ghana (Ghana Statistical Services (GSS), 2012) and the fastest growing city in West Africa (Joseph, 2013) with the projected population of 371,351 people in 2010 (GSS, 2012). In addition to the growing demand is the current global climatic change processes which possess threat to access to portable and affordable water in the future.

Consequently, lack of access to safe and affordable water comes with public health problems.

In 1990 studies carried by UNICEF found a resurgence of guinea worm epidemics in Northern Ghana after the then Ghana Water and Sewerage Corporation (GWSC) instituted cost-recovery measures for pumps maintenance and tariffs. Being able to assess the reliability of water supply to satisfy future demand is therefore crucial in order to plan for future and make informed decisions towards preventing possible future water crises.



**1.3 Relevance of the study**

According to International Fact-Finding Mission (2002), about seventy percent of diseases in Ghana is due to inadequate rural water supply and sanitation coverage. And in spite of Ghana attaining the MDG 7B (halving the proportion of people without access to safe drinking water) (UN, 2013), but it has large population, especially in the northern part of the country with unmet need of safe drinking water (Cheng *et al.,* 2013). More than 50 % of the population in northern Ghana still lack access to safe and affordable drinking water, and use unimproved water, i.e., surface water, drinking water sources (UNICEF, 2012). This means much people are affected with water related issues especially in northern Ghana.

Most disturbingly, acute shortage of water in Ghana associated with climate change could see the country become one of the countries suffering from water shortages in the world by 2025. It is expected the country to experience a decline in annual river flows from 15-20 per cent by 2020, rising to 30-40 percent by 2050, according to a study conducted by the Agency for Water Research in Ghana, the Institute for Water Research under the supervision of the Council for Scientific and Industrial Research (Kankam *et al.*, 2011). Also, the upscaling of irrigation in the basin has a direct impact on the competing water uses as well as downstream water use and environment (Ofosu, 2011). The possible future implications of the above mentioned factors on Tamale water supply therefore worth investigating in order to plan and avoid future water crises. And to do so, we need quantitative information as to how water demands and other factors (such as climate change) affecting water resources are going to evolve in the future.

However, it is not possible to predict exactly how water demands and other factors are going to evolve in the future. But since population growth, increase in water demand and climate change are intertwined with water resources availability, computer based Decision Support Systems (DSS) can be used to study and evaluate the impact of these factors on future water availability. A set of realistic scenarios can be built using WEAP (Water Evaluation and Planning) in order to forecast and evaluate the impacts of the above factors on the sustainability of the water resources. The outcome will therefore help water managers and water users in decision making.

## 1.4 Objectives of the study

### 1.4.1 Main Objective

This study is intended to assess the sustainability of raw water supply in Nawuni River for Tamale metropolis and environs.

### 1.4.2 Specific Objectives

Specifically, the study is intended to achieve the following objectives:

- To determine the current water demand and supply in the metropolis and environs.
- To assess impact of population and socio-economic growth on water demand and supply source
- To determine the impact of competing water uses upstream on the water resource supplied to Tamale and environs.

- To assess the impact of prolonged drought on the raw water source and water supply

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Water is crucial to the existence of human and all living organisms (NWP, 2007), a key to prosperity and wealth and identified as one of the most essential natural resources (Arbués *et al.*, 2003). These resources all over the world are under increasing pressure through a combination of factors, including population growth, pollution, and the effects of climate change (Scheffran *et al.*, 2011). These lead to the situation where many people lack access to adequate water supply for meeting their basic needs (Abey, 2013). An analysis of future availability of the resource is important considering the impact of the above mentioned factors.

This chapter of the study seeks to review literature on concepts (sustainability, scarcity and shortage), the availability and state of global water resources with emphasis on Ghana, driving forces of water resources sustainability; climate change impact and competing water uses on the water resources and increasing demand and supply trends attributed to population and socio-economic development.

## 2.2. Sustainability, scarcity and shortage

### 2.2.1 Sustainability

Sustainability as a word brings tremendous variation of definitions when it is connected with the management of water resources. Debate on the definition of sustainability is affected among those who differ over what it is should be sustainable and how to achieve it (Loucks, 2000). This study adopts the definition of „water sustainability" by which „„*sustainability means a continuous supply of clean water for human uses and other organisms''* (Schnoor, 2010). It does not specify exactly how much water we have. Instead, it refers to the

availability of sufficient water for the foreseeable future.

There is uncertainty in trying to develop a sustainable plan for water resources. This uncertainty in sustainability does not happen only because of the lack of knowledge of what the future will deem an important, but also how our actions today will affect tomorrow (Jeffrey, 2003). Since it is not possible to predict exactly how factors affecting sustainability are going to evolve in the future, it is therefore appropriate to use a scenarios analysis approach in this study. Various forces affect the nature, timing and the availability of water, which changes all the time. Water availability to meet future demand depend on three factors: climate variation and global weather patterns, human changes to flow pathways and water use, and quality of water changes by human (DNR, 2010). As a result, a number of studies on water demand have been carried out in both developed and developing countries (Abbey, 2013).

2.2.2 Scarcity and shortage

There is no widely acceptable definition of water scarcity, such that the term water shortage has been used synonymously with water scarcity (Pereira *et al.*, 2009). When water scarcity is caused by man but with temporarily water imbalance including groundwater and surface water over-exploitation, low reservoir capacity, it is referred to as the water shortage (Pereira, 2011). Deterioration of water quality is often associated with water shortages and like drought, it aggravates the related impacts. Inability to sustainable management of water shortage may lead to a permanent state that is hard to deal with (Asare, 2004).

Water scarcity comprises *water shortage or deficit*, *water stress*, and *water crisis*. *Water stress* is the difficulty of obtaining sources of fresh water for use during a period of time and may lead to further depletion and degradation of available water resources (Musee *et al.,* 2014). *Water shortages* may occur due to climate change, such as changing weather patterns, including droughts and floods, increased pollution, and increasing human demand and excessive use of water. Water *crisis* is a situation where the available drinking water within the region is less than the demand in that region (Rahaman *et al.,* 2005). Water scarcity is attributed to two converging phenomena: the increasing use of fresh water and the depletion of fresh usable water resources (Clifford, *et al.*, 2011) and climate change (Bates *et al.*, 2008).

### 2.3 World water stock and demand

Understanding the problem of scarcity of fresh water begins by looking at the distribution of water on the planet. Water is a natural resource everywhere, which covers nearly three quarters of the Earth's surface (Klaver, 2012), but 97.5 percent of the water on earth is salt water (Saleth *et al.*, 2004). Only 2.5 percent of the world's water is fresh water, but more than two-thirds of that is locked in the form of ice and snow in Greenland, Antarctica, arctic islands and mountainous regions (Postel *et al.*, 1996). Unfortunately, less than 1 percent of the world fresh water is what is available for direct human use which is found in lakes, rivers, wetlands, etc. (UN Water, 2013). About 108,000 cubic kilometers ($km^3$) precipitate annually on the earth‟s surface. And about 60 Percent (61,000 $Km^3$) evaporate directly back into the atmosphere, leaving 47,000 $Km^3$ flowing toward the sea (Seckler *et al.*, 1998).

The only renewable source of fresh water is continental rainfall (which generate more or less constant global supply of 40,000 to 45,000 cubic kilometers per year). The world population keeps growing by about 85 million annually. At the same time, the availability of fresh water per capita decreases rapidly (Barlow, 2010). Globally, the consumption of water is doubling every 20 years, more than double the rate of increase in the population, and put tremendous pressure on aquatic ecosystems. Most disturbingly, we are diverting, polluting and depleting the limited source of fresh water at an astounding rate (Hefny, 2010). The concern becomes more urgent when it is recognized that almost all of this growth will occur in developing countries, many of which had inadequate or barely adequate to support the population levels that existed in 2000 (Bigas, 2012), and Ghana being no exception.

In 1995, about 18 countries were considered water scarce in that they did not have the water resources sufficient to meet the basic needs of its population, and 11 more were water stressed because, they do not have sufficient water resources to meet the needs of all their people for at least part of the year (Jury and Vaux, 2007). The population of these 29 countries was over 450 million. At the beginning of 2000, one-sixth (1.1 billion people) of the world's population have no access to water supply and two-fifths (2.4 billion people) did not have access to improved sanitation. According to WHO (2000), majority of these people live in Asia and Africa, where two out of five Africans lack improved water supply. In 2000, for example, about 12 percent of health problems in Ghana in the form of severe inflammation in the eye, diarrhea and skin diseases was directly as a result of poor water supply or lack of it (IFFM, 2002).

Water is essential for achieving the United Nations Millennium Development Goals set to expire in 2015. It is already known that the world is lagging behind the target for sanitation, which is expected to be missed by more than a billion people (WHO/UNICEF, 2012).
Sustainable Development Goals (SDGs), otherwise known as global objectives, are built on the Millennium Development Goals (MDGs), eight anti-poverty goals that the world was committed to achieving by 2015. For SDGs, the agenda of sustainability is broader, go much

further than the Millennium Development Goals to address the root causes of poverty and the global need for development that works for all people. The SDGs will form an integral part of the forthcoming long-term national development plan (National Development Planning Commission, 2015). Target specific for water (SDG 6) means that the management of water resources can no longer be subordinate or taken for granted. The goal 6 of the proposed 17 SDGs is to ensure availability and sustainable management of water and sanitation for all.

Demand for scarce water resources are increasing in the world rapidly, challenging its availability for food production and putting food security worldwide in danger. Agriculture, upon which a growing population rely for food, is competing with industrial, household, and environmental uses for this limited water supply (Mark *et al.,* 2002). Water withdrawal in developing countries is expected to increase 27 percent over a 30 year period, while developed countries withdrawal will rise by 11 percent. Together, the consumption of water for domestic and industrial, and livestock uses - that is, all uses- non- irrigation will greatly increase, rising by 62 percent from 1995 to 2025 (Mark *et al.*, 2002). By 2050, world's population is expected to exceed 9 billion people (Gerland *et al.*, 2014) and with the continuous increase in the demand for water, it is expected that four billion of these people will live in areas with short chronic water supply (UN Water, 2007).

## 2.4 Water resources in Ghana

Freshwater covers nearly 5 percent (11,800 $km^2$) of the total land area of the country (GEOR, 2006). This is made up mainly of three major river systems. The Volta River System, which comprises river Oti, Sissili, White Volta and Black Volta, covers 70 % of the total freshwater resources of the country. The South Western River System, such as Birrim, Ankobra, Pra, and Offin, takes 22 % while the Coastal River System, which include rivers like Todzi and Aka covers the remaining 8 % (GEOR, 2006; NWP, 2007). The Volta river system which is the largest river system in the country is shared with Mali, Togo, Burkina Faso, Benin and Cote d‟Ivoire. The two basins in the southwestern part of the country are also transboundary - the Bia River is shared with Côte d‟Ivoire, while the lower reaches of the Tano river form part of the boundary with Côte d‟Ivoire. The annual total runoff in the basins is about 56.4 million cubic meters. The Volta, the coastal system and the southwestern contribute 73.7, 6.1 and 29.2 %, respectively, of the annual runoff originating from Ghana (Ministry of Works and Housing, Ghana, 1998).

Only two percent constitute the total withdrawal of the total actual renewable water resources. A key aspect in terms of water resource in the country is the variability of water between seasons and from year to year (Foster *et al.*, 2011). The average annual rainfall ranges from 2150 mm in the extreme southwest of the country, decreasing constantly eastwards and northwards to about 800 mm in the southeast and about 1000 mm in the northeast of the country (WRC, 2000). The country actual renewable resources are estimated to be 53.2 billion cubic meters per year (Abubakari, 2015), and this can be translated into availability per capita of about 1,900 cubic meters per year.

The available groundwater is also in commercial yield in Cenozoic and Mesozoic sedimentary rocks formation underlying Volta basin (FAO, 2008). The formation of sedimentary origin composed mainly of Voltaian, which occupies about 43 % of the total area of Ghana, with yield of 1.0 up to 12.0 $m^3$/ha in depths ranging between 20 and 80 m.

And the formation of non- sedimentary - mainly composed of crystalline basement complex of pre Cambrian origin, which occupies 57 percent of the total area of the country with 1.5 yields up to 32.0 m/ha in the depths of 20 to 100 m. The quality of groundwater resources in Ghana are generally good excluding in some cases of localized contamination with high levels of iron and fluoride, as well as mineralization with high dissolved solids, especially in some coastal aquifers (Odame-Ababio, 2003).

### 2.4.1 State of water resources in Ghana

When Ghana is compared in terms of available freshwater resources with other countries like South Africa, Israel, Cyprus, and Australia that are considered as water scarcity nations (Global Water Intelligence, 2009), Ghana can conveniently be described as having abundant freshwater resources (NWP, 2007). Relying on such information however, can be deceitful because of the pervasiveness of seasonal and perennial water scarcity all over the country (Asare, 2004).

The water resources of the Volta Basin which covers 70 % of the total freshwater resources of the country (NWP, 2007) is one of the poorest watershed areas of Africa (with the average income estimated at US$ 800) and the 9th largest river basin in sub-Saharan Africa (Asare, 2004). Other river basins in Ghana but outside the Volta river system are the coastal (SWC) and the southwestern system. These systems are also under threat as a result of both climatic and non-climatic factors and studies have shown that climate change is likely to have adverse impacts on the water resources (Obuobie *et al.*, 2012).

According to Ghana's Minister of Water Resources Works and Housing (2010), interacting with stakeholder‟s employees in the water sector pointed out that from 1960 to 2010, the amount of raw water available for Ghanaians reduced by a factor of 3! He attributed this to the growing population. And according to him Ghana's population has grown from 6.5 million in 1960 to 24 million in 2010. He added, with the annual rate of growth of the population, this reduction factor would doubles to six in 2050. That is, the water available in the country would dropped by a factor of 6! From the above, it means that the water available to Ghana today is only 27 % of what it was in the 1960s, and will be only 16 % by 2050. Aggravating the situation he said was the pollution of the water resources by human activities (Edmond, 2012). The water resource base in Ghana is therefore, under threat. Urgent adaptation measures are therefore needed to help Ghanaians cope with the dwindling freshwater resources.



### 2.4.2 Water demand and supply in Ghana

In Ghana, rainfall is not rare and many rivers do not stop flowing, but millions of people has been denied clean water. In fact Ghana suffered from shortages in portable water, especially in the Northern Region, where 40 percent (CWSA, 2007) of people use water from unimproved sources. And this has led to water-borne diseases such as diarrhea, hepatitis A, typhoid, cholera (Barnes *et al.*, 2009). Shortages of water and quality decline are among the problems that need greater attention and action. Due to lack of adequate structures along with rapid population growth, the gap between supply and demand for water expand continuously (Doe, 2007).

According to NWP (2007), the total demand for potable water in Ghana is 967,744 $m^3$/day. Ghana Water Company Limited (GWCL) supplies 605,469.69 $m^3$/day, amounting to 62 percent of total demand. Consequently, there are serious deficits in coverage. It is estimated that 50 % of Ghana„s population who reside in urban areas, 90 % have access to portable water sources. However, it is important to emphasize that, only about 30 % of this have access to potable water, which, in most cases, is supplied intermittently. The other 60 percent rely on the other supply sources such as standpipes, protected dug wells, protected springs and harvesting of rainwater (NWP, 2007).

Generally urban communities in Ghana take the larger share of their water supply from rivers, at dams and diversion structures which need to be treated to meet health standards. Surface water sources can probably serve all urban needs for the near future through corresponding programmes of development and conservations (Karikari, 2000). For convenience sake, however, private individuals who can afford depend much on groundwater supplies through either hand-dug wells without pumps or boreholes fitted with pumps.

In Northern Ghana, about 37.5 percent of the residents use unprotected ponds, lakes or streams for drinking water supply. And this problem is aggravated by lack of safe sanitation, again especially in Northern Ghana where 92 percent still lack access to improved sanitation (Barnes, 2009). The population of Tamale alone (the capital of Northern Region) is 371,351 requires 7.5 million gallons of water daily (Edmond, 2012) which is projected to 15 million gallons of water daily by 2015. With the increasing demand couple with climate change effects call for answers as to whether the resource can sustain the demand.

As water demand rises worldwide, the availability of fresh water in many countries are likely to decline because of climate change, warns the United Nations‟ World Water Development Report (WWDR4) (Cosgrove, 2012). And as all these challenges to the current status quo will be amalgamated in one way or another by change in climate, it will be crucial for decision-makers to know why climate change will play such an important role. Besides, leading to increase in temperatures, decision-makers need to know exactly how the change in climate impact water security (Bigas, 2012).

## 2.5 Climate change impact on water resources

Climate change is now a scientifically established fact (UNDP, 2008) and the Intergovernmental Panel on Climate Change (IPCC) has accepted it as a threat to sustainable development (UNESCO, 2006). A number of sectors such as water resources and coastal resources, agriculture, human health, energy, industry, forestry and fisheries and wildlife could be affected by climate change (Andah *et al*., 2002). Water resources arguably is the most crucial area to look at in the study of climate change impact. This is because climate change has a direct impact on the availability, timing and variability of supply and demand (Luis *et al*., 2005). Observational records and climate projections provide enough evidence that freshwater resources are liable and have the potential to be greatly influenced by the change in climate, with wide-ranging effects on human societies as well as ecosystems (Mall, 2006; Bates *et al*., 2008).

Changes in climate brings about an aggregation of the worldwide hydrological cycle and can lead to significant impacts on regional water resources (UNESCO, 2006). This has effects on both surface and groundwater supply, industrial and domestic water uses as well as irrigation water needs, water for hydropower and ecosystem (IPCC, 2001). The 3$^{rd}$ IPCC report, estimated worldwide rise of average temperature of 0.8 °C to 2.6 °C by 2050 and 1.4 °C to 5.8 °C by 2100. The study also showed an increase in annual rainfall as a result of change in the high and middle latitudes and most equatorial regions, as well as a general reductions in the subtropics (Bates *et al* ., 2008 ). Exacerbating the situation are many forms of water pollution from dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution, with possible negative consequences for the ecosystems, the water supply system reliability and operating costs, as well as on human health.

Climate change is expected to aggravate current and future pressures on water resources. It is expected that climate change will have impact on the availability of water resources through changes in the distribution of rainfall, soil moisture, and glaciers and ice/snow melt, and rivers and underground water flows (UN Water, 2012). In recent years, it has become clear that climate change worldwide is a scientific fact (IPCC, 2007). The rapidly growing body of scientific literature is an indication of increasing awareness that climate change effect water resources worldwide.

Globally, hydrological cycle is effected by climate change (Arnell, 2004). It changes the amount and timing of the flow of the river, challenges the coping capacities of existing water infrastructure and existing management systems, and brings higher risk and water shortage flood. The recent water management practices may not be robust enough to cope with the effects of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems (Bates *et al.*, 2008). Adaptation and mitigation options therefore need to be conducted across multiple water-dependent sectors. This is to ensure continue water supply during drought conditions (Bates *et al.*, 2008).

### 2.5.1 Climate change Impact in Africa

African countries in particular are expose to change in climate as a result of the desertification process, reduction in run-off from watersheds, decreasing soil fertility and dependency on subsistence agriculture, as well as rapid population growth (Urama *et al.*, 2010). In addition, one-third of the people in Africa live in drought-prone areas and is liable to the drought impacts (IPCC, 2007). In some cases the frequency of occurrence of droughts is aggravated by human activities. Drought possess both direct and indirect effects for human livelihood (Pavel, 2003). Climate change is expected to increase the risk of drought in Africa. Since the late 1960s,

drought has caused a lot of suffering in Africa. Severe droughts were experienced in 1973 and 1984, when all African countries have suffered low rainfall, which particularly affected several million people in the Horn of Africa and the Sahel, and South
Africa (AWDR, 2006).

For rainfall in most parts of Africa, there is either a decrease in annual precipitation or any long-term trend rate has been observed (Boko *et al.*, 2007). There is an observed increase in the annual variation in most parts of Africa. According to Conway (2011) there was marked drying across most parts of the Sahel region from the 1970s and decadal swings in rainfall in the southern African associated with ENSO (El Niño-Southern Oscillation). There was an Observed rainfall decrease of about 2.4±1.3 percent per decade (Holm *et al.*, 2001). This rate was faster in West Africa (-4.2 ± 1.2%) and in north Congo -3.2 ± 2.2 % per decade. Thus climate change has the potential to impose additional pressures on water availability and demand for water in Africa (Bates *et al.*, 2008).

2.5.2 Climate Change Impact in Ghana

Ghana is prone to climate change and variability due to its location in the tropics (Dovie, 2011). Geographical location adjoining the Atlantic Ocean to the south under the influence of contrasting ocean‟s and 16 air changes can largely be receptive to intense climate events (Dovie, 2009; EPA, 2009). This is because the surface of the small land of Ghana could expose the country to all these changes, and this can lead to a large deficit in rainfall (Dovie, 2011). Evidence abounds in Ghana that the temperatures in all the ecological zones are on the increase while rainfall levels has generally been erratic (Onyenechere, 2010). Therefore, the national economy is likely to suffer from the effects of climate change because it depends on climate-sensitive sectors such as agriculture, energy, forestry, etc. (Owusu K. *et al.*, 2008).

There is no doubt that Ghana has experienced climate change with significant effects (2009, EPA). Research conducted by EPA showed that, there is:

I. 1°C increase in temperature over a 30-year period from the historical records;

II. increased evaporation;

III. decreased and highly variable rainfall pattern, and

IV. frequent and pronounced drought spells

Unfortunately this trend is projected to continue into the future. Already Ghana is predicted to become water stress nation by 2025 even without considering climate change according to studies at CSIR-WRI. In the face of the increase in the frequency and intensity of severe weather events in the future, it is likely that climate change will exacerbate water scarcity in the future in many places in the country. The CSIR-WRI 2000 report on climate change and water resources estimated:

- a general decline in the annual flow of the river in Ghana by 15-20 % from 2020, and 30-40 % for 2050,
- a reduction in groundwater recharge from 5-22 % for 2020 , and 30-40 % for 2050,
- increase the demand for irrigation water from 40-150 % for 2020 and 150-1200 % for 2050
- decline in hydropower generation of 60 % for 2020 and,
- By 2020, all the river basins would be vulnerable and the whole country will be facing a severe water shortage (Kankam *et al.*, 2011).

In addition, Dovie (2009) stated in WRI (2010) Report, that astringent drought, extended dry spells, fluctuating rainfall regimes and rain floods of 1983, 1998, 2005 and 2007, respectively in Ghana are examples of severe weather events due potentially to climate change events. In fact the extreme drought of 1982/83 caused Government of Ghana (GoG) to apply for help to the United Nations Sudano- Sahelian Office (UNSO) to fight desertification (Abbey, 2013). Using scenarios, studies conducted by various researchers revealed that there will be decline in rainfall between 15- 20 % and 30-40 % for the year 2020 and 2050 respectively (AntwiAgyei, 2012).

### 2.5.3 Climate change Scenario

Climate change scenario is described as coherent and internally consistent and acceptable to potential future states of the world (Ekström, 2005). Scenarios of Climate change are reasonable representations of the future that are consistent with the assumptions about future emissions of greenhouse gases and other pollutants, and with our understanding of the impact of rising concentrations of these gases on the global climate (IPCC-TGICA, 2007). Various climate change scenarios can be used to analyse the exposure unit"s sensitivity to climate change in order to help policy makers decide appropriately.

### 2.5.4 Types of climate change scenarios

There are various types of climate change scenarios, ranging from the scenarios that have been developed on an arbitrary basis on expert judgment (arbitrary climate change) to scenarios based on the climate in the past (analogue climate change scenarios) to scenarios based on the production model. The simplest scenarios are synthetic, or arbitrary, whilst those from General Circulation Model (GCMs) are most complex.

In this study, climate change impact was evaluated using Water Year Method. In Water Year Method, historical data (e.g. rainfall, stream flow) in a simplified form is use to examine the impact of future changes in hydrological patterns (SEI, 2015). Under Water Year Method, future inflow is predicted through variation of the inflow data from the current account which serve as the base year, according to the Water Year Sequence and Definitions specified in the hydrological section.

Hypothetical event or set of events testing, or approximation of historical patterns can be done using Water Year Method. For example, system can be tested using Water Year Method in the light of hypothetical or historical drought conditions.

**2.6 Decision Support Systems (DSS)**

Computer based Decision Support Systems (DDS) are being used worldwide in order to manage more wisely our water resources. DSS is a combination of the tool and the process of structuring problems, thus, aiding decisions. WEAP is a main component of decision support systems (DSS), which provides a framework that can be accessed by stakeholders, strategic planners and decision makers.

According to Simonovic (1996) DSS must help decision makers at the upper levels, must be flexible and respond to questions quickly, must provide for "what if" scenarios and must consider the specific requirements of the decision makers (Arranz, 2006). Scenarios are self - logical story – lines which represents how system can evolve over time in a specific socio-economic environment and under a specific set of technology and policy conditions. In WEAP, a scenarios can be established and compare to evaluate their impact. All scenarios start from a common year, for which the model Current Account data are established (SEI, 2015).

### 2.6.1 Water Evaluation and Planning System (WEAP)

WEAP is comprehensive, clear and easy to use, and attempts to help and not to substitute for the skilled planner (SEI, 2015). The operation of WEAP is based on the basic principle of water balance accounting which can be applied to municipal and agricultural systems, simple or complex river systems. It works in a monthly time- step on the fundamental principle of water balance (SEI, 2008).

WEAP is an important tool that inform society on the climate change adaptation toward policy making process. The inputs for WEAP include: rainfall, temperature and humidity, infiltration, and wind speed. Each of these inputs can be drawn from the baseline scenarios, and used to predict the amount of rain that falls in a particular area, runoff in streams, groundwater recharge, or evatranspiration through vegetation. WEAP also allows the user to build scenarios, for example, an increase in temperature or rainfall, along with assumptions about demand for water, infrastructure and regulation. All human activities could be included in the WEAP in order to predict water shortages and water quality base on a model scenario.

Depending on the goals of the user, WEAP can either be used as a database, as a tool to predict or as a tool of policy analysis. The system is represented in terms of supply sources (such as rivers and groundwater and reservoirs), water transport (withdrawal, transfer) and water demand and requirements. As a database, WEAP provides a system to keep the water demand and provide information. As a tool for forecasting, WEAP simulates water demand and supply, flows and storage, and the generation of pollution as well as treatment and discharge. As an instrument of policy analysis, WEAP evaluates a full range of options for water resources development and management, it takes into account multiple and competing uses of water systems (SEI, 2015).

### 2.6.2 Reasons for the use of WEAP

WEAP puts the evaluation of specific water problems in a conceptual framework. Merge more than several dimensions: between supply and demand, between the quantity and quality of water, and between the objectives of economic development and environmental constraints (SEI, 2015). The capability of WEAP is unique in representing the effects of demand management on water systems. Based upon the following capabilities, WEAP as a central component of Decision Support Systems was selected since it meets the criteria requirements such as:

- Easy to use interface facilitates learning, data input, and scenario development
- Input can be from files or user specified functions
- Multiple scenarios can be run and displayed graphically at one time
- Use of notes allows for internal documentation of scenarios
- Hydrology may be climate driven or from gage data
- Several internal modules to choose from (eg Hydropower generation, Financial analysis, Water quality)
- Dynamically links to other models
- WEAP can be used at various levels, spatially and temporarily
- Recently, WEAP received a great deal of attention as it is applied at the national and international levels
- priority –based water allocation system
- Enable stakeholders to get involved in management procedures through interactive data-driven model. This will increase public awareness and acceptance.

2.6.3 Applications of Water Evaluation and Planning (WEAP)

WEAP, developed by the Stockholm Environment Institute in the early nineties is been used all over the world in order to perform scenario analyses for the management of water resources. WEAP applications support many studies worldwide. For instance it has been used to assess the impacts of different water management practices in the Aral Sea Region (Raskin *et al.*, 1992). In Richard Musota thesis (2008), WEAP was used to assess water use and management practices in the watershed and the organization of various stakeholders' perceptions, interests and influences on sustainable water management.

Holger Hoff *et al.*, (2011) applied WEAP to analyze the management of transboundary water resources in the Jordan River basin. Zakari *et al.*, (2011) used WEAP to optimize and allocate present and future Niger River resources between competing water demands. G. SanchezTorres Esqueda *et al.*, (2010) assessed the impacts of climate change on the variation of water availability in the irrigation districts in the Guayalejo-Tamesí River Basin in Tamaulipas, México. They used WEAP to define vulnerability of the water resources in the case study river basin, considering the effects of climate change on water availability in the municipal, industrial, and agricultural sectors. The applicability of WEAP as a Decision Support Systems (DSS) in this study is intended to assess the sustainability of raw water supply in Nawuni River for Tamale metropolis and environs.

**2.7 Chapter Summary**

Review of the scientific literature in this chapter considered availability and state of global water resources with emphasis on Ghana, and driving forces of water resources sustainability. Literature showed that water resources all over the world are under pressure through a combination of factors, including the rapid increase in demand due to population growth, pollution and climate change impacts.

Global water security is seen as one of the most important priorities in the development agenda and this is evident from many of the studies done to assess the current situation and the future of resources. From the literature per capita available fresh water in Ghana is declining at a fast rate. More work therefore needs to be done as far as understanding future water availability is concern in the country. Basically from the literature, the driven forces of water availability include: economic and population growth and climate change impact.

# CHAPTER 3: STUDY AREA AND METHODOLOGY

## 3.1 Introduction

*This section describes in brief the study area and the data use for the study. Also the methodology and the set-up of the Water and evaluation model are described.*

## 3.2 Study Area

The Nawuni River is an important source of potable water where it provides water supply to about 500,000 people. It is the main raw water source for Residents of the Tamale metropolis, Tolung, Kumbung and Savulugu districts in the Northern Region of Ghana.

This study was conducted in the White Volta at Nawuni, which is located about 40 km northwest of Tamale (Capital of the Northern Region of Ghana). The White Volta River and its main tributaries in the northern part, the Red Volta (Nazinon) and the Kulpawn/Sissili rivers, take their sources in the central and north-eastern portions of Burkina Faso (WRC, 2008). The river flows south to enter Ghana, it turns west to be joined by the Red Volta, and continue west through the upper east region and then turns south, where it is joined by several tributaries, including the river Kulpawn and Nasia. From southwards it flows to Nawuni, flowing west to Daboya then south again where it is joined by the River Mole before entering the Volta Lake

(WRC, 2008). Nawuni lies between latitudes 9°351 and 9°451 N and longitudes 1°101 and 1°251 W (Figure 3.1and Figure 3.2).

The surface area of the Nawuni catchment is 106,000 $km^2$ (McCartney, *et al*., 2012) and about 91,000 $km^2$ at Nawuni  with the total length of 1,140 km of the main channel (Obuobie and Bernd, 2008). The climate is semi-arid to humid with annual rainfall varying from 600 mm in the extreme north of the basin to about 1200 mm in the extreme south (VBRP, 2002) while the mean temperature range between 27-30 $^oC$ annually (McCartney, *et al.*, 2012).

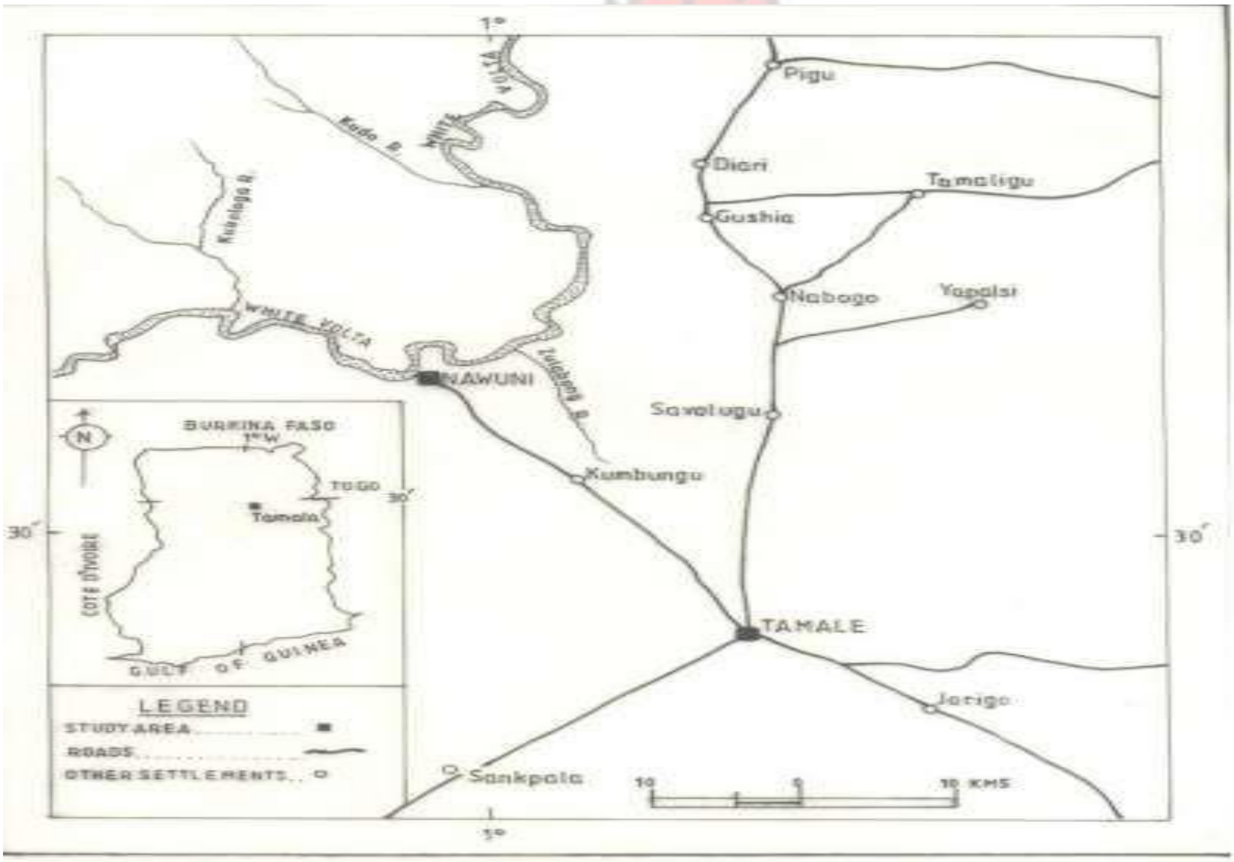


Figure 3.1: Map of Tolon-Kumbung and Tamale showing the study area (Nawuni).  (Source: Obodai and Laweh, 2009)


Figure 3.2: Map of the study area showing White Volta (left) and Ghana Water Company abstraction point (right).

### 3.3 Data Requirement

Data collection to define the current water resource and supply situation in the area. All data used in the study were obtained from the following agencies tabulated in the Table 3.1 below

Table 3.1: Tabulation of Data Required and Related Agencies

| Data | Agencies/ Sources |
|---|---|
| 1. Urban water supply | Ghana Water Company Limited (GWCL) |
| ➢ Demand categories | |
| ➢ Demand patterns | |
| ➢ Losses | |
| ➢ Coverage | |
| 2. Other water uses | Literature |

| | |
|---|---|
| ➢ Rural domestic water demand | |
| ➢ Irrigation water demand | |
| ➢ Livestock water use | |
| 3. Hydrological data | Hydrological Service Department |
| ➢ Streamflow | |
| ➢ Environmental flow requirements | |
| 4. Meteorological data | Ghana Meteorological Agency |
| ➢ Rainfall | |
| 5. Population census | Ghana Statistical Service Department |

### 3.4 Identifying Water Uses and Demand

Water uses identified in the study area can be put into consumptive and non-consumptive. Non-consumptive water uses include: small scale fishery and water transport by small canoes. The study focus on consumptive uses which are classified into the following main categories: irrigation water demand, urban and rural water supply and livestock watering. Under the urban water supply, water demand is classified into Commercial, Domestic, and Institutional water demand by Ghana Water Company Limited (GWCL).

#### 3.4.1 Urban and rural water demand

Social and economic activity is measured by activity levels, and the water use rate is the average annual water need per unit of activity. The activity levels for 2015 was estimated from 2010 population census obtained from Ghana Statistical Service Department using annual growth rate of 2.9 % of Tamale. The annual water use rate for the various classes of urban water demand was estimated from daily and monthly consumption of the categories obtained from the Ghana Water Company Limited.

All people, regardless of their stage of development and their social and economic conditions, have the right to safe drinking water in quantities and quality equal to their basic needs (Salman, 2014). The water demand for rural domestic was estimated by multiplying per capita demand of rural people in Ghana in liters/person/day by the estimated population of the surrounding communities of the Tamale city. The unit water demand (35 l/p/d) applied was adapted from the design values generally used by GWCL, which are differentiated according to settlement size and time (WRC, 2008) as shown in Table 3.2.

Table 3.2: Unit water demand (liters/capita/day)

| ***Settlement size*** | ***Category*** | *2008* | *2015* | *2020* | *2025* |
|---|---|---|---|---|---|
| *< 5,000* | Rural | 35 | 35 | 35 | 35 |
| *5,000-15,000* | urban | 55 | 65 | 75 | 85 |
| *15,000-50,000* | urban | 85 | 85 | 90 | 95 |
| *> 50,000* | urban | 105 | 110 | 115 | 120 |

Source: WRC, 2008

### 3.4.2 Livestock water demand

In addition to crop cultivation, the production of livestock is an important source of rural livelihoods in the northern parts of the Volta basin. The method for rearing livestock is usually free-range except during the rainy season when some of the animals are confined to prevent destruction of crops. The predominant livestock reared by farmers comprises of cattle, sheep, goats, pigs, fowls and guinea fowls (Mul *et al.,* 2015) with an average annual growth rate of 2.5 % inferred from regional time-series data obtained from Ghana and Burkina Faso (Ministry of Food and Agriculture, Ghana) (McCartney *et al.,* 2012).

Livestock water consumption was estimated by multiplying per capita consumption of water by the estimated livestock population within the study area; using livestock density of 10 animal units/km$^2$ for cattle and 25 animal units/km$^2$ for small ruminant (FAO, 2005). Water requirement for cattle in grassland ranges between 40-100 l/h/d (Markwick, 2007) and small ruminant (sheep, goat) consume between ¾ to 1 ½ gallons of water per day (Lemus, 2008); which is translated into about 5 l/h/d.

Population density of livestock per square kilometers (km$^2$) in the study area according to FAO report (2005) indicates that cattle density in the area is at maximum 10 cattle/km$^2$ while small ruminants are at maximum 25 ruminants/km$^2$ making a total of thirty-five (35) animal units/km$^2$. Livestock annual water use rate was estimated using per cap consumption of 70 l/d and 5 l/h/d for cattle and small ruminants, respectively. Water demand for fowls and guinea fowls were however consider insignificant in this study. Table 3.3 shows estimated water demand for livestock, urban and rural.

Table 3.3: Water demand for livestock, urban and rural demand sites

| **Demand type** | **Activity levels** | | **Annual water use rate** | **Annual total** |
|---|---|---|---|---|
| | **Quantity** | **Units** | | |
| **Urban water supply(m$^3$)** | | | | |
| Domestic | 428,412 | People | 32 | 13,709,184 |
| Institutional | 361 | | 3580 | 12,92,380 |

| | | | | |
|---|---|---|---|---|
| Commercial | 1861 | | 746 | 1,292,268 |
| **Rural Domestic demand($m^3$)** | | | | |
| Domestic | 171,074 | People | 13 | 2,223,962 |
| **Livestock watering($m^3$)** | | | | |
| Cattle | 600,000 | Livestock units | 25 | 15,000,000 |
| Small ruminants | 1,500,000 | Livestock units | 2 | 3,000,000 |

3.4.3 Irrigation water demand

A number of small and commercial riverine irrigation water uses were identified upstream of the GWCL abstraction point. Irrigation schemes identified include: Nangodi, Dinga (Diare), Sogo, Dipali, Savelugu irrigation and small scale irrigation at Nawuni. Information on water demand on the various scheme was obtained mainly from the fallowing sources: Goes, 2005 and Alhassan, 2015. The table below present irrigation water use upstream.

Table 3.4: Irrigation water demand

| *Irrigation water demand ($m^3$/ha)* | *Activity levels (ha)* | *Annual water use rate* | *Annual total* |
|---|---|---|---|
| *Nangodi* | 184 | 7,542 | 1,387,728 |
| *Dinga (Diare) irrigation* | 115 | 1,304 | 1,500,000 |
| *Sogo irrigation* | 151 | 9,934 | 1,500,000 |
| *Dipali irrigation* | 148 | 10,135 | 1,500,000 |

| | | | |
|---|---|---|---|
| *Savelugu irrigation* | 165 | 8,471 | 1,397,760 |
| *Nawuni irrigation* | 65 | 7,542 | 490,200 |

Source: Goes, 2005 and Alhassan, 2015.

The remaining demand sites considered in the model are the reservoirs development upstream. The small reservoirs (SRs) were considered as consumptive water demand. Small reservoirs have impact on the run off water contributing to the main river flow; because they stored and only release water onto the river during the wet season when full, hence they were considered as demand site. A sum of 239 reservoirs were identified with the total annual water demand found to be 4.2 $Mm^3$ (Joachim, 2013). The average annual water demand per small reservoir was estimated to be 18000 $m^3$. Table 3.5 shows inventory of small reservoirs upstream.

Table 3.5: Inventory of Small Reservoirs

| ***Sub-catchments*** | ***Number of small reservoirs*** |
|---|---|
| *Pwalugu* | *47* |
| *Yarugu* | *84* |
| *Yagaba and Wiasi* | *98* |
| *Nawuni* | *10* |
| *Total* | *239* |

Adapted from Joachim, 2013

Similarly using the assumption made by de Condappa *et al.*, (2009), it was assumed that large irrigation reservoirs can be modelled in WEAP as a consumptive water demand which is equal to the storage capacity of the reservoir minus the inactive storage or, when inactive storage is unknown, to seventy five percent (75 %) of the storage capacity. Below are the demands of large reservoirs identified upstream (Table 3.6).

Table 3.6: Large irrigation reservoirs.

| ***Name*** | ***Storage capacity ($Mm^3$)*** | ***Inactive storage ($Mm^3$)*** | ***Demand ($Mm^3$)*** |
|---|---|---|---|
| *Tono* | 90 | Unknown | 67 |
| *Vea* | 20 | Unknown | 15 |

Adapted from de Condappa *et al.*, 2009

### 3.5 Monthly variation of demand sites

In demand sites, such as industrial sites, water use may be constant throughout the year. However, the other demands sites, such as the domestic and irrigation vary greatly from month to month. Monthly variations for domestic were estimated from the historical annual water consumption. Analyses of historical annual water consumption obtained from GWCL showed variation in the amount of water consumed during each month. The demand variation for the study period (2015-2035) was presumed to follow the same pattern. Likewise monthly variation of irrigation demand site was estimated from the annual water consumption to get percentage of annual water use in each month. The percentage calculated in each month was applied in all the years of the study period. WEAP uses the demand percentage variation to transform the yearly demand into a set of monthly demands.

Table 3.7: Annual variation coefficients of demand sites

| Month | Demand variation (%) | | |
|---|---|---|---|
| | Domestic | Small Reservoir | Irrigation |
| January | 10 | 0 | 18 |
| February | 8 | 0 | 18 |
| March | 10 | 0 | 13 |
| April | 8 | 0 | 0 |
| May | 8 | 0 | 0 |
| June | 6 | 15 | 0 |

| | | | |
|---|---|---|---|
| July | 8 | 35 | 0 |
| August | 7 | 40 | 0 |
| September | 7 | 10 | 0 |
| October | 8 | 0 | 17 |
| November | 10 | 0 | 17 |
| December | 10 | 0 | 17 |

Source: Domestic demand variation estimated from water consumption obtained from GWCL. Irrigation demand variation estimated from annual water demand of small Private and commercial irrigation in Nawuni catchment (Alhassan, 2015). And reservoirs demand variation from Salomon (2015).

### 3.6 Calculation Algorithms

Operation of WEAP is based on the basic principle of water balance for every node and link in the system on monthly time step subject to priorities of demand, supply preferences, mass balance and other constraints. Mass balance equations are the basis of the monthly water accounting of WEAP: total inflows minus the total outflows equal to the net change in storage, if any. WEAP operation is based on a monthly time step, from the first month of the Current Accounts year through the last month of the last scenario year.

Demand calculation can be done in two ways; Monthly Demand and Annual Demand with Monthly Variation, to input and calculate demand. The Monthly Demand option allows the user to input demands values month by month manually or using a ReadFrom File function, monthly demand can be read from a file. The Annual Demand with Monthly Variation option can be used to express demand based on an annual level. Using it, one can enter an activity level (e.g., amounts of hectares) and water use rate (e.g., annual water consumption for each crop) associated with that activity level. Then one can use Monthly Variation to vary demand. In this study, Annual Demand with Monthly Variation option was used since the data used are in daily and annual water consumption per capita.

For each demand sites, the monthly demand represents the amount of water needed by demand on monthly bases. **Annual Demand in WEAP**: Water demand sites demand is calculated as the sum of water demand for all demand sites‟ bottom-level branches (Br). A bottom level branch is one that has no branches below it.

$$\textit{Annual Demand} = \textit{Total}\ \text{Activity}\ \textit{Level} \times \textit{Water Use Rate} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1).}$$



**Monthly supply requirements:** Supply requirements represents the actual volume of water required from the supply sources. Supply requirements for each demand site takes into account the rates of re- use and distribution losses and demand site management strategies to reduce the demand. For a demand site, in a month of a year, we have:

$$\textit{Monthly Supply}\ \text{Requirement} = \frac{\textit{Monthly Demand} \times (1-\text{Reuse}\ \textit{Rate}) \times (1-\textit{DSM Savings})}{1-\textit{LossRate}} \ldots\ldots\ldots \text{(2)}$$

**Supply and Resources:** The Supply and Resources section is used to calculate the amount, availability and allocation of supplies, given the monthly supply requirement established from the definitions of the system demand, and the definitions of Hydrology.

**The transmission Links:** water is delivered from the supply nodes to satisfy demand at demand sites. The amount of water that is delivered to the demand sites is equal to the amount withdrawn from the source minus any losses.

$$\textit{Trans.link outflow} = \textit{Trans.link Inflow} - \textit{Trans. Link Loss} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{(3)}$$

**Priorities for Water Allocation**: The highest priority is satisfied fully before considering lower priority. WEAP follows the Convention, where higher priorities are assigned lower numbers (for example, priority 1 is higher than the priority 2, etc.). However, if the requirements of the flow have the same priority as any demand site, the flow requirements will be satisfied first. For this study the assumption was that, there is no cooperation between upstream and the downstream. Water allocation was therefore based on „„„first come first served‟‟‟ i.e. water allocation decreases from upstream to downstream. Small reservoirs (SRs) is assigned priority 1 since they first capture runoff water before it gets to the main river. Riverine irrigation upstream is assigned priority 2. Values of the priority parameter range from 1 to 3 with the lowest water allocation priority being given to Urban and rural water supply located downstream. Like small reservoirs, livestock water is assigned priority 1.

### 3.7 Building of the model

Models are call „‟areas‟‟‟ in WEAP which represent schematic for the water supply system; which involves all the river systems, the reservoirs, and other important components of the water supply system under consideration. The extent of the project area is define by boundaries that limit the areas. GIS based Raster and vector is added to the project area in the building of the area.

General parameters (the Years, Time Steps and Units) are set once the area is open. The current account for this study was set to be 2015 and the last year to 2035. The current account year was 2015 because this was when the demand component activity levels are fairly known. The Steps per year is set to be 12 and the Boundary of the Time Step to be „„„Based on a Calendar Month‟‟‟, starting with the month of May.

After setting parameters, relevant data for the river system was input. The streamflow values are entered as head flow for the stream on the current account year (2015). Demand is satisfied by connecting the supply system to each demand site in the schematic view through transmission link. The return flow links are then connected back to the river. Water that are not consumed can be directed to one or more demand sites. The return flow routing is then set. The return flow routing represent the percentage of the total outflow from the demand node. The return flow should be sum to 100 %.

***Environmental flow requirements***

It must be recognised that any abstractions from the White Volta River system will have an impact on the aquatic ecosystem that are associated with the river and also the inflow into the Volta Lake which can cause a reduction in the hydro-electric output from the Akosombo Dam and Kpong power stations. To sustain a reserve of the river flow for environmental "maintenance", a minimum flow requirement introduced by WRC in calculating downstream of the main water abstraction points was used; which is a simple percentage (10 %) of the average dry-season flow recorded since 1996, i.e. after commissioning of the Bagré Dam (WRC, 2008).

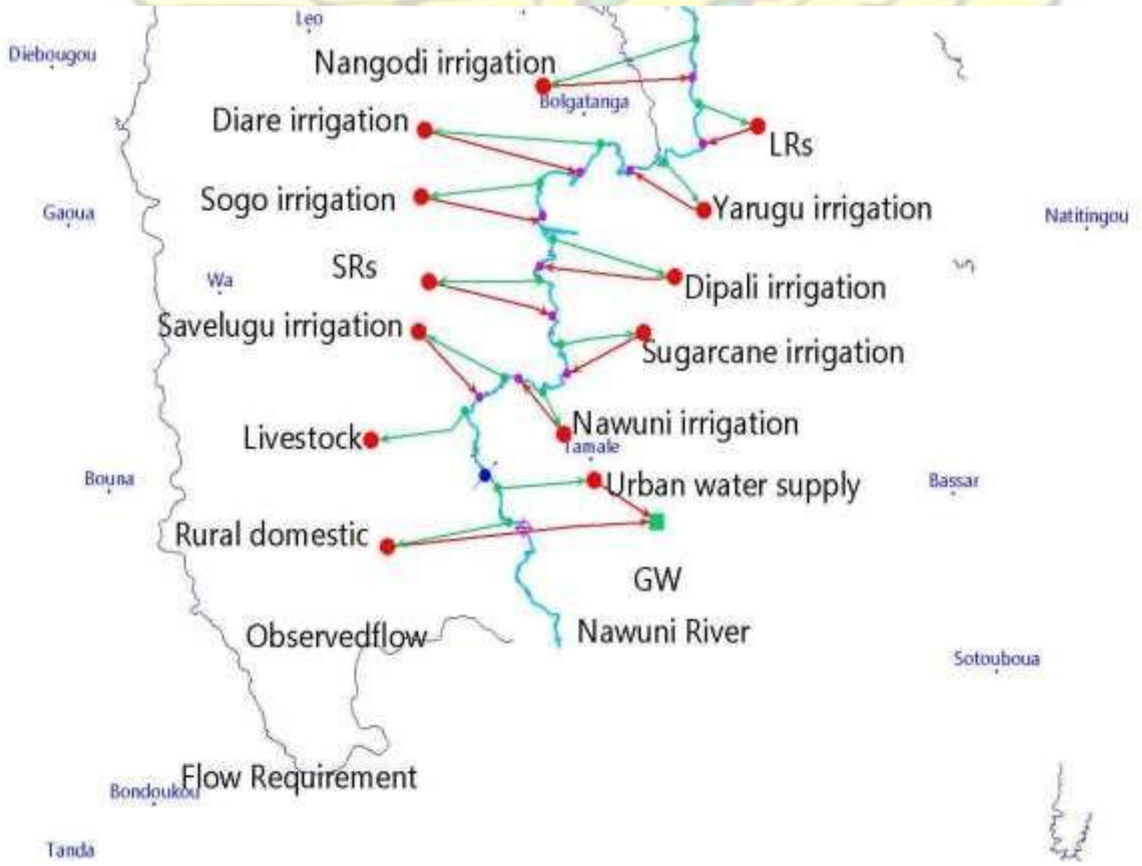

Figure 3.3 Schematic view of the river and modelled parameters in WEAP

### 3.7.1 Model Calibration and Validation

Calibration was performed to fit simulated data to observed flow data from gauging station. WEAP includes a link to parameter estimation tool (PEST) that allow the user to automate the process of comparison between the outputs to the historical observations notes and modify the parameters model to improve accuracy. Calibration and validation were performed using streamflow data of years 2004–2008 and 2009–2013 respectively, for which hydrologic data were most complete. The range of resulting values from the calibration and validation process is shown in Figure 3.4.

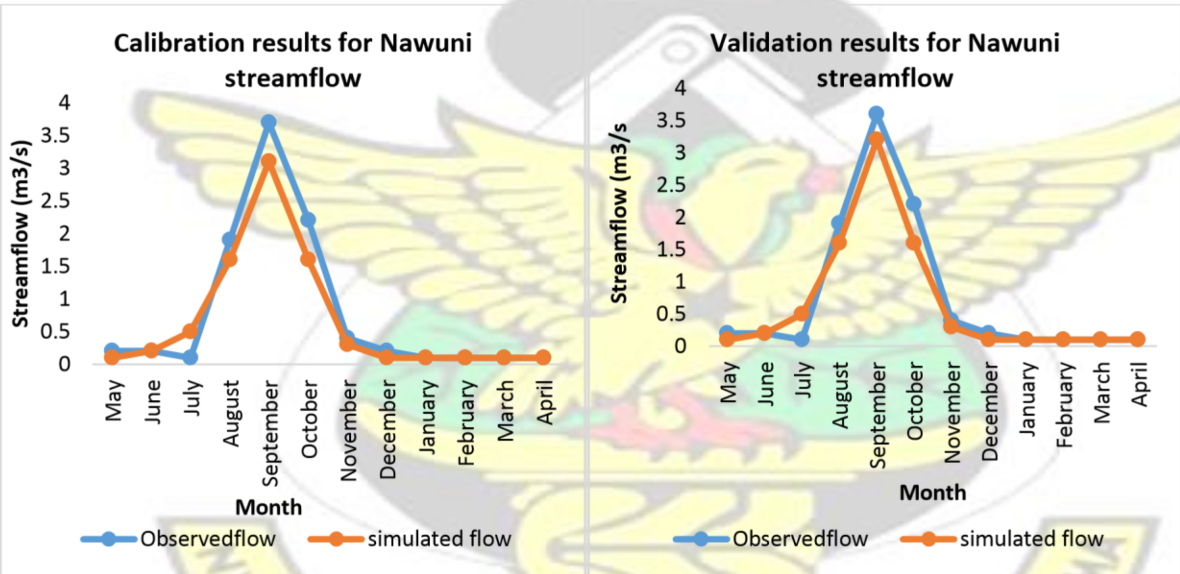


Figure 3.4: Calibration (left) and Validation (right) for Nawuni streamflow

The calibrated model results were then validated to check the accuracy of the model's representation of the real system. The coefficient of determination ($R^2$) and Nash-Sutcliffe simulation efficiency (*ENS*) were used to check the accuracy of the model predictions. The values obtained for coefficient of determination ($R^2$=0.8511) and Nash-Sutcliffe simulation efficiency (*ENS*=0.9345) indicated that the model accurately represent the real system for the simulated time period.

### 3.7.2 Reference scenario

The current account year serve as a base year where data for the current water demand and supply is added. A default scenario call „„Reference Scenario"" then carries forward the current account into the entire project period (2015-2035). The „„Reference Scenario"" established from the current account simulate the likely evolution of the system without any intervention. And lastly, scenarios asking „„what if"" questions are built to change the „„Reference Scenario"" and analyse the impact of change in policies (SEI, 2015).

Climate change projections in West African Region are inconsistent in projecting rainfall, with an almost equal number projecting an increase and a decrease in rainfall (Mull *et al.*, 2015). Andrein *et al.,* (2000) however, showed that rainfall-runoff pattern of the Volta basin is not linear (Ofosu, 2011); which means that the river flow is very sensitive to climatic variations (e.g. rainfall) (Figure 3.5). The high variability in both temporal and spatial distribution of rainfall over the basin causes a corresponding high variability in streamflow (Mul *et al.,* 2015). The long term annual rainfall was therefore modified over the projected study period to depict the climate variation using Water Year Method. Figure 3.6 show deviation of the annual rainfall from the normal in the study area.

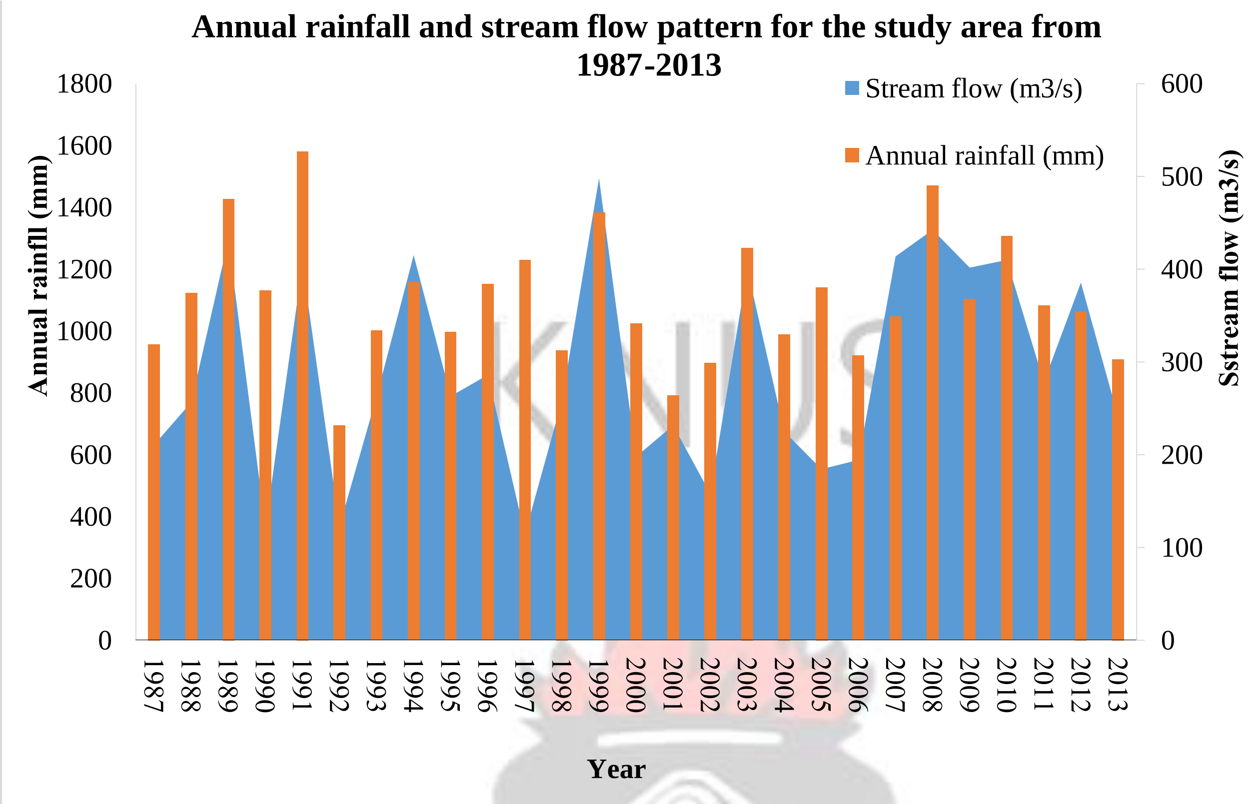


Figure 3.5: 27-year annual rainfall and stream flow pattern for the study area from 1987-2013

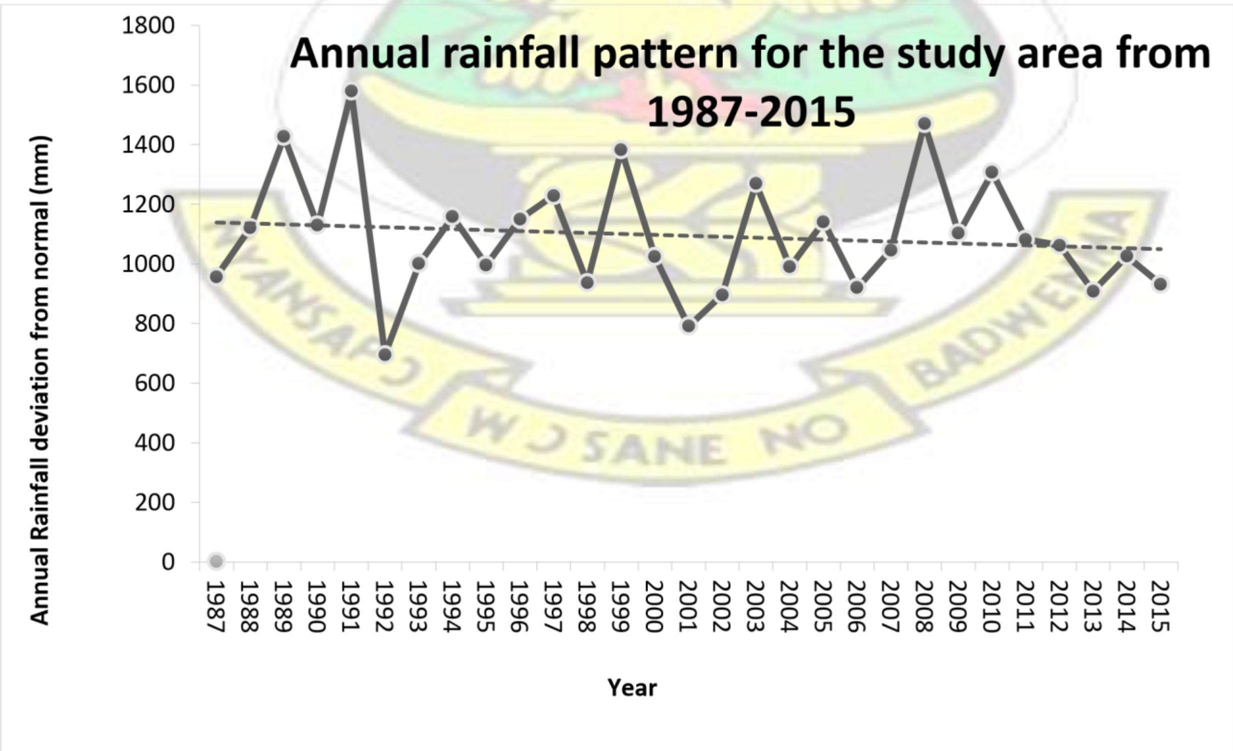

Figure 3.6: Deviation of 29-year annual rainfall from the normal for the study area

The water year method represent variation in climatic data such as streamflow and rainfall. Water Year Method consist of defining differences in the climatic regime (for example Very wet, Wet, Very dry, Dry) as compare to the Normal year which is usually given a value of one. Each of the years that is non-Normal (Very wet, Wet, Very dry, Dry) was determined by estimating how much more or less water flow into the system in relation to the Normal year by statistical analysis of the historical rainfall from 1987 to 2015 of the study area.

The value for Dry year is less than one and the wet year has value greater than one. For instance, if a Dry year has 30 % less inflow than the Normal year, 0.7 will be entered for the Dry year. The modified factors use to represent the climate variability were: Very wet = 1.31, Wet = 1.08, Dry = 0.90, Very dry = 0.78. These modified factors were calculated by first grouping the rainfall figures into five bins (quintiles). The first quintile was indicated as Very wet, the second quintile as Wet, the third quintile as normal, the fourth quintile being dry and the last quintile as very dry. Then how each year vary from the normal was computed using the mean of the ratio between the rainfall figures of each quintile and the average value of the entire data as shown in Table 3.8 below.

Table 3.8: Range of rainfall and modifying factors for climatic variations

| ***Climate variation*** | ***Very Wet*** | ***Wet*** | ***Normal*** | ***Dry*** | ***Very Dry*** |
|---|---|---|---|---|---|
| *Range of rainfall (mm)* | 1306.8 – 1579.8 | 1129.8 – 1269.3 | 1026.3 – 1121.9 | 937-1024 | 695.3 – 931.7 |
| *Modifying factors for rain fall* | 1.31 | 1.08 | 1.00 | 0.90 | 0.78 |

The category of climate variation was then assigned to each year of the period of the study. And the climatic variation was assigned to the Scenarios in the analyses in order look at effect towards water demand and supply. For the Reference scenario, the following sequence in the Table 3.9 below was assigned.



Table 3.9: Climate categories for Reference scenario

| ***Year*** | ***Sequence of Climate Variation*** |
|---|---|
| ***2015*** | Dry |
| ***2016*** | Normal |
| ***2017*** | Very dry |
| ***2018*** | Wet |
| ***2019*** | Very wet |
| ***2020*** | Very dry |
| ***2021*** | Dry |
| ***2022*** | Wet |
| ***2023*** | Dry |
| ***2024*** | Wet |
| ***2025*** | Wet |
| ***2026*** | Dry |
| ***2027*** | Very wet |
| ***2028*** | Dry |
| ***2029*** | Very wet |
| ***2030*** | Dry |
| ***2031*** | Very dry |
| ***2032*** | Very dry |
| ***2033*** | Very wet |
| ***2034*** | Dry |
| ***2035*** | Wet |

### 3.7.3 Scenarios building

In WEAP, scenarios usually begin from a base year for which the current account data is established. The „"Reference Scenario"" usually established from the current account to simulate the likely evolution of the system without any intervention. In this study, the analyses of the scenarios aimed at possible future situation in the year 2035. Scenarios asking

„„what if questions that represent changes in policy and future development include:

#### 3.7.3.1 Scenario 1: High population and socio-economic growth.

As a developing country, we have to note that the intensive urbanisation which was experienced by the industrialized nations is currently under way in developing countries. Recently, more than four out of every ten Ghanaians live in a city or town with more than 5,000 people. If the current trends of rapid urbanization continue, by 2020 more than half of Ghanaians will be living in urban settlements. And this trend is what the Tamale Metropolis is currently experiencing (Naab *et al.*, 2013).

Tamale is among the fastest-growing cities in Ghana with an annual growth rate of 3.3 %; expanded from a village of about 1500 inhabitants in 1907 to its present (2012) status of a metropolis of 444 000 people (Gyasi *et al.*, 2014) with the average annual population growth rate of about 5.4 % within this period. Domestic demand for water is driven by increase in population and the industrial demand for water by expansion of industries for socioeconomic development (van Drunen *et al.*, 2006). Scenario 1 is established to evaluate the impact of high population and socio-socio-economic growth on the water demand and supply for Tamale and environs.

3.7.3.2 Scenario 2: Competing water uses upstream**.**

The water uses identified upstream are irrigation use and livestock watering. The White Volta irrigation potential is estimated to be six percent of the catchment area representing 314000 ha (Wiafe, 1997). And when compared the potential to the developed area showed that over eighty percent of the potential irrigable area is not developed (Ofosu, 2011). This implies that there is still high opportunity to upscale irrigation. The study conducted by Ofosu (2011) in three sub catchment upstream of the study area revealed an irrigation growth rate of 5.6 percent from 2005 to 2010. He attributed this trend to the upscaling of private led-irrigation system; which contribute 74 percent of the total irrigated area. He also stated that a number of factors identified in the study has potential of further upscaling irrigation growth beyond the growth rate of 5.6 percent observed in the past. Also a number of small reservoirs are being constructed and more irrigated lands exploited.

In addition, the Ghana Sugar Development Company proposes establishing a large-scale sugarcane irrigation scheme in the basin to abstract water directly from the White Volta River between the Nasia and Nabogo tributaries in the Northern Region. In the first phase of the proposed project, direct water abstraction from the White Volta River up to a maximum of 9 $m^3$/sec during the low flow period would be made to irrigate 7,500 ha of sugarcane. And the second phase, an additional abstraction of 10 $m^3$/sec to irrigate up to 15,000 ha, which only can be realised in conjunction with the establishment of a storage facility (WRC, 2008). The implications of the future trend on the downstream water uses is however worth noting. This scenario therefore looked at the impact on the sustainable water supply for Tamale:

a) If riverine irrigation upstream expand at a rate of 8%.
b) Development of small reservoirs at a rate of 3.1% per year.
c) Implementing the first phase of the proposed large-scale sugarcane irrigation.

3.7.3.3 Scenario 3: Extended Dry Climate Sequence

Though Climate change projections in the West African Region are inconsistent in projecting rainfall (Mull *et al.*, 2015), studies conducted into the past climate in the Volta basin showed reduction in rainfall since the early 1970s (Owusu, *et al.*, 2008). Between 1950-70 and 197190, for instance, due to a decrease in rainfall, the mean annual runoff in the White Volta and the Oti decreased by 23.1% and 32.5%, respectively (McCartney *et al.*, 2012. Scenario 3 is built in order to look at the impact of prolonged drought on the water resource availability to meet future demand. The following sequence was assigned For the Extended Dry Climate

Sequence Scenario (Table 3.10).

Table 3.10: Climate categories for scenario 3

| ***Year*** | ***Sequence of Climate Variation*** |
|---|---|
| ***2015*** | Normal |
| ***2016*** | Normal |
| ***2017*** | Very dry |
| ***2018*** | Wet |
| ***2019*** | Very dry |
| ***2020*** | Very dry |
| ***2021*** | Dry |
| ***2022*** | Normal |
| ***2023*** | Wet |
| ***2024*** | Wet |
| ***2025*** | Dry |
| ***2026*** | Normal |
| ***2027*** | Normal |
| ***2028*** | Dry |
| ***2029*** | Normal |
| ***2030*** | Very dry |
| ***2031*** | Very wet |

| | |
|---|---|
| ***2032*** | Very dry |
| ***2033*** | Wet |
| ***2034*** | Dry |
| ***2035*** | Wet |



# CHAPTER 4: RESULTS AND DISCUSSION

## 4 Introduction

In this chapter, analyses of scenarios which consist of different set of assumptions are considered. The analysis takes into account of the increasing demands for water resulting from socio-economic and population growth, prolonged drought and competing water uses upstream Nawuni catchment; and the implication of future trend. Using WEAP, the alternative assumptions are evaluated which aimed at possible future situations in the year 2035. The output analysed include: supply requirement, supply delivered, unmet demand and reliability with regard to the alternative assumptions made.

The results for alternative assumptions were also compared in order to evaluate their impacts on water availability to meet future demand. However, the water use and allocation modelling was restricted to surface water resources only in this study. Also the scenarios analyses considered only reliability of the water supply source in terms of water availability as a source for meeting future demand, and does not take into consideration the various technical aspects as precondition for meeting water demand in the future e.g. appropriateness and efficiency of water intake structure, treatment plant capacity and water supply distribution network.

### 4.1 Current situation of water demand and supply for 2015

Before any scenario was developed the current water supply and demands for various demand sites was analysed. The Analyses also take into consideration the Monthly average available water in relation to supply requirement for 2015.



As observed in the figure 4.1, the reservoirs‟ water requirement occur during the month of June, July and August. This is the period of the year when reservoirs are filled. The highest supply requirement (3 million cubic meters) for Urban and rural occur in November, December and January. Water supply requirement for livestock however remain constant throughout the year. The results also revealed that high supply requirement for different users‟ (irrigation, Urban and rural water demand) are observed during the dry season (January to March) which has low flow. Water shortages in the future is likely to occur during this period.

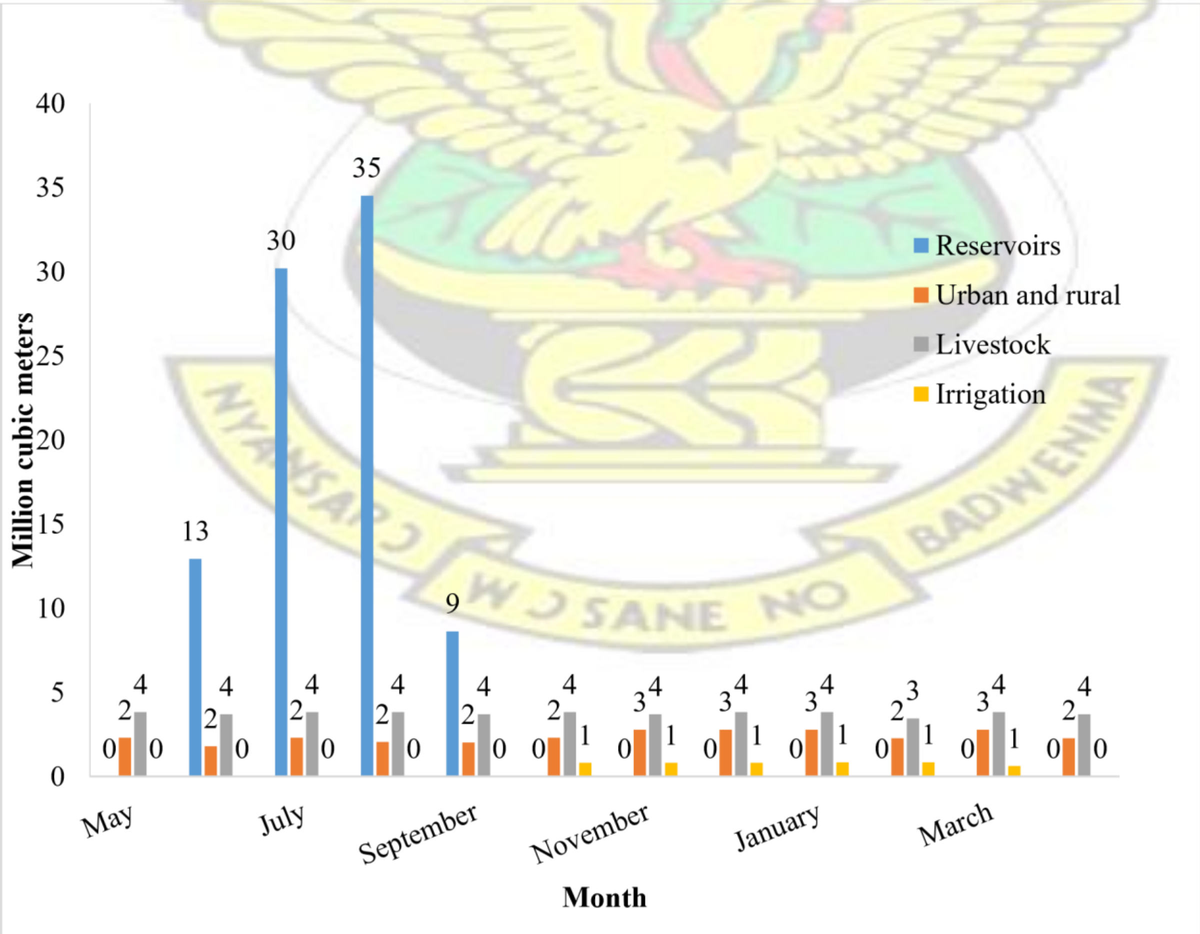

Figure 4.1: Monthly supply requirement for the demand sites (2015).

Figure 4.2 shows annual water requirement for different water uses in the catchment. It is evident from the figure that, Reservoirs for irrigation water requirement and riverine irrigation gave a total agricultural annual water requirement of 125 Million cubic meters in the catchment while Urban and rural, and livestock water requirement are 20 Million cubic meters and 23 Million cubic meters, respectively. The total water requirement for the demand sites in the catchment is 148 Million cubic meters.

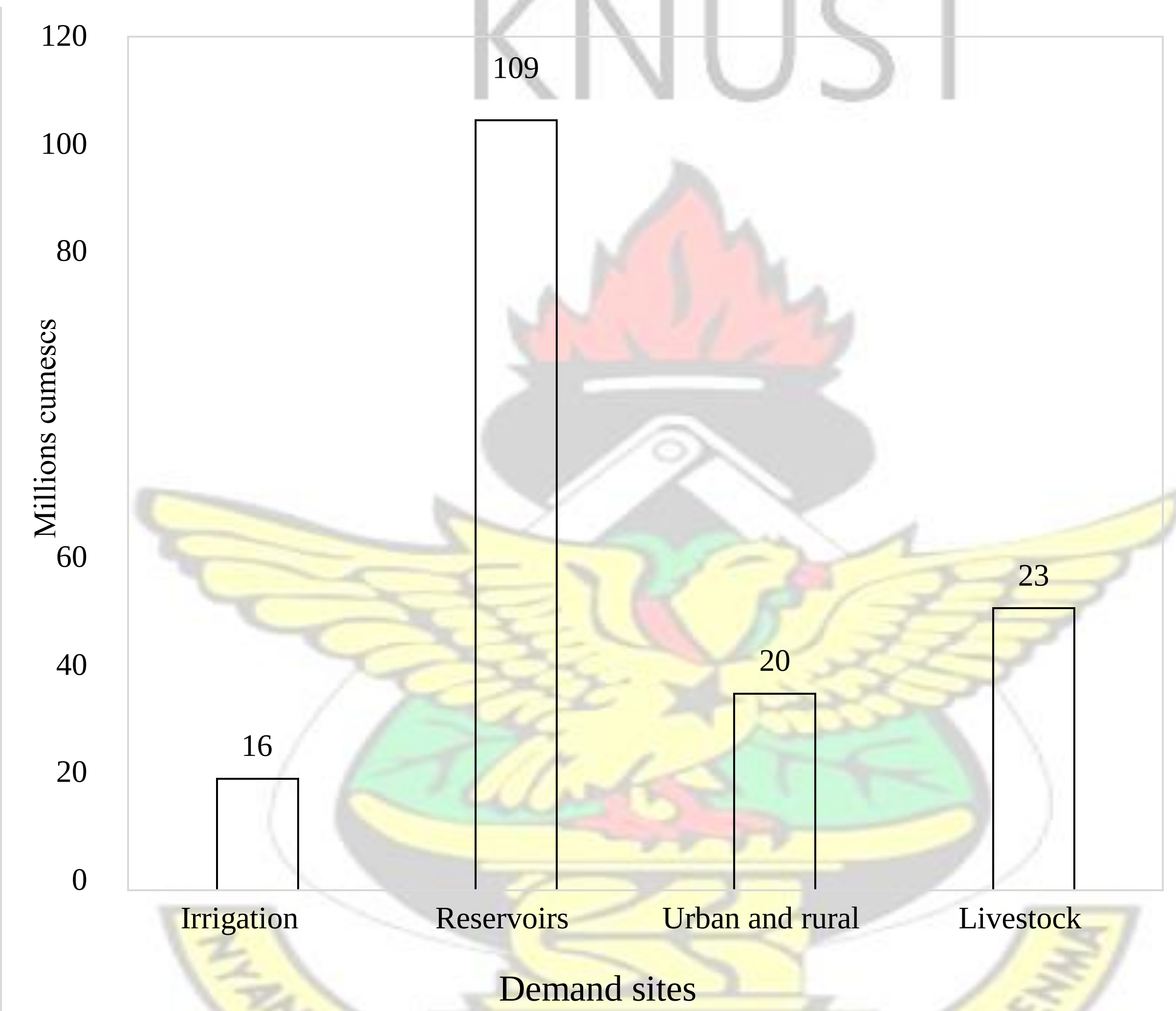

Figure 4.2: Annual supply requirement for the demand sites (2015).

Under the Urban and rural water requirement (supply requirement for Tamale and environs), Domestic water requirement has the highest value (17.1 Million cubic meters) and Institutional water requirement being the least (1.3 Million cubic meters). Water requirement for Commercial is 1.4 Million cubic meters. Figure 4.3 show annual water requirement for Tamale Metropolis and environs.

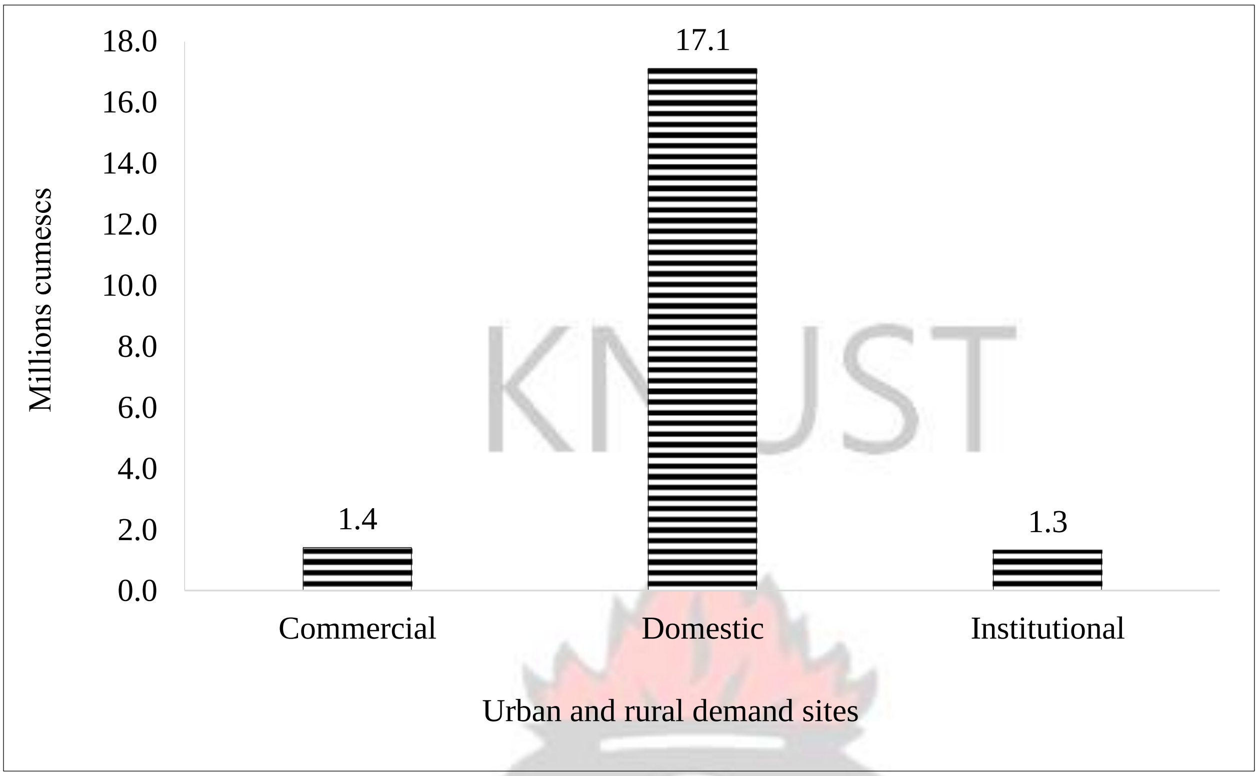


Figure 4.3: Annual supply requirement for Tamale and environs for 2015.

The current monthly average water requirement among multiple water users however indicates that, the current water use is low compared to the current average supply available as observed in the figure 4.4. Exclusion of loses, remaining stream flow is the flow after meeting supply requirement for various demand sites.

The impact of the current water uses on the available stream flow is shown in Figure 4.4. There is no much difference between available streamflow and the remaining stream flow under the current situation except of the period from June to August where there is a slight drop. This is the period of the year when reservoirs are filled. There is a drop of 2% of the total streamflow for the current situation.

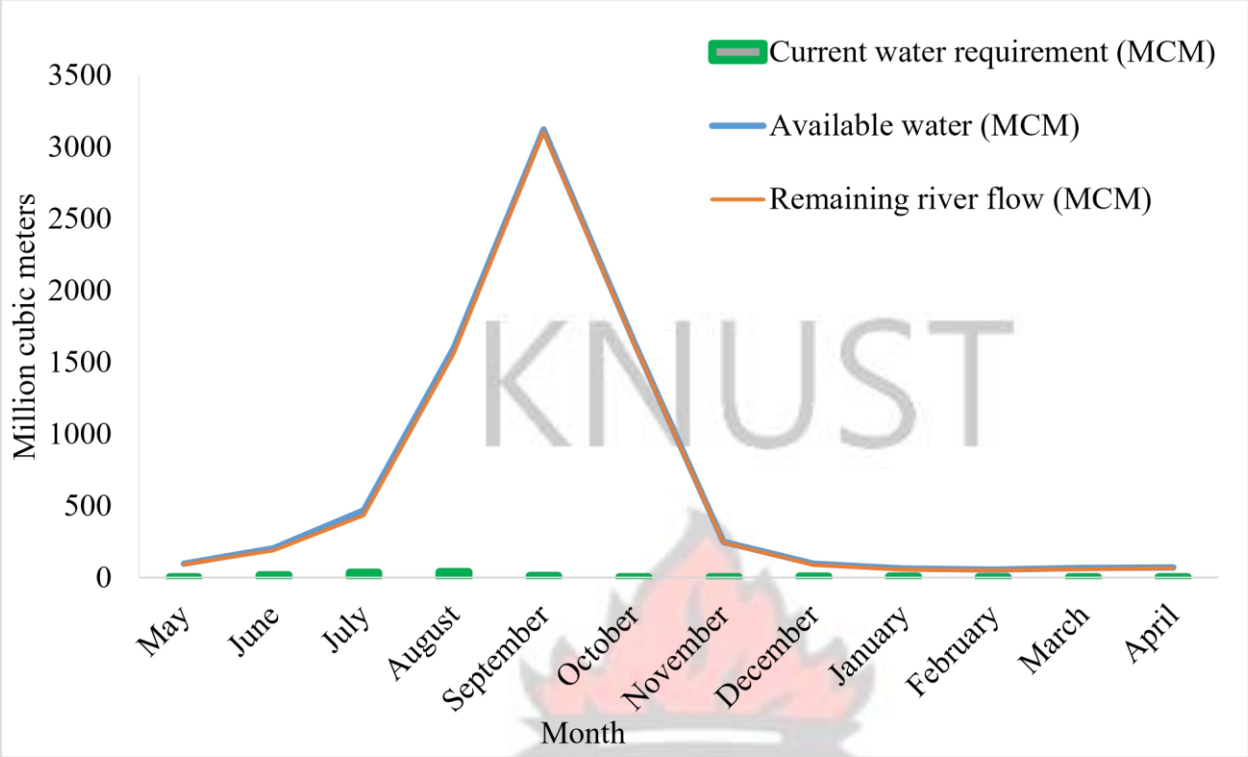


Figure 4.4: Current Monthly average inflow and outflow

Water supply requirement is fully met under the current situation. Reliability is therefore 100% for demand sites as shown below (figure 4.5).

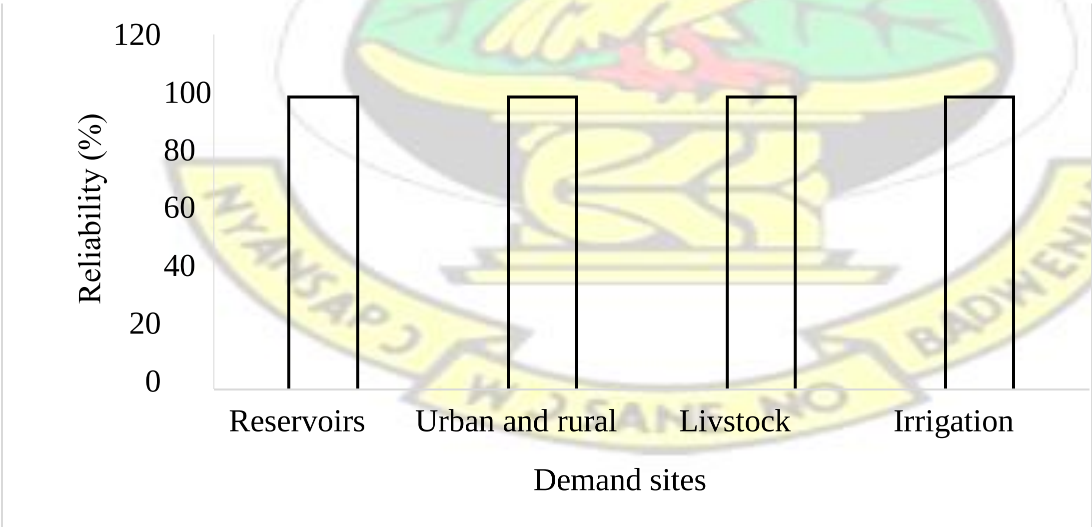


Figure 4.5: Reliability for the Demand Sites for 2015

## 4.2 Baseline (Reference) scenario

Reference or baseline scenario simulates likely evolution of the system without intervention. In this scenario, current annual growth rate of 2.9 % and 2.5 % was applied to human and livestock population, respectively that are likely to occur and not depend on any intervention and policy change. The analysis was also based on the current growth rate of irrigation. The irrigated area in the upstream of the catchments has been growing at rate of 5.6 % since 2005 (Ofosu, 2011). Water demand and supply from 2015 to 2035 of all water users was modelled. The Model generated the water requirements for the next 20 years.

### 4.2.1 Supply Requirement

It is shown from the figure 4.6 that, the water supply requirement for Tamale City and the environs (urban and rural water requirement) estimated at 20 Million cubic meters in the base year (2015) increased to 33 Million cubic meters in 2035. The increase in supply requirements for the city and rural is due to increasing population growth. Also the water requirements for irrigation and small reservoirs increase from 16-31 and 4-6 Million cubic meters, respectively; which can be attributed to expansion of the irrigated area. Likewise the demand for livestock is increasing due to increasing livestock population. However water requirement for large reservoirs remain constant throughout the study period.

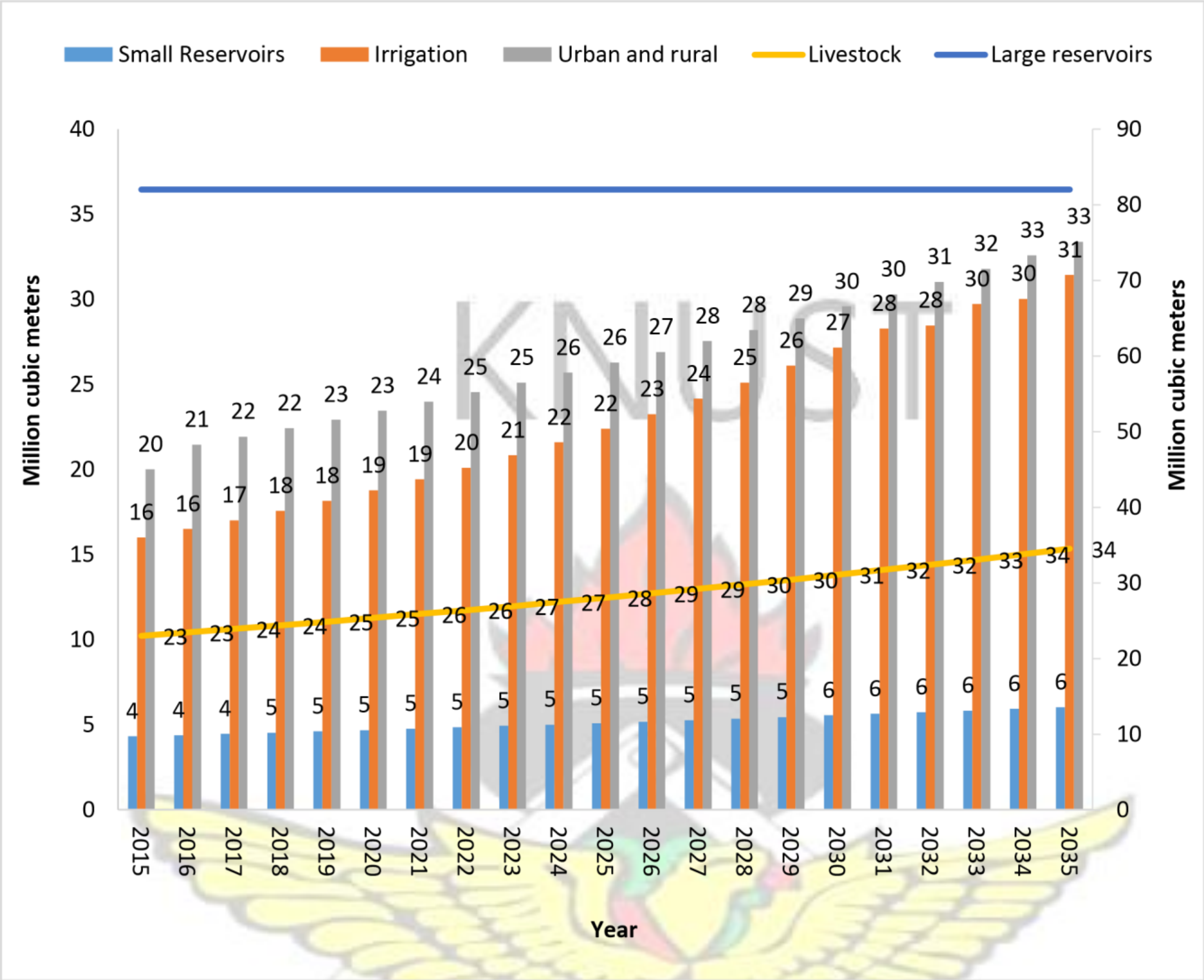


Figure 4.6: Water Supply Requirements for demand sites in Million Cubic Meters

4.2.2 Supply delivered

The supply requirement and supply delivered to the various demand sites as shown in the figure 4.7 do not vary; the supply delivered is 100 % for all demand sites in all years. Hence there is no shortage of supply. That is, unmet demand has zero (0) value for 2015 to 2035 all for the demand sites.

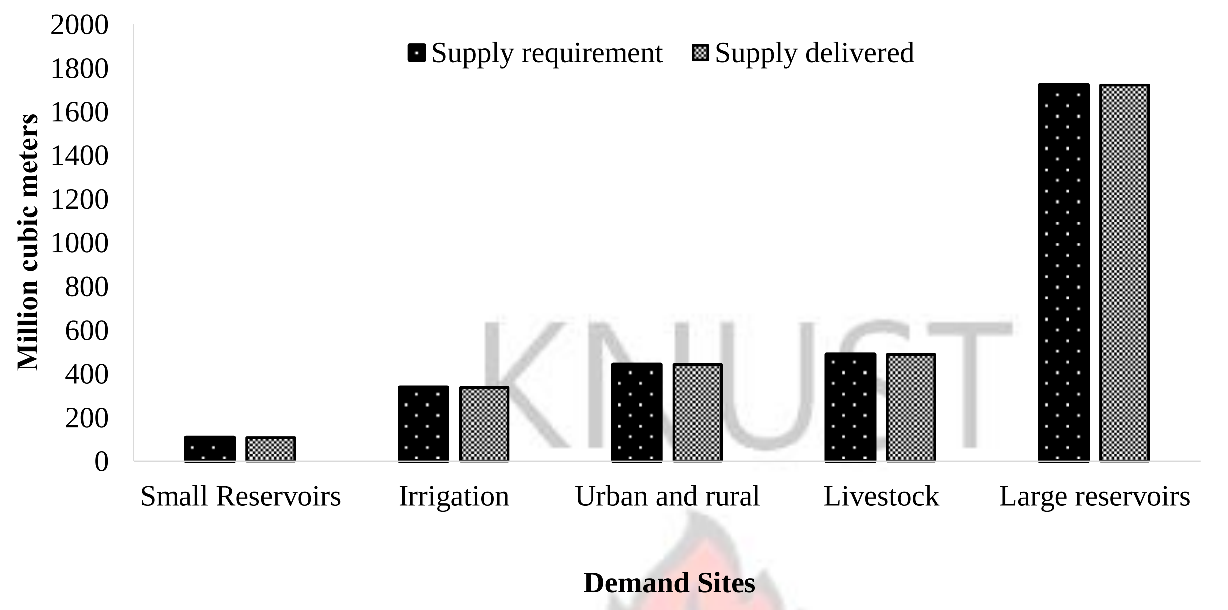


Figure 4.7: Water Supply delivered to the demand sites (Million cubic meters).

### 4.3 Scenario 1: High population and Socio-economic growth

In this scenario, the twin pressure of rapid urbanisation resulting in high population growth, and socio-economic growth have been considered. The scenario is created in order to foresee the future increase in water demand impact on the availability of water resource supplied to Tamale city and the environs taking into account population and socio-economic growth.

Study conducted by Ofosu (2005) in Kamasi revealed that, „water demand grows at an exponential rate of 5 % with socio-economic growth contributing 2.74 %‟. In this scenario, annual water use rate for domestic, commercial and institutional which link to population was assumed to increase at rate of 2.7 % as a result of industrial and socio-economic growth of Tamale. Under the WEAP manage scenario tool, a scenario is added in order to evaluate the impact of: Increasing population growth rate from 2.9 % to 5 % and 2.7 % increase in urban annual water use rate.

4.3.1 Supply Requirement

Figure 4.8 below show water requirement projection base on both scenarios, high population and socio-economic growth, and reference scenario. Though an increasing trend (from 2015 to 2035) of water requirement of both scenarios is observed, it is however noted that, the water requirement for the case of high population and socio-economic growth gives much higher value in 2035 compared to reference scenario; which can be attributed to the couple effect of high population growth rate and increase in annual water use rate resulting from socio-economic development. The total annual water requirement for Scenario 1 is observed to be 1,488 Million cubic meters in 2035 compared to The Reference scenario which has a total annual water requirement of 240 million cubic meter (Figure 4.9).

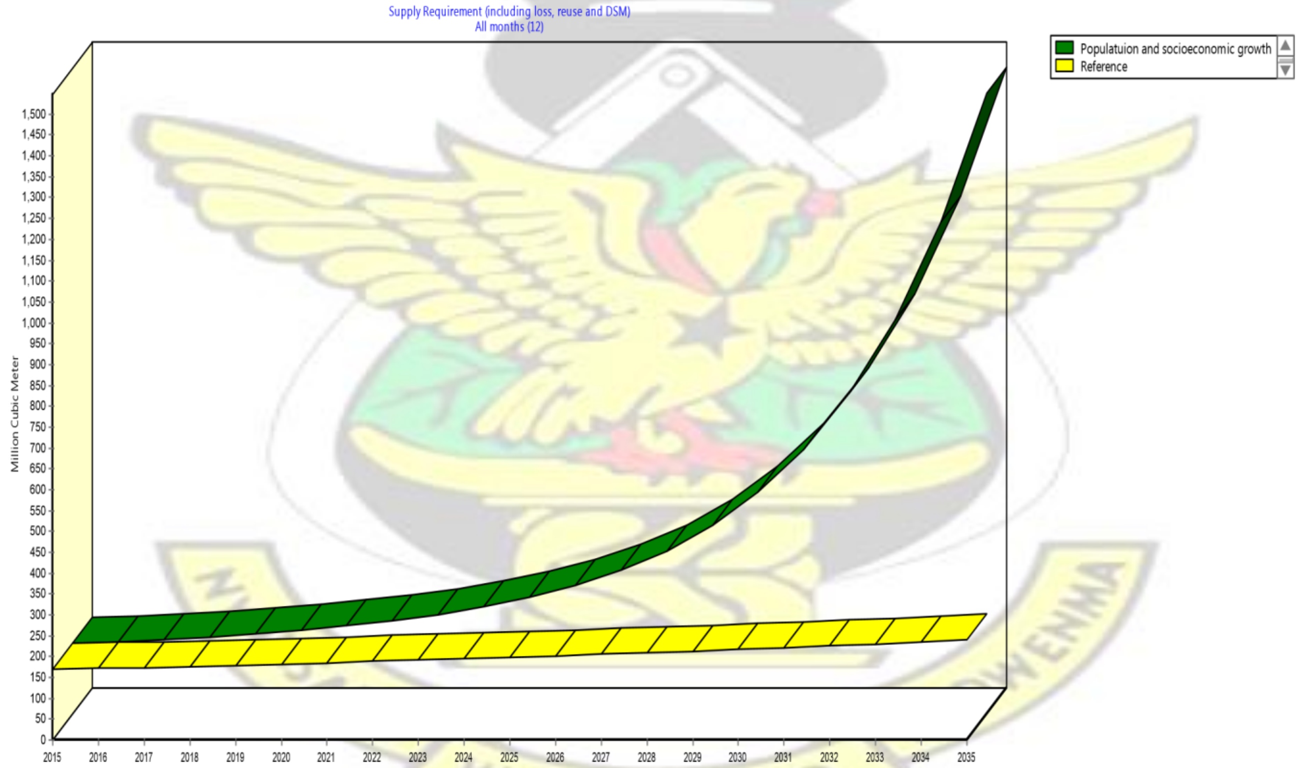


Figure 4.8: Water supply requirement Projection from 2015-2035 for Nawuni Catchment under Reference scenario and Scenario 1: High Population and socio-economic Growth

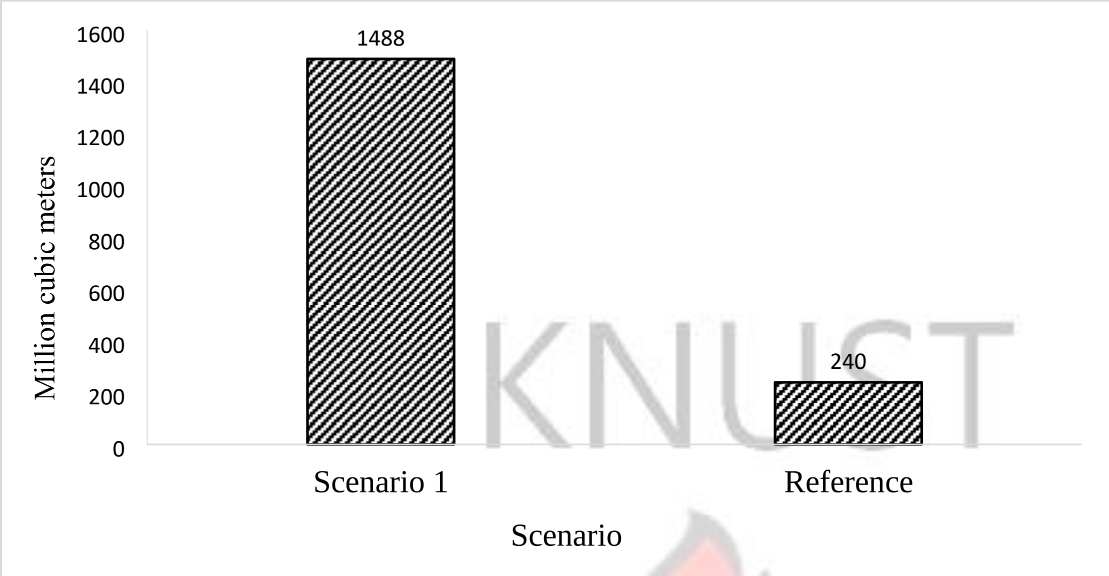


Figure 4.9: Water supply requirement Projection for 2035 for Nawuni Catchment under Scenario 1 and Reference scenario

4.3.2 Supply delivered and un-met demand

For irrigation, livestock, small and large reservoirs‟ demand sites, the supply requirement and supply delivered are the same while supply requirement and supply delivered for urban and rural demand site varies. That is, supply delivered 100 % in all years for all demand sites exception of urban and rural demand site where in some years, there is shortage of supply i.e. supply delivered is less than 100 %. This indicates that under the scenario of high population and socio-economic growth, there will be shortage of water supply within the projected period (2015-2035). Figure 4.10 show total supply requirement and supply delivered for next 20 years.

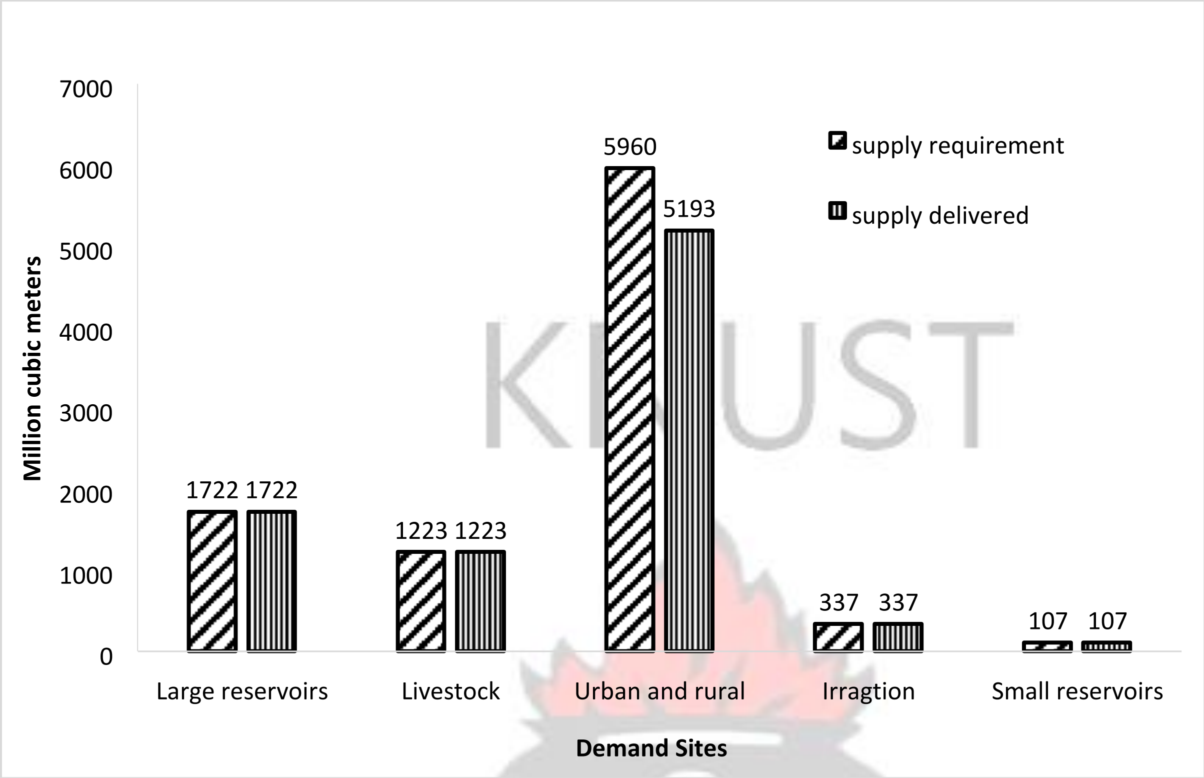


Figure 4.10: Total supply requirement projection for 2035 in million cubic meters

Figure 4.11 indicate the results of unmet demands for the urban and rural water demand site from 2015-2035, generated from the WEAP model. From the results generated it is observed that urban and rural demand site has an un-met demand of 4.1 Million cubic meters for the year of 2032 which increased to 229 Million cubic meters in 2035. The un-met water demands are shown in Figure 4.11

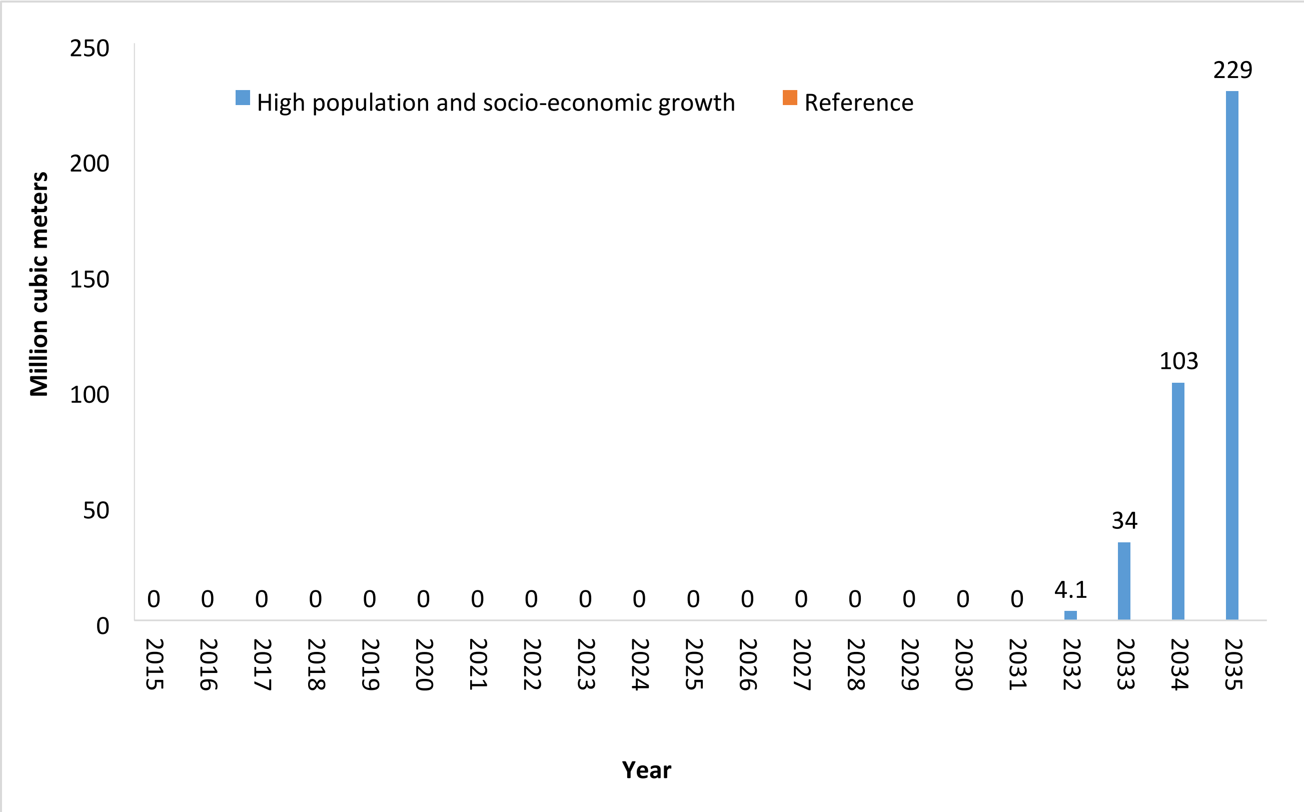


Figure 4.11: Un-met Water Demands (Millions Cubic Meters)

### 4.3.3 Supply reliability

Exception of Urban and rural demand site, all demand sites are fully fulfilled i.e., reliability is 100 % as shown in Figure 4.12. For urban and rural water demand site, reliability is 88 % i.e., 12 % of the demand is not fulfilled.

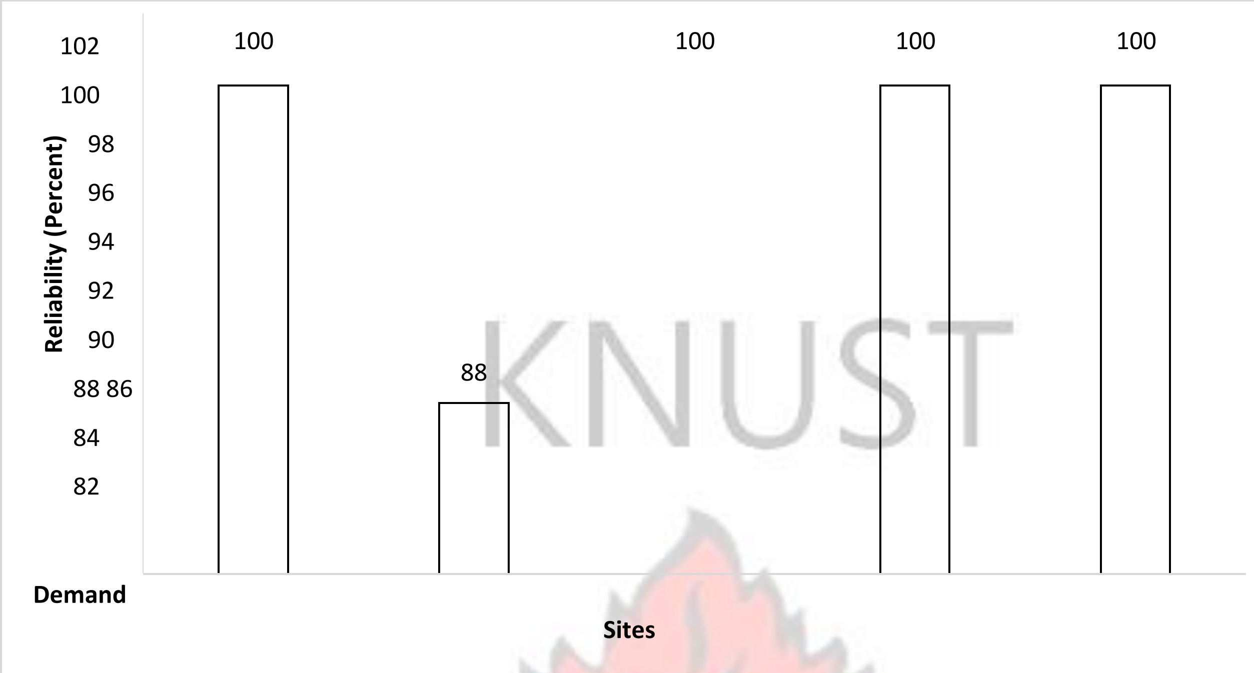

Figure 4.12: Reliability for the Demand Sites

4.3.4 Impact on available water

The impact of scenario one on the available water for supply is shown in Figure 4.13. It is indicated that there is a reduction in the streamflow throughout the year. The highest percentage (38 %) drop occurs in January and February. This is the period of the year where there is high demand for water. There is a total annual drop of 7 % of the streamflow for this scenario. It is also indicated in the figure that, the remaining river flow is lower than supply requirement during the dry season (December to April). This implies that, there will be serious water shortages in the future if water demand increase beyond what is predicted in this scenario. Therefore high population and socio-economic growth have impact on sustainable water supply from Nawuni River for Tamale and environs in the future especially during the dry season as shown in the Figure 4.13.

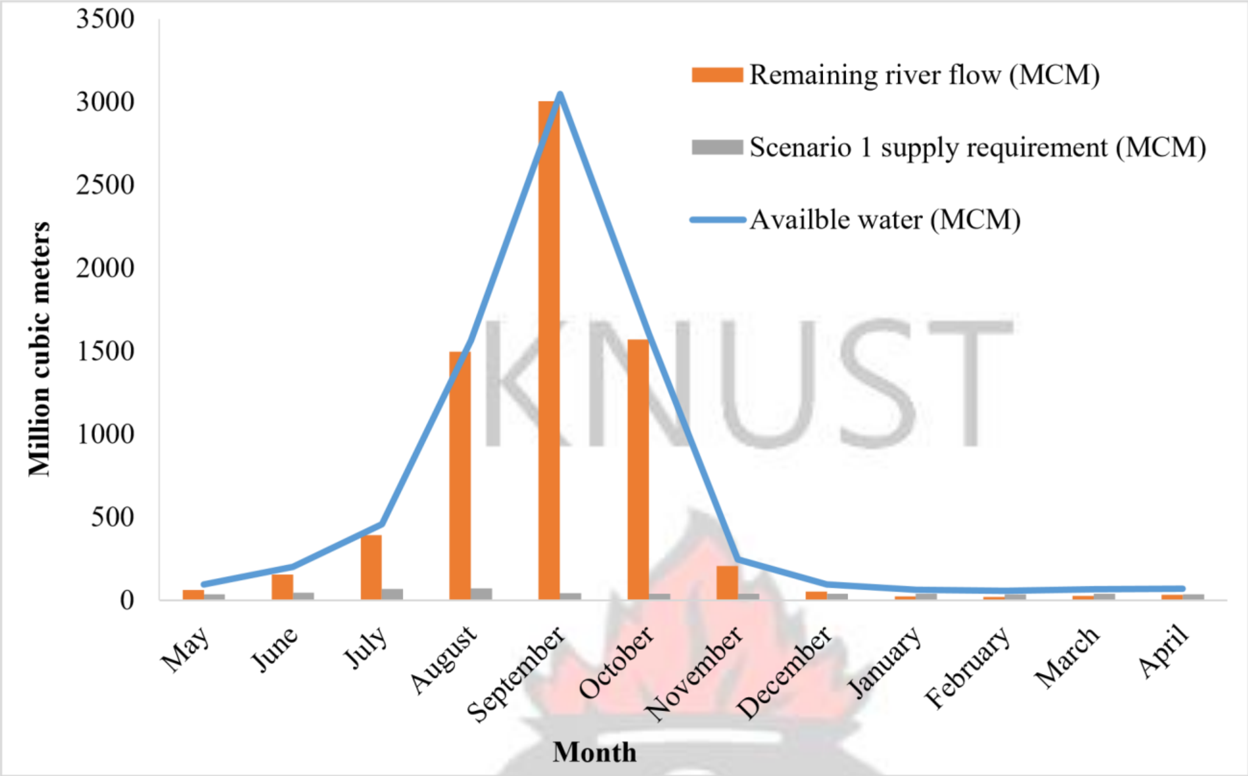


Figure 4.13: Monthly average inflow and outflow under scenario 1 (2015-2035)

### 4.4 Scenario 2: Competing water uses upstream

Due to the competition for water needs and the upstream - downstream effects of growing water uses, this scenario seek to assess the potential impact of intensifying water uses upstream and the possible future effects for sustainable water supply for Tamale Metropolis and the environs. This scenario is added based on the consideration that the current rate of riverine irrigation and small reservoirs development may increase in the future. In order to assess the future implication of this development, scenario named "Intensifying upstream water use" is added to look at the impact of:

- Increasing riverine irrigation rate from 5.6 % to 8 %;
- Increasing small reservoirs growth rate from 1.7 % to 3.1 % per year;
- Implementing the first phase of the proposed large-scale sugarcane irrigation upstream.

4.4.1 Supply Requirement

The water requirement generated for the demand sites for next 20 years is shown in Figure 4.14. It is observed from the figure that water supply requirement for irrigation under scenario 2 increased from 130 to 205 Million cubic meters from 2015 to 2035 compare to reference scenario which increases from 130 to 174 Million cubic meters. The total supply requirements of the reference scenario is 3142 Million cubic meters which increased to 3547 (Figure 4.15) under scenario 2 representing 11 % increase in upstream water use.

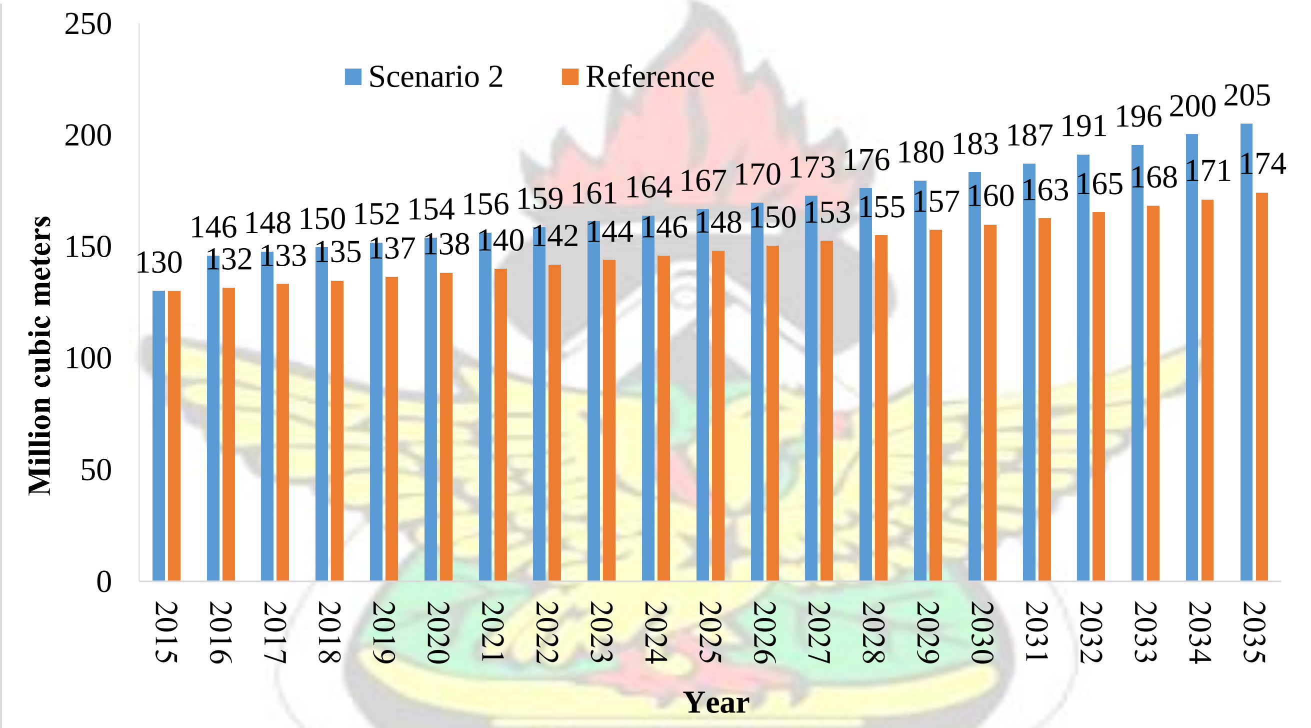


Figure 4.14: Supply requirement Projection from 2015-2035 for Nawuni Catchment under Reference Scenario and Scenario 2: Intensifying upstream water use

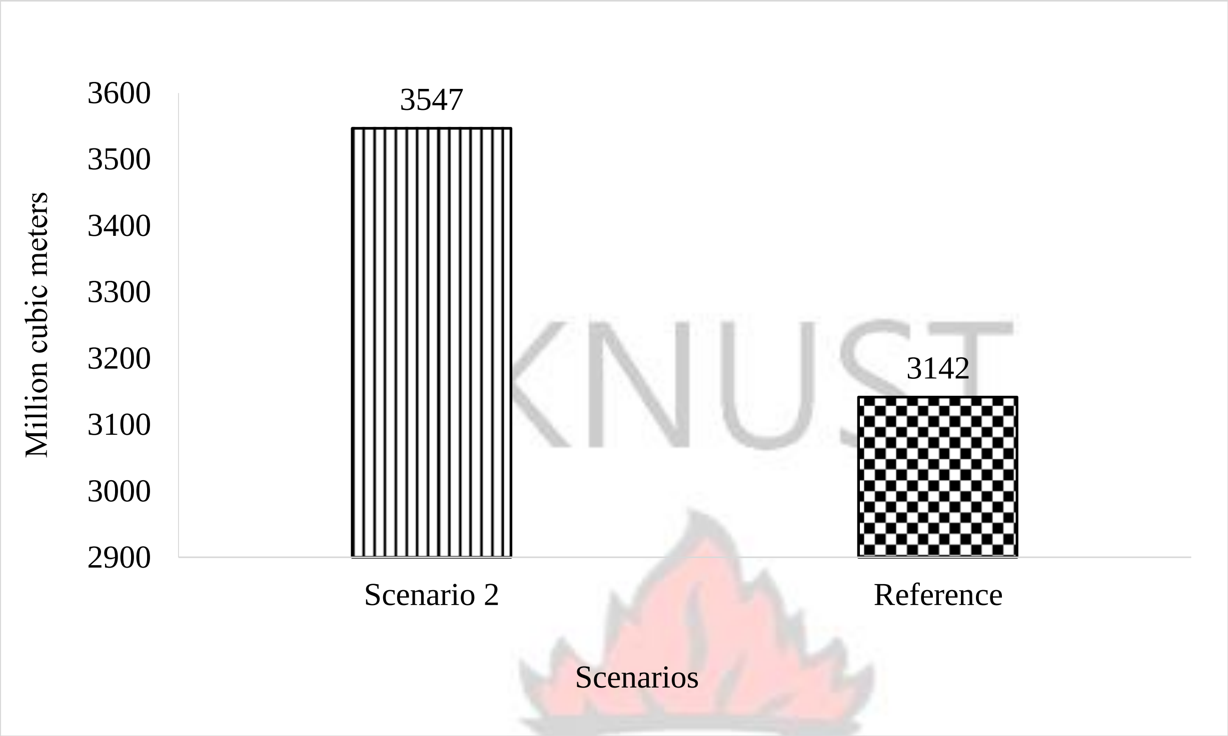


Figure 4.15: Total Supply requirement Projection from 2015-2035 for Nawuni Catchment under Reference Scenario and Scenario 2: Intensifying upstream water use

### 4.4.2 Supply delivered

It is observed from the figure 4.16 that, the supply requirement and supply delivered to the various demand sites do not vary under this scenario; the supply delivered is 100 % for all demand sites in all years. Hence, zero is observed from 2015 to 2035 for unmet demand for all the demand sites, therefore, supply requirement is fulfilled for all demand sites despite intensifying upstream water uses.

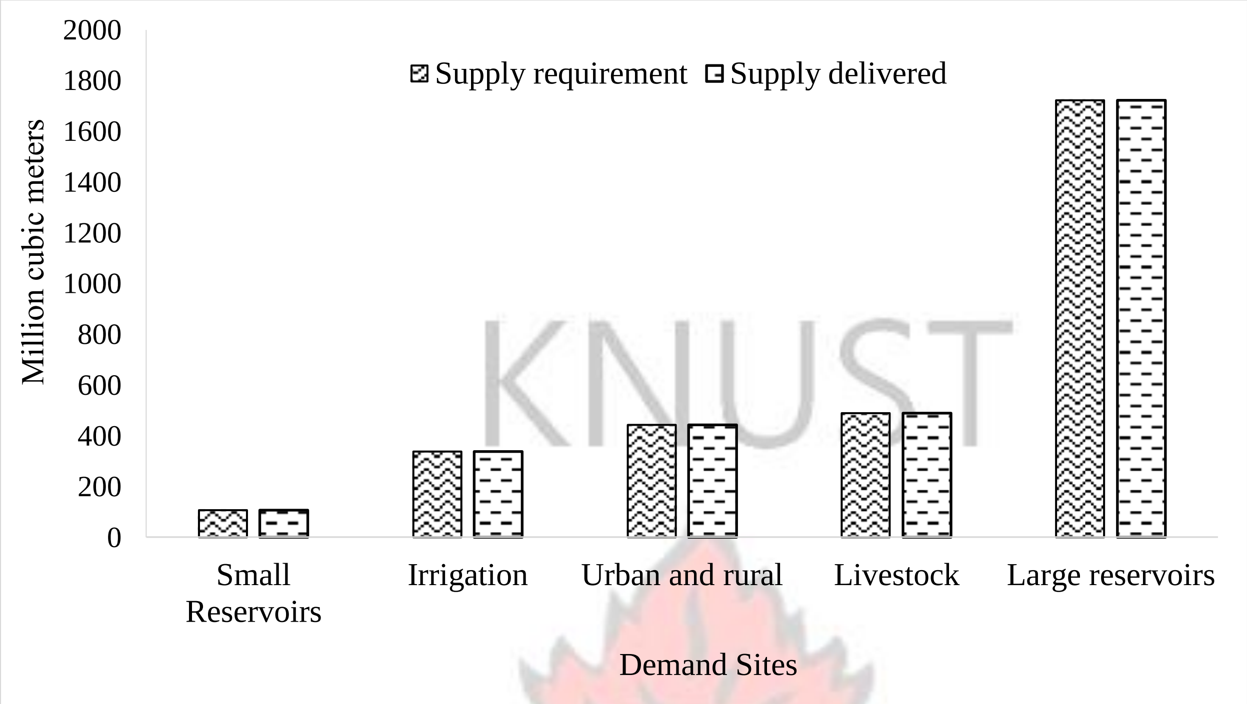


Figure 4.16: Water Supply delivered to demand sites (Million cubic meters).

4.4.3 Impact on available water

The total water abstraction by all demand sites combined from the river could be said to have insignificant effects on the available water flow in the river. As shown in figure 4.17 there is slight reduction in the streamflow throughout the season which represent 2.5 % drop of the total streamflow under scenario 2: intensifying upstream water use. It is also evident in the figure that, the supply requirement is lower compare to remaining river flow for all months. This implies under normal climate condition of scenario 2: intensifying upstream water use as described has no significant impact on the river flow for downstream water use. Hence has no impact on the availability of water supplied to Tamale metropolis and environs.

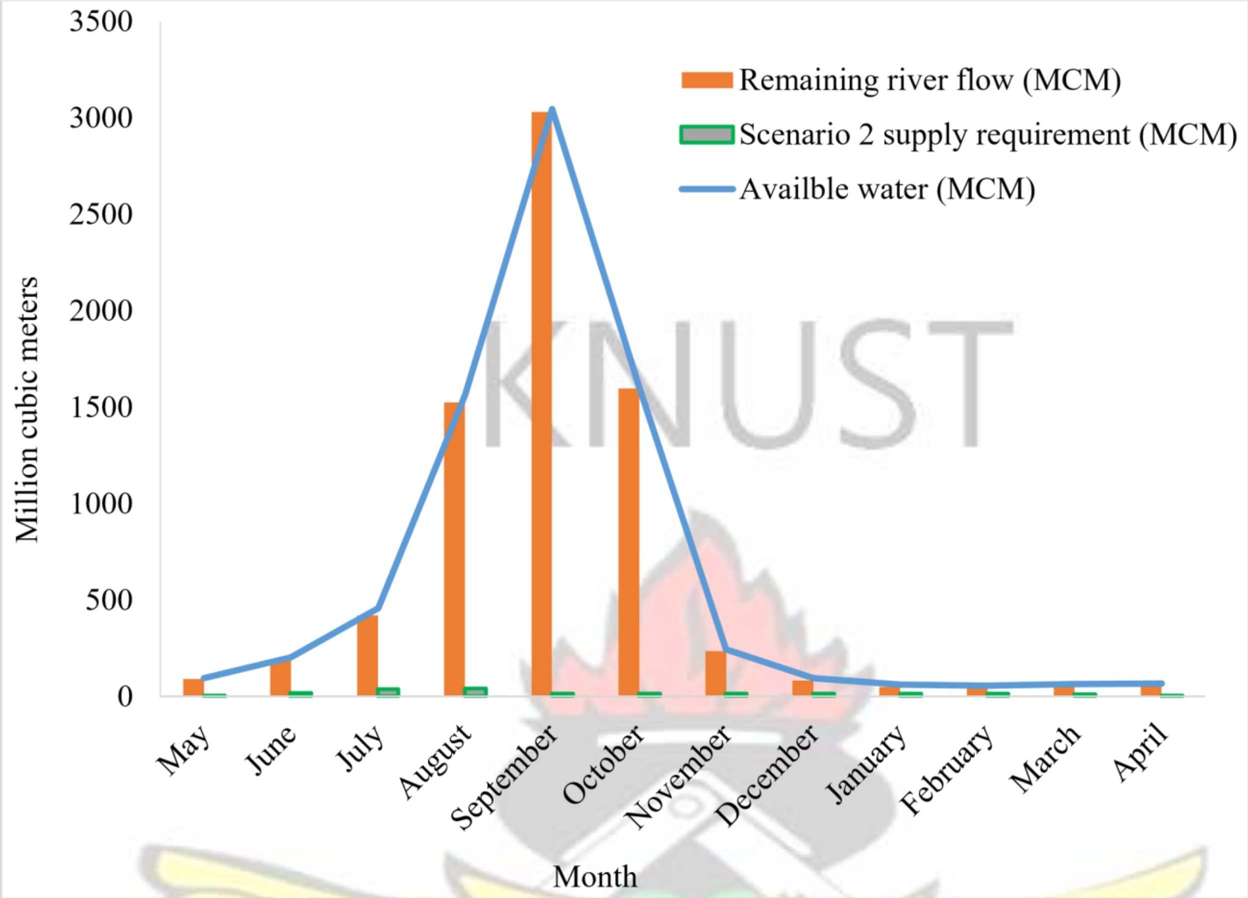


Figure 4.17: Monthly average inflow and outflow at scenario 2 (2015-2035)

### 4.5 Scenario 3: Extended dry climate

The previous scenarios only varied demand and not supply. In order to examine the supply variation and the resources, Water Year Method is used. Water Year Method is a simplified way use to see how variation of natural climate data (streamflow, rainfall) can be considered in WEAP modelling using scenario analyses. The water year sequence created as described in the previous chapter comprises climate variation sequence for the scenario period. The climate sequence is modified and assigned to each of the years of the study period to look at the impact of prolonged drought on water availability for supply. The modified sequence for the Extended Dry Climate is assigned to scenario 3 to look at the impact of drought under each scenario: scenario 1: High population and socio-economic growth, scenario 2: intensifying water use upstream and the Reference scenario so that to evaluate the impact towards water demand and supply. From the results, where scenario 3 is gotten from the scenario 2 (intensifying water use upstream) and Reference Scenario, water demand is said to be fully fulfilled. However, where scenario 3 is inherited from scenario 1: High population and Socio-economic growth, there is shortage of water supply starting from 2030. Figure 4.18 show the results for unmet demand for Extended Dry climate inherited from scenario 1: High population and Socio-economic growth starting from the year 2030.

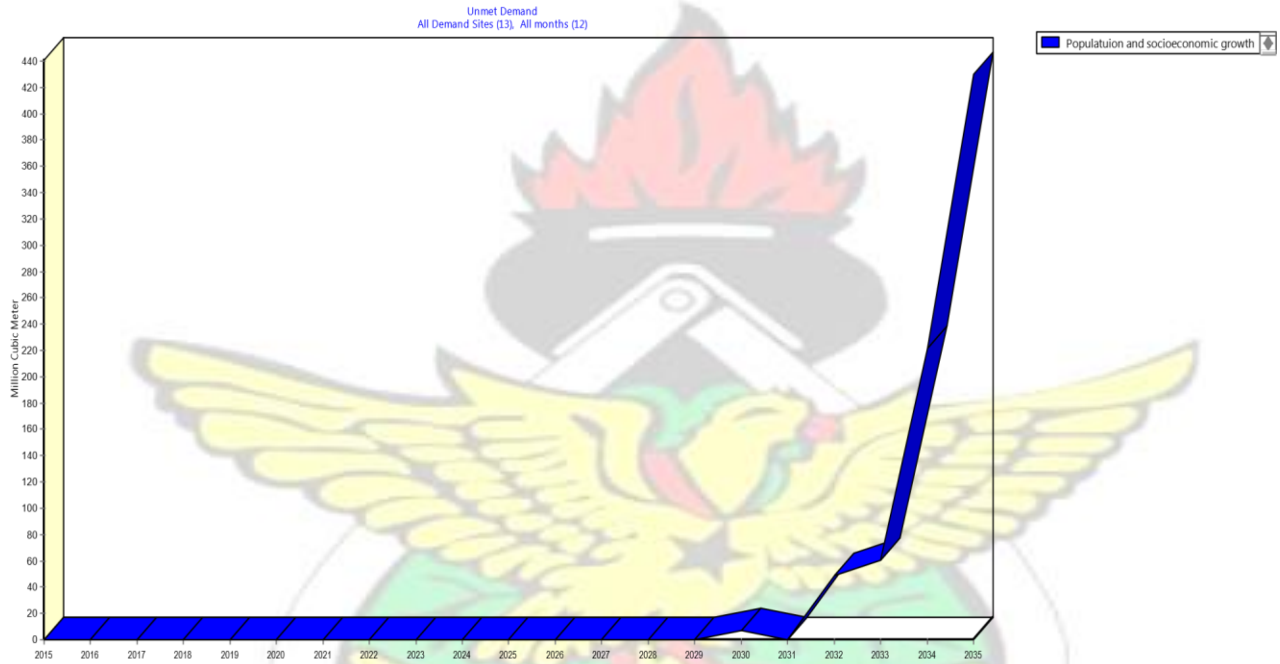


Figure 4.18: The results for unmet demand for scenario 3: Extended dry climate sequence

Table 4.1 shows the results for unmet demand for Scenario 1 and unmet demand for Scenario 1 inherited from Extended Dry Climate. As showed in the table, the values for unmet demand is much higher when Extended Dry Climate occurred under Scenario 1. It is also observed in the table that, there is zero Unmet Demand in 2031, even though there is a rise in demand for water resulting from high population and socio-economic growth. This is because 2031 is a Very Wet year (Table 3.10) where there is an increased in precipitation and headflow to the river which mitigate the increased in demand for water. On the other hand, in the Dry and Very dry years (e.g. 2030, 2032 and 2034) the High population and Socio-economic growth is aggravated by the reduced precipitation and headflow in the river in these years which is indicated by higher values of unmet demand as showed in Table 4.1. This therefore indicated that, unmet demand increased substantially with High population and Socio-economic growth rate for Extended Dry climate.

Table 4.1: Projection of Unmet Demand from 2015-2035 of Scenario 1 and unmet demand of Scenario 1 under Extended Dry Climate Sequence

| *Years* | ***…28*** | ***2029*** | ***2030*** | ***2031*** | ***2032*** | ***2033*** | ***2034*** | ***2035*** |
|---|---|---|---|---|---|---|---|---|
| *Scenario 1* | 0 | 0 | 0 | 0 | 4.1 | 34 | 103 | 229 |
| *Scenario 1 under Dry Climate* | 0 | 0 | 10 | 0 | 54 | 66 | 287 | 342 |

4.5.1 Impact on available water

The impact of Extended Dry Climate Sequence on the streamflow occurring under Scenario 1, Scenario 2 and Reference scenario is shown on the figure 4.19. There is reduction in available total annual streamflow by 10 %, 13 % and 10.14 % for Reference Scenario, Scenario 1, and Scenario 2, respectively, inherited from Extended Dry Climate. The impact of the above scenarios (Reference Scenario, Scenario 1, and Scenario 2) on the available streamflow is therefore exacerbated by extended dry climate. This means prolonged drought has impact on water demand and supply in the future particularly when it is occurred under high demand resulting from population growth and socio-economic development.

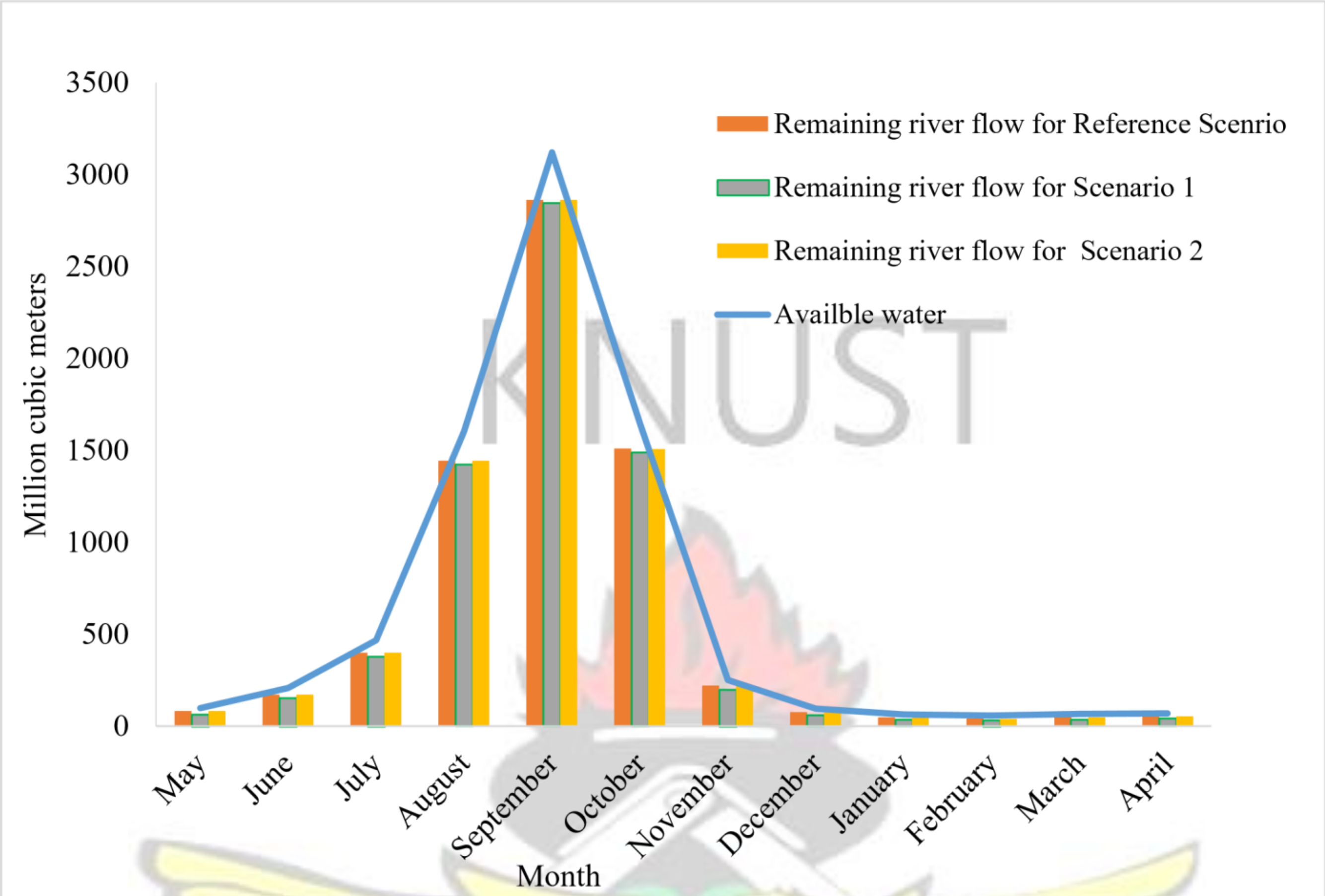


Figure 4.19: Monthly average inflow and outflow at scenario 1, 2 and Reference Scenario for Extended Dry Climate Sequence (2015-2035)

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The overall goal of the study was to assess the sustainability of raw water supply from Nawuni River for Tamale metropolis and environs using Water Evaluation and Planning Model (WEAP). Base on the study conducted, the objectives have been achieved. The assessment was based on current and possible future conditions of demand and supply and how supply source respond or could react to alternative scenarios in terms of increasing demand and natural variation in climate (stream flow, rainfall).

The study considered 20 years from 2015 to 2035 with 2015 being the base year. Current Accounts year (2015) adopts the existing situation of water demand and supply of the study area from which Reference Scenario, a default scenario is generated for the period specified for this study (2015 – 2035). The assessment was based on the following scenario:

- The current account (Year 2015) ⟶ Reference Scenario
- Scenario 1: High population and Socio-economic growth
- Scenario 2: Intensifying upstream water use
- Scenario 3: Extended Dry Climate (Prolonged drought) occurring under each scenario

Based on the result for the base year (2015) and Reference Scenario the available water resources is sufficient up to the year 2035. The results shows zero value for 2015 and 2035 for the unmet demand for various demand sites. However, the assessment made on scenario 1: high population and socio-economic growth, the result showed 229 million cubic meter of Unmet Demand in year 2035 for Urban and rural demand site. This implies that, there will be shortage of water in future if the Scenario of High Population and socio-economic growth occurred. This also had impact on the supply source. There is 7 % reduction in the total annual streamflow in the catchment under Scenario 1.

Based on the Scenario 2, where the potential impact of intensifying water uses upstream and the possible implications for sustainable water supply for Tamale Metropolis and the environs was assessed, the results show 100 % reliability i.e. demand was fully fulfilled. This means intensifying upstream water use as projected in the study do not have impact on the downstream water availability on sustainable water supply for Tamale Metropolis and the environs.

Finally, under Scenario 3, where the supply and resources data was altered using the Water Year Method to look at how natural variation in climate data (stream flow, rainfall etc.) affect Demand and supply. The Water Year Method represent the variation in climate. The climate variation was adjusted to evaluate the impact of prolonged drought on water availability for supply. From the results, where Extended Dry Climate (prolonged drought) occurred under scenario 2 (intensifying water uses upstream) and Reference Scenario, the water demand is said to be fully satisfied. This implies intensifying upstream water use under Extended Dry Climate as projected has no impact on downstream water use.

However, from the results where Extended Dry Climate is inherited from scenario 1: High population and Socio-economic growth, it was observed that, water supply can only accommodate up to 2029. In 2030, there is deficit of supply of 10 million cubic meter which increased to 342 million cubic meter in 2035 under Urban and rural demand site. For the supply source, there was drop in available total annual streamflow by 10 %, 13 % and 10.14 % for Reference Scenario, Scenario 1, and Scenario 2, respectively under Extended Dry Climate.

## 5.2 Recommendations

It is recommended to investigate possible options of water storage reservoir to mitigate the effect of extended dry season. Also a complete study should take into account integrating other factors such as land used change and the groundwater recharge within the catchment. Finally, alternative water sources such as ground water should be considered; so as to serve as a supplement for urban and rural water supply.

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## APPENDIX

Summary of water demand data for WEAP modelling

| **Demand type** | **Activity levels** | | **Annual water use rate** | **Annual total** |
|---|---|---|---|---|
| | **Quantity** | **Units** | | |
| **Urban water supply** | | | | |
| Urban Domestic ($m^3$/p) | 428,412 | People | 32 | 17,136,480.00 |
| Institutional ($m^3$) | 361 | | 3580 | 1,292,380 |
| Commercial ($m^3$) | 1861 | | 746 | 1,388,306. |
| Rural Domestic ($m^3$) | 171,074 | People | 13 | 2,223,962 |
| **Livestock watering ($m^3$/unit)** | | | | |
| Cattle | 600,000 | Livestock units | 25 | 15,000,000,000 |
| Small ruminants | 15,00,000 | Livestock units | 2 | 3,000,000 |
| **Irrigation water demand ($m^3$/ha)** | | | | |
| Nangodi | 184 | Hectares | 7,542 | 1,387,728 |

| | | | | |
|---|---|---|---|---|
| Dinga (Diare) irrigation | 115 | Hectares | 1,304 | 1,500,000 |
| Sogo irrigation | 151 | Hectares | 9,934 | 1,500,000 |
| Dipali irrigation | 148 | Hectares | 10,135 | 1,500,000 |
| Savulugu irrigation | 165 | Hectares | 8,471 | 1,397,760 |
| Nawuni irrigation | 65 | Hectares | 7,542 | 490,200 |
| **Reservoirs ($m^3$)** | | | | |
| Small reservoirs | 239 | | 18000 | 4,202,000 |
| Tono (large reservoir) | 1 | | 67 | 67 |
| Vea (large reservoir) | 1 | | 15 | 15 |

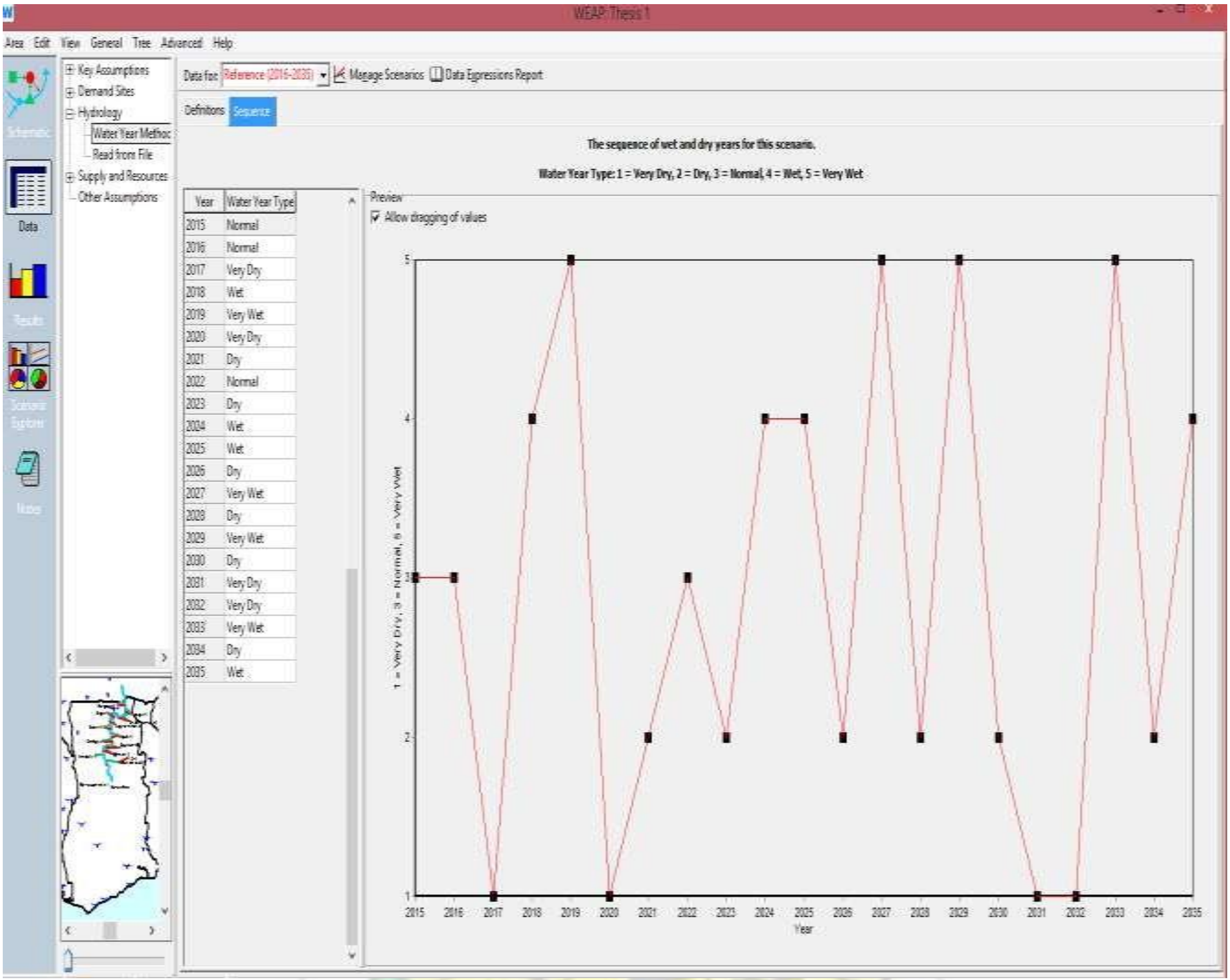
Water Year Sequence estimated from historical rainfall from 1987 to 2015

| ***Year*** | ***Water Year Type*** |
|---|---|
| *1987 1988* | Dry |
| *1989 1990* | Normal |
| *1991* | Very wet |
| *1992* | Wet |
| *1993* | Very wet |
| *1994* | Very dry |
| *1995* | Dry |
| *1996* | Wet |
| *1997 1998* | Dry |
| *1999 2000* | Wet |
| *2001* | Wet |
| *2002* | Dry |
| *2003* | Very wet |
| *2004* | Dry |
| *2005* | Very dry |
| *2006* | Very dry |
| *2007* | Wet |
| *2008* | Dry |
| *2009* | Wet |
| *2010* | Very dry |
| *2011* | Normal |
| *2012 2013* | Very wet |
| *2014* | Normal |

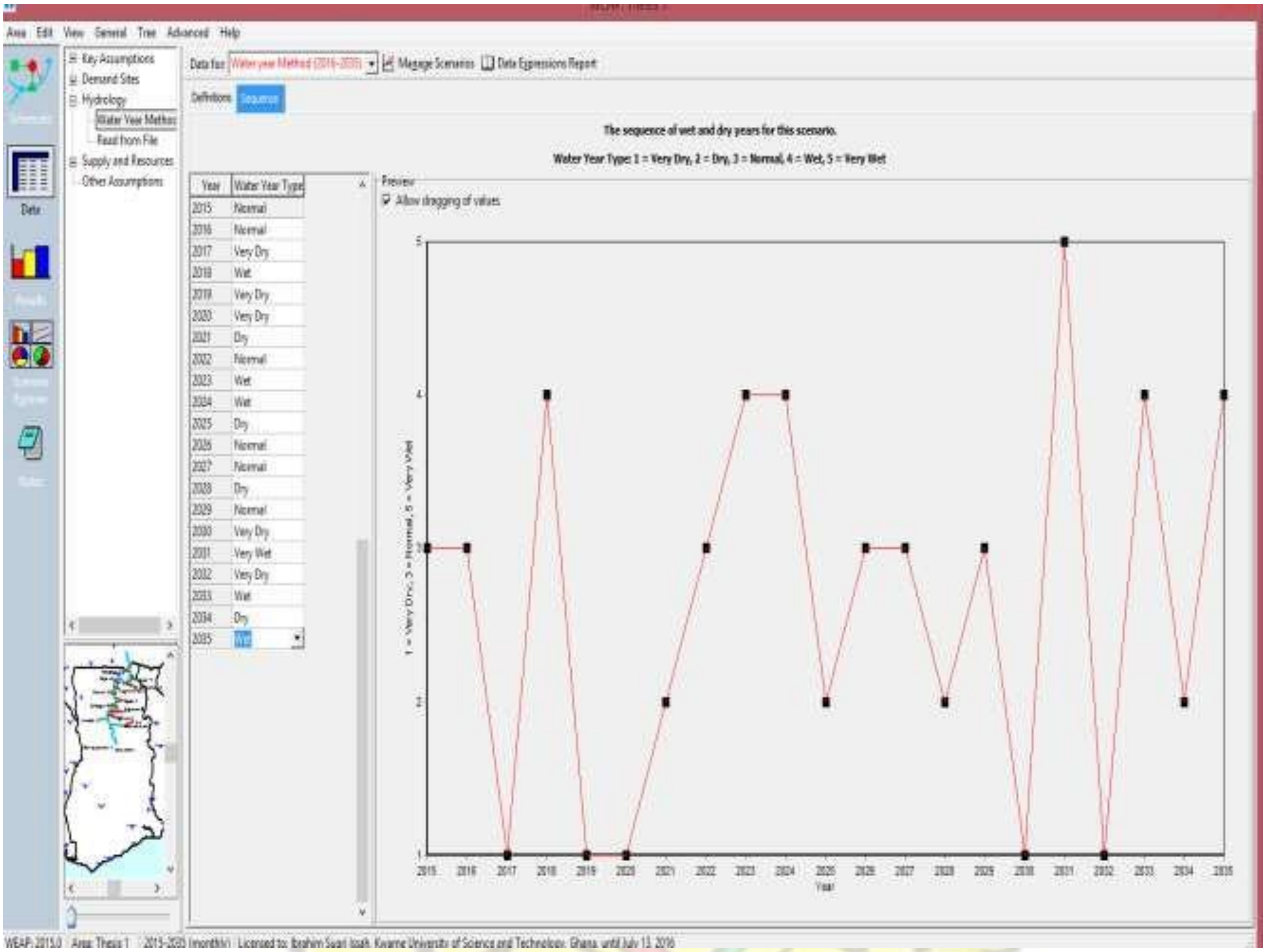
| | |
|---|---|
| *2015* | Very wet |
| | Normal |
| | Normal |
| | Very dry |
| | Normal |
| | Very dry |



Water year sequence for Reference scenario




Water year sequence for extended dry sequence




The Overall Results Generated by the Model Up to Year 2035


Data Variables
Scenarios
Reference
High population and economic growth
Intensifying upstream water use
Water year Method
Data
Results
Reference
High population and economic growth
Intensifying upstream water use
Water year Method