ASSESSMENT OF WATER AVAILABILITY UNDER THE INFLUENCE OF CLIMATE VARIABILITY IN GORONYO RESERVOIR, SOKOTO STATE, NIGERIA

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

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DECLARATION

I declare that the work in this dissertation entitled "**Assessment of Water Availability Under the Influence of Climate Variability in Goronyo Reservoir, Sokoto State, Nigeria**" has been performed by me in the Department of Water Resources and Environmental Engineering. And all the literature consulted is duly referenced. No part of this dissertation was previously presented for another degree at this or any other Institution.

Lukman Adesile MUHAMMED ____________ ___________

P16EGWR8032 **Signature** **Date**

CERTIFICATION

This dissertation entitled **“ASSESSMENT OF WATER AVAILABILITY UNDER THE INFLUENCE OF CLIMATE VARIABILITY IN GORONYO RESERVOIR, SOKOTO STATE, NIGERIA”** by **Lukman Adesile MUHAMMED** as required by the governing body for the award of Master of Science in Water Resources and Environmental Engineering.

Prof. (Engr.) A. Ismail ____________ ___________
Chairman Supervisory Committee Signature Date

Dr. B. K. Adeogun ____________ ___________
Member Supervisory Committee Signature Date

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Head of Department Signature Date

Prof. Sani A. Abdullahi ____________ ___________
Dean, School of Post Graduate Studies Signature Date

DEDICATION

This work is dedicated to Almighty Allah, Mohammed’s Family, and my loved ones.

ACKNOWLEDGEMENTS

Utmost gratitude to Almighty Allah (the creator of the universe, living and non-living things) for providing the ability, good health, and resources to perform this study. May the peace and blessings of Allah be on the noble Prophet, Muhammad (SAW).

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ABSTRACT

Climatic parameters are exposed to variation due to the atmospheric concentration of greenhouse gases. Hence, it is essential to assess the water availability and demand under the climate variation in Goronyo Reservoir, Sokoto State Nigeria. since the supply of water is one of the significant tasks in water resources management. In this study, estimation of available water, demand, and unmet demand was simulated using Water Evaluation and Planning (WEAP) Software with the opinion of assessing the availability of water for its uses under climate change, The Reservoir is situated in Goronyo Local Government Area, Sokoto State, Northwest Nigeria. The study uses Water Evaluation and Planning (WEAP model) software to assess the influences of climate variability on the water availability of the area. This model allows simulation and analysis of various scenarios and water allocations. The water availability, Demand, Supplies, and Unmet were modeled with climatic data and water use rate. The model was satisfactorily calibrated and validated. Simulations were proposed for various climatic situations considering global climate change model (GCM) predictions and the linear trend of the data. Nine (9) selected climate change scenarios of temperature increases (i.e. 0, +0.4, +0.8, +1.2 oC) combined with an increase or decrease in rainfall (0, -10%, +10%) were applied for the study area in the WEAP model software for simulation. The model was used to analyze the linkage between water availability and demand for domestic and irrigation uses. This was projected to the future to analyze what would happen in years to come up to 2070. The demand and unmet were obtained as the output of the model. Results showed that the mean average volume of 737.9 million cubic meters (MCM), the maximum average volume of 824.3 MCM mainly in the wet period ranges from May – October, and the minimum mean average volume of 546.6 MCM mostly in a dried month i.e. April available in the reservoir. The annual total demand for various uses from 2018 to 2070 was obtained to be 7069.4 MCM and the annual average of 133.4 MCM. Meanwhile, the unmet demand was with annual total ranges from 1157.5 MCM to 1199.7 MCM and an annual average of 21.84 MCM to 22.64 MCM. The highest unmet was recorded under Scenario 9 with a 1.2 ^{o}C increase in temperature and a 10% decrease in precipitation. In Conclusion, it was found that the demand in the area is 6 times higher in years to come i.e. 50 years from now and the deficit is 61% increased. It is recommended that the irrigation system (furrow irrigation system) should be improved to minimized water demand and also extraction from other means such as groundwater could relieve the stress on the available source, the reused of wastewater for other domestic uses such as the washing of lawn and watering of gardening will also help a lot in utilizing limited available resources.

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Abbreviations

IWRM	Integrated Water Resources Management
WMO	World Meteorological Organization
RCM	Regional Climate Model
GCM	General Circulation Models
OGCM	Oceanic General Circulation Model
AOGCM	Atmospheric – Oceanic General Circulation Models
MCM	Million Cubic Meters
GRIP	Global Rice Science Partnership
AGCM	Atmospheric General Circulation Models
WHO	World Health Organization
FAO	Food and Agricultural Organization
SEI	Stockholm Environmental Institute
ITCZ	Inter-Tropical Convergence Zone
IPCC	Inter-Governmental Panel on Climate Change
SCN	Scenario

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The most important element or component to life on earth is water, often it is a scarce /rare resource that is ultimate for living. It is most imperative and fundamental in many parts of the universe for both domestics and agricultural uses, the means to accomplish and achieve sustainability in production systems. It is crucial to maximizing net return with the resources available but this could be regarded as a complex problem because of factors that affect this process, for example, climatic variation, the configuration of irrigation system, subsidy policies, and costs of production. Numerous districts are confronting daunting freshwater management difficulties, distribution of limited water resources, ecological quality, and policies for maintainable or sustainable water use are issues of expanding concern (Uitto, 2004; Conway et al., 2009).

The human population is fast-growing, the fast advances made in the industry and agriculture have brought about a rapidly expanding or increasing utilization of water by man, to the degree that water availability as well as, the control of unnecessary water use has become an important issue in the advancement of districts of the world (Williams, 2010). Over the last years, it has been established that supply management is inadequate in solving the massive competition for water with increasing per capita water use, population increment, urbanization, pollution, and storage (Wang et al, 2009). Similarly, UNESCO (2006), established that the requirement for various uses such as municipal, industrial, farmland, and supply is increasing, yet lack of demand management policies implies that increasing demand will likely exceed the supply available, thus water shortage.

The term climate is regularly referred to as the normal weather condition of a place over an extensive period. Likewise, in a detailed form, as the statistical explanation in terms of the mean and variability of pertinent amounts over some time extending from months to thousands or a huge number of years. The usual time frame is 30 years, as characterized by the World Meteorological Organization. The Intergovernmental Panel on Climate Change (IPCC) built up the variation of the earth temperature for as long as 140 years (Abdullahi et al., 2014)

The fourth evaluation report of IPCC demonstrated that the temperature during 1995-2006 at the global level has increased and the occurrence of hefty precipitation became more recurrent. Additionally, the global average surface temperature as forecasted for 2080 – 2099 will ascend between 1.1^{o}C and 6.4^{o}C greater than what it was from 1980 - 1999, and this leads to an increase in crop productivity (IPCC 2007). It evidently illustrates the effect of variation in climate. The most advanced tool to simulate the global climate system response to greenhouse gas concentrations is General Circulation Models (GCMs), with models, an assessment of the future climate would be possible (Yang et al., 2011; Hsu et al., 2011), and the issue of uncertainty may be moderated by considering multiple models (Liu, et al., 2009; Huang, et al., 2012). In accordance with some literature, there will be additional problems as regards the management of water resources because of differences in rainfall distribution and increase in temperature as a result of a change in the climate. climatic variation increases changes in atmospheric conditions and thereby changed water resources, their circulation in space and time, the hydrological cycle of water bodies, and water quantity. The water cycle is altered by climate change, but due to the complexity of the hydrosphere in the Earth system, it is challenging to predict how precipitation patterns might go.

According to Abdullahi (2014), the people living in Sokoto consider rivers and streams within the basin as a significant source of surface water for their municipal and agricultural demands. Consequently, even a small reduction in runoff within the watershed could have dramatic effects on the welfare of the region. climate variations will bring about a quick increase in the surface temperature, alterations in the pattern of precipitation, and evapotranspiration rates (Vicuña *et al*., 2011).

Modeling and investigation techniques for assessing the water distribution competencies of reservoir/river systems are essential to the proper management of the highly variable water resources of a watershed. The use of hydrologic and institutional is paramount in evaluating the availability of water and the soundness of such appraisals (Sieber *et al.,* 2002).

WEAP is an acronym for water evaluation and planning model is a software model for integrated water resources planning which operate on the basic principle of the water balance equation, it is a water evaluation and planning system developed by Stockholm Institute which provides capabilities for comparing water demands and supplies as well as forecasting demands. It has an accessible interface and transparent data structure that make it suited as a tool for delibrations between a diverse group of stakeholders (SEI, 2007).

WEAP is a generic computer tool that is suitable mainly for water surface water planning, it doesn’t take into consideration groundwater input, though improvement is being made over time to increase its suitability, however, because of its generic nature, it is not capable of capturing every fine distinction of water resource system.

The requirement of various water demands would be affected by the variation of meteorological events under the conditions of climatic variability, the reservoir which was constructed to cater for flood control, water supply, recreation, fishing, and so on. This research work is to assess the impact of climate variability on water availability for various usage in Goronyo Reservoir, Nigeria.

1.2 Statement of The Research Problems

Climatic parameters are exposed to variation due to the atmospheric concentration (the composition) of greenhouse gases. These lead many researchers to carry out studies on the influences of climatic variability on various water usage or demands since the supply of water is one of the most significant tasks for water management. An impact evaluation of water demand under climate change is essential.

The countless country is experiencing alarming problems in terms of managing their freshwater. Apportionment of these limited resources, environmental nature, and strategies for usage sustainability are concerned issues. Therefore, it is of utmost importance to study the present and future condition of Goronyo Reservoir under the influence of climate change to come up with strategies to ensure future availability to cater to the water demand.

Climate change cause rises in world temperatures which leads to an increase or exacerbation of the hydrological alternation, resulting in severe or harsh dry periods and wetter periods, also, more recurrent severe events. European Environment Agency, reported that the eminent side effect associated with water resources are temperature increment, alteration in the pattern of precipitation, and the probable rise in prevalence of droughts and flooding. Alterations in precipitation are anticipated to vary from one part to another with some regions becoming wetter and some dryer. A warming climate will affect water availability or quantity in different cities or regions of the world. For instance, as predicted by climate models, Northern part of the country (Nigeria), there will be a reduction in streamflow per annum and lake levels. In some locality, extreme persistent heavy rainfalls may result or cause local flooding.

Activities that rely upon tremendous extraction of water for utilization for example, industrial, agricultural and domestic consumption will be affected by climate variation due to changes in flow regimes and reduction in annual water availability. Poor management and/or allocation of water resources may result in conflicts among users during water shortages in the dry season and or drought periods, especially during scarcity.

1.3 Aim and Objectives

1.3.1 Aim

To assess the impact of climate variability on the Goronyo Reservoir for both current and future water availability Using WEAP Software

1.3.2 Objectives

a. To estimate the available water in the study area (Goronyo Reservoir)
b. To determine water demand for various uses such as domestic and agricultural uses
c. To forecast water availability in the area of study under climate change influences.

1.3 Justification

Assessment of water availability in reservoirs will enable effective planning and management of water resources, especially during the dry season/period. This will thereby reduce the water crisis in the area. Meanwhile, climate variability is expected to worsen the crisis in the water among users, especially during the dry season (Yilmaz, 2015).

Goronyo Reservoir has been known to provide water for both domestic and agricultural purposes, the research work will therefore provide an estimate of how much more or less water will be available in the reservoir or required from the reservoir by water users if the climate is varied or changed by specified or prescribed amounts.

This research work would provide the necessary information on water availability, demand, and unmet demand in the area and this knowledge will help to come up with mitigating measures to be adopted to ensure continual availability of water in the area. For instance, initiation of effective allocation of water for different purposes to prevent conflicts that may arise particularly during scarcity.

1.4 Scope of the Study

This research is limited to the assessment of the influences of climate variability on water availability in Goronyo Reservoir, Sokoto State, Nigeria using the WEAP software model. Hence, this study does not assess the impact of climate change on groundwater and water quality.

1.5 Limitation

The availability of observed data was a major problem because the study area is situated in a remote area. The Dam operator made it clear that the equipment might be tampered with because no security measure was put in place.

CHAPTER TWO

LITERATURE REVIEW

2.1 Climate

A simple definition of climate is the average weather condition of a place. A description of climate over a period (which could be from few years to few centuries) encompasses the averages of appropriate compositions of the weather during that period, together with the statistical variations of those components (IPCC, 1990). Climate is defined in terms of 30 years means, and higher-order moments about those means. It can also be described as the statistical explanation in terms of the mean and variability of meteorological variables such as temperature, rainfall, and wind over a period of time spanning from months to thousands or millions of years, but the usual period is 30 years, a definition given by World Meteorological Organization (WMO, 1988).

2.1.1 Climate system

The Climate system comprises water on and below the earth, snow, ice, rock, soil, plant, animals, and humans which are further categorized as atmosphere, cryosphere, lithosphere, and biosphere. Which under the influence of solar radiation accepted by the earth, determines the climate of the earth surface, although climate relates to the different states of the atmosphere, only the other portion of the climate system also have important roles in forming climate through their associations with the atmosphere (WMO, 1992). The seasonal and geographical distribution of global climate is dependent on combined interaction between the various part of the climatic system (Miller et al., 2005). The additional illustration is in figure 2.1.

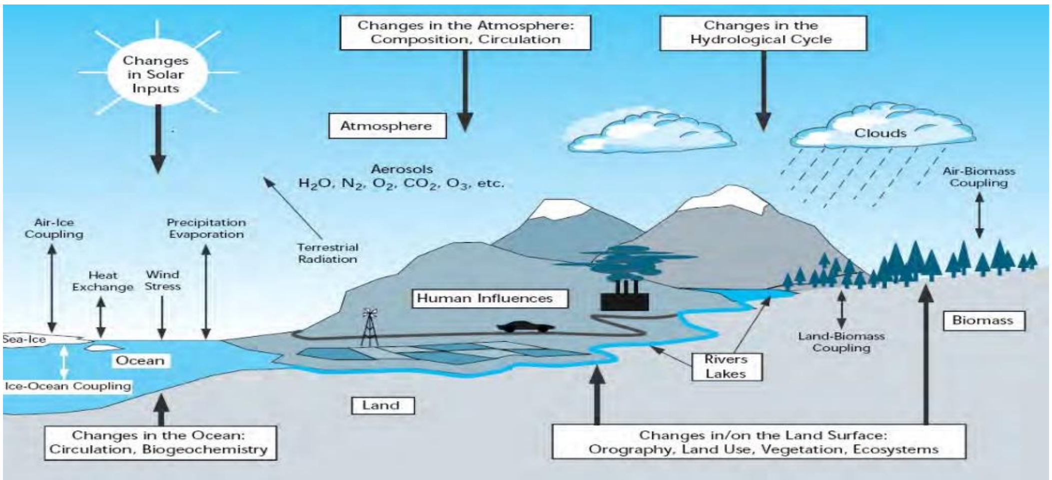


Figure 2.1: Graphical Illustration of the Components of Climatic System

(Source: Miller et al., 2005)

2.1.2 Climate change and climate variability

Climate change occurs as a result of alterations or modifications of the earth's climatic system over a space of time as a result of either natural variability or man-made (IPCC, 2001). On the other hand, UNFCCC (1992) defined change in climate as any alteration in the weather that is caused either directly or indirectly by human activities which change the constituent of the atmosphere coupled with another natural variability that occurred over a longer period. Mitchell et al. (1966) referred to climate change as all forms of climate instability irrespective of their statistical nature or physical causes.

Climate changes are normally classified as long-term, short-term and fluctuations based on the time scale, climate changes happening over time scales higher than or within those found with the orbital forcing frequencies of between 41,000 and

9,508,000 years are known as long-term, climate changes happening for time scales shorter than those found with the orbital forcing frequencies are classified as short-term; while climate abnormalities on time scales less than 100 years are referred to as climate variability (Matondo et al, 2004). The climate experience changes if there exist alteration in climate variable such as temperature (IPCC, 2007), the United States

Agency for International Development (USAID, 2007), reported that while climate variation affects the whole world, the resultant changes would not be the same globally; there may be noticeable variations at country levels, climate change causes a big challenge to Africa’s economic growth, long-term prosperity, and the living of the already susceptible people.

In contrast, climate variability is defined as the fluctuation in the mean state and other statistics of the climate on all temporal and spatial scales that exceeds that of individual weather events. The variations occur as a result of either natural processes or external forces (anthropogenic). Climate variability can cause sudden changes, such as floods, droughts, or tropical storms. These changes can make great impacts on a country’s economy especially when the larger portion of the economic growth depends on weather and climate. the influences of climate variability and change have a higher effect on the less privileged in developing countries than those living in more developed nations (USAID, 2007).

2.1.3 Global climate change

It was reported that the global mean surface temperature has already risen by about 0.07^{o}C per decade in the past centuries (IPCC, 2007). The increase has been more significant (about O.18^{o}C per decade) in the last 25 years, in which decade (2001-2010) was reported as the warmest decade on record. The average temperature in that decade was higher than 1961-1990 mean by 0.46°C, and it was higher than the (1991-2000) decade by 0.21°C. However, 1991-2000 was also wanner than the decades before it, consistent with a long-term warming trend (WMO, 2011).

“However. due to prevailing global warming, mountain glaciers and snow cover have declined in both hemispheres”. The universal average water level (sea level) has been rising since 1961 at a mean rate of 1.8 mm/yr. and it was at 3.1 mm/yr. in 1993., in which the expansion is due to heat, melting glaciers, ice caps, Greenland and Antarctic ice sheets play a great role, causing the sea level rise (IPCC, 2007). Moreover, in the eastern regions of South and North America, northern Europe, and northern and central Asia. a noticeable rising in rainfall has occurred. This occurrence of intense precipitation events has risen over most areas which are accompanied by warming and an increase in atmospheric water vapor. However, there has been some rainfall deficit in the Sahel, the Mediterranean, Southern Africa, and parts of southern Asia (IPCC, 2007).

The African Ministerial Council on the Environment (AMCEN, 2011) reported that widespread changes in extreme events occur. It started that, cold days, cold nights, and frost occur less frequently, while hot days, hot nights, and heatwaves occur more frequently, more severe and persistent droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics.

2.1.4 Climate variability and change in Nigeria

(Hengeveld et al., 2005) provided the criteria that can be applied to study evidence of climate change in a region. These include: upward in temperature, rising evaporation, reduction in the quantity of rainfall in the continental interiors, rising rainfall in the coastal region, increasing changes in climate patterns, and increasing rate and severity of extreme weather-related events for example; thunderstorms, lightning, floods, landslides, drought, unpredictable rainfall pattern, sea-level rise, increasing desertification and land degradation, evaporation, loss of forest cover and biological species which have been confirmed to exist in Nigeria. Moreover, the additional proof of climate change in Nigeria is the rise in rainfall quantity in the coastal areas since the 1970s, and a continuous decrease in precipitation amount and length in the continental interiors of the semi-arid region of Nigeria. The rise in precipitation in the coastal areas could be the major cause of floods affecting the coastal cities of Warri, Lagos, Calabar, and Port Harcourt as observed by Ogundebi, 2004; Ikhile, 2007; Nwafor, 2007; Umoh, 2007; Odjugo, 2010, Moreover, Odjugo (2005; 2007) also found that the number of rainy days has reduced drastically in northeastern Nigeria and in the Niger Delta coastal areas. These two changes in climate patterns are proof of the existence of changing climate in Nigeria.

FME (2011) reported that the Nigerian Meteorological Agency in 2008 studied the Nigerian Climate from 1941 to 2000 periods and observed the following changes:

(a) Rainfall: With past periods, from 1941 to 2000 periods, there was late-onset and quick cessation of rainfall, which shortened the length of the rainy season in various parts of the country. From 1941 to 2000, annual rainfall dropped by 2-8 mm across most parts of the country but increased by 2-4 mm in a few places (e.g. Port Harcourt).

(b) Temperature from 1941 to 2000. the long-term temperature increase was observed in most parts of the country. The main evaporation was in the Jos area, where a slight cooling was recorded. The most noticeable increases were recorded in the farther northeast. Extreme southwest and extreme northwest where the average temperature rose by 1.4 – 1.9 °C.

Additionally, (Odjugo, 2010) reported that the temperature in Nigeria has risen between 1901 and 1970. The mean air temperature between 1901 and 2005 was 26.6 °C while the rise in temperature for 105 years was 11°C and rainfall has also declined. The rising temperature and falling in Rainfall in the semi-arid region of Sokoto, Kastina, Nguru, and Maiduguri may have led to the rising evaporation, drought, and desertification in

Nigeria as informed by (Odjugo and Ikhuoria, 2003); (Adefolalu, 2007).

Additionally, the loss of forest and biological species constantly in Nigeria is related to global warming and climate change (Ayuba et al., 2007). Nevertheless, the study carried out by (Omojola and Fasona, 2005) on climate variation, human safety, and communal clashes in Nigeria conveyed that all the stations in the Sahel region recorded the greatest rainfall during 6 decades (1941 -2000) periods. The greatest rainfall was recorded in the 1950s and the least was linked with the 1980s from the total decadal mean. The resultant change in land cover between 1976 and 1995 revealed the loss of prime arable lands due to climate change.

2.1.5 Impacts of climate change

The impacts of climate change could be on natural as well as human systems. The difference between the potential and lingering impacts can easily be recognized based on adaptation consideration (IPCC, 2001). Potential impacts refer to the effects that may occur as a result of the forecasted climate variation without considering adaptation; while residual (lingering) impacts refer to the effects of change in climate that would occur after adaptation (Levina et al., 2006). The various influences of climate change are droughts in some areas while flooding in others affecting agriculture, food security, and properties. Leading to changes in both surface and underground water supply and devastating ecosystems amongst others (Sawa et al., 2011). Also, according to the report by (USAID, 2007), the impacts of climate change include: rise in Sea level, change in intensity, timing and spatial spread of rainfall, changes in temperature and the frequency, intensity, and duration of extreme climate events such as droughts, floods, and tropical storms.

2.2 Climate Change Modelling

The climatic system is a composite interaction between chemicals and physical processes, which has kept on advancing from the 1950s with improvement in the scientific know-how. The established methods of examining our climatic system are through how the atmospheric components relate with one another by illustration. In any case, no matter how transparent the modeling technique is, it nevertheless presents a hurdle because the interactions operate on varied timescales extending from hours to decades. For this reason, influences and individual magnitudes of atmospheric variation are derived from scenarios, which have been established from climate studies to forecast likely changes in the future climate.

2.2.1 Climate change scenarios

The climate change scenarios are combinations of plausible and/ or likely sequences variations in upcoming or forthcoming climate. These scenarios help in evaluating the future consequences of atmospheric changes and help the authorities concerned to formulate suitable control and formulate adaptive measures to contain or take in these changes.

2.2.1.1. Types of Climate Change Scenarios

(IPCC-TGICA, 2007) Scenarios on climate change are classified into three main categories. They are:

a) Synthetic or Arbitrary Scenarios

In these scenarios, Climate system sensitivity is assessed by altering the key variable (climatic variable) in line with judgments laid by expertise as regards expected future change. In some instances, combined key variables are used. For example, is considering an increment in temperature between 1- 3^0C and 10% increases in precipitation or decrease by the same percentage or no changes at all. Scenarios of this trend can be sufficient to showcase or present future value. If the adopted changes in the key factors are based on professional opinion derived from climatologists or climate models.

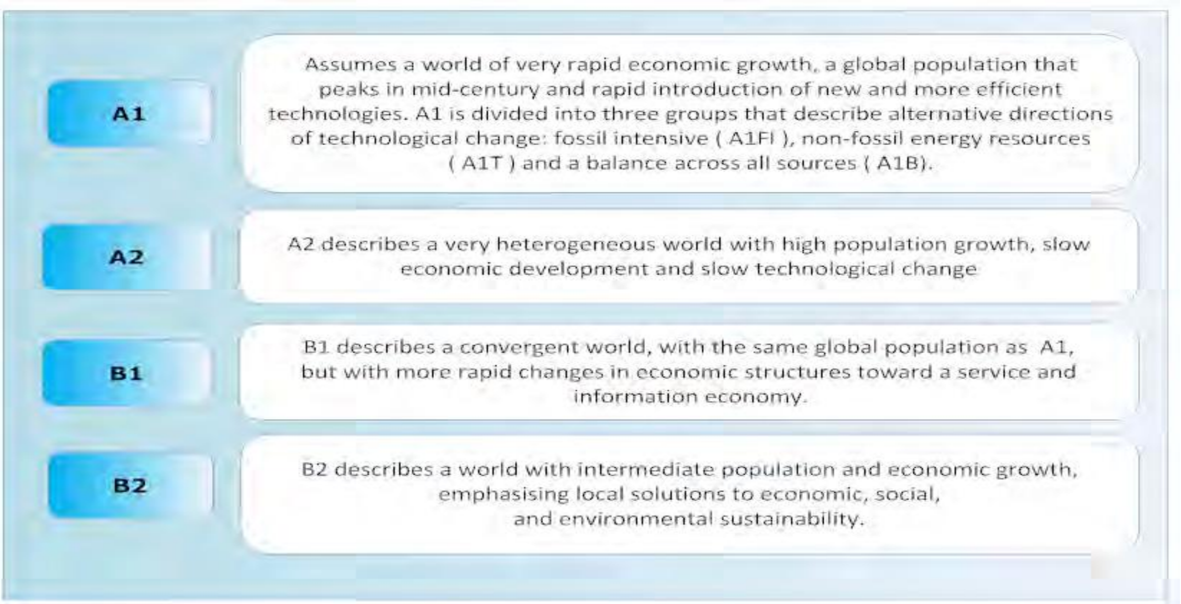
b) Analogue Scenarios

This type of Scenario makes use of historical records and measured value to reconstruct the climate because the historical record gives the best representation of inter and intra decadal changes in the climatic system and its distribution regionally. But, the quality of the observations matters. This type of reconstruction usually covers hundreds to thousands of years past and this gives detailed variation in climate than the observed records. So, forecasted scenarios would be developed from past climatic behavioral records.

c) Climate Models

These models try to simulate or imitate the processes that characterize the climate models, which recreate the whole Earth's climate are referred to as worldwide climate models. These have coarse spatial resolutions (up to 300km grids spacing, which translates to one theoretical value per 300km by 300km grid cell) and range from simple one-dimensional to complex three-dimensional models known as general circulation models (GCMs). GCMs can additionally be broken down into oceanic GCMs (OGCM) and atmospheric GCMs (AGCM). Combinations of the two models are used in the simulation of land surface and atmospheric and are referred to as atmospheric-ocean general circulation models (AOGCMs).

Climate models have been parameterized utilizing four main emission scenarios of anthropogenic driving published by the IPCC Special Report on Emission Scenarios (Nakicenovic et al., 2000) for use in atmosphere change studies. These situations, characterized with respect to four storylines namely A1, A2, B1, and B2, were built to investigate future socio-economic developments in terms of economies, populace development, and technological progression. A comprehensive portrayal of these situations is given in Figure 2.2.



A1

Assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B).

A2

A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change

B1

B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy.

B2

B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability.

Figure 2.2: The Established Scenarios from IPCC Special Report on Emission Scenarios (Nakicenovic., 2000)

Global Climate Models (GCMs) have been used to forecast variations in climate until the end of the 21st century by numerous institutions of climate research specialization. I PCC Data Distribution Centre provides more information on these institutions, their models, and analyses data. Presently, the ideal mechanism for simulation of climate both present and future are AOGCMs according to Hewitson et al, (2005). But, they have to be downscaled to be of use in local impact studies, due to their low spatial resolutions, which require higher resolutions covering from ten to a hundred kilometers. Therefore, downscaling processes are required to obtain local scale detail from the

AOGCM simulations Engelbrecht, (2005). The three main techniques, according to Mearns et al. (2003), used in downscaling are:

a) Variable resolution time-slice GCM experiments: This involves climate simulation at a resolution of a higher grid in an array of 100km globally and 50km locally is viable or feasible over a time scale (usually shorter) of several decades. Specific time slices of interest are identified and modeled in finer spatial detail.

b) Nested regional climate models: This modeling method uses lower resolution GCM which is embedded with the high-resolution regional climate model (RCM). This is referred to as ‘nesting’ the RCM within the GCM. Meanwhile, the output from the GCM at its nesting boundary is the input to the nested. These types of models are also recognized as limited area models (LAMs).

c) Empirical/ statistical interpolation: Statistical downscaling includes modeling the connection between the significant variables from GCMs (predictors) to the local variables (predictands). Afterward, the Global Climate Model predictors are input into the statistical model to evaluate the corresponding regional predictands. A more comprehensive description of the above methods of downscaling can be obtained from Mearns et. al., (2003) and Wilby et. al.,(2004).

2.3 Hydrological Modelling and its Significance

Hydrological modeling contains the comprehensive interpretation of observed, analyzed, and expected interaction of different hydrological forms which differ in duration and space, for example, precipitation, infiltration, runoff. Hydrologic processes are better understood with modeling, hydrological modeling helps us predict or envisage possible results of present and future scenarios, therefore it helps in providing solutions to actual world's problem with which the detail unachievable with conservative analysis method (pen and paper). Additionally, it's very important in hydrology because of the difficulty to ascertain the aforementioned interactions physically at a satisfactory typical number of points in a catchment. Moreover, according to Schulze, (2000), there is a need for earlier determination of any likely alteration to the hydrological system as a result of human activities to put control measures in appropriate timing. Hence, modeling happens to be the only means to tap into the future and determine what could happen if present conditions remain unchanged, improve or worsen.

2.3.1 Classification of hydrologic models

It can be classified as regards its purpose, structure, and complexity as reported by Hughes (2004) and Fu (2005). Below are the details of each category.

a) Purpose of the model

In this type of model, the modeling objectives or its purpose determines the choice of the model to be used. For instance, short event floods modeling requires a single event model whereas, simulation of longer sequences of occurrence requires continuous models. In water resources management, models with combined imitation of hydrology and storage effects, abstraction, and return flows are more ideal or preferred.

b) Model Structure

This type of hydrological modeling tries to describe the response of various outputs such as groundwater, streamflow, and soil moisture in response to the climatic inputs in the hydrological processes. Simple models are known to use few parameters and therefore do not obtain detailed representation whereas, complex models define every input and output process, though, this required many parameters. Hence, the multiplicity of a model is determined by the extent of the definition above.

c) Spatial complexity

In these types of models' techniques, the choice of approach to used verily based on the quality of available data or accessible for the area of interest. in this category, there are two main modeling methods. One seeing or treating the area as a homogeneous unit and generalized the parameters and the other breakdown the total area into sub-areas or units based on geometrics shape or natural drainage. Here the flow processes are described at each point within the total area whereas, the reverse is the case for the homogenous entity type in which the flow processes are treated as a whole.

d) Temporal complexity

Here, the hydrological processes are defined based on the time step of the model used. The time steps can differ from minutes to a year or can vary within the model run to capture distinct events like extreme rainfall or flood.

2.3.2 Types of hydrologic models

The difference between different types of hydrological models is very tough to identify because every model comprises a collection of modules, which calculate the different components or parts of the hydrological process. The conformity of a particular module to a certain type of model is determined by the quality of available materials (data) and the objectives of the model (Ochieng, 2007). A presentation of completeness hierarchical outline and description of each type of model as compiled from (Linsley Jr. et al. 1982), (Olsson: Pilesjö, 2002), (Skidmore 2002), (Ochieng, 2007), (Ragunath

2006) and (Refsgaard,2007). Generally, models classification can be done in two logical methods:

Deductive models: are kinds of models that develop their conclusion based on general known reasons that are dependent on physical laws, which are well accepted.

Inductive models: This type of model utilize a sequence of realities to originate or prove a conclusion. There is a remarkable link between the fact and conclusion however, the exact process may not be known. This rational approach leads to the discovery of patterns from observed data. Different models type emerges in accordance to the logical approach used, some of which are as follows:

Stochastic models: According to Ragunath, (2006). These models present the idea of probability since they are built on the possibility of the occurrence of input data or the parameters of the model itself. Therefore, the output will also vary.

Deterministic models: These types of models use mathematical relations built on physical laws and not chances of occurrence to describe the catchment processes. It functions within established initial and boundary conditions. These (Deterministic models) are additionally grouped as highlighted below:

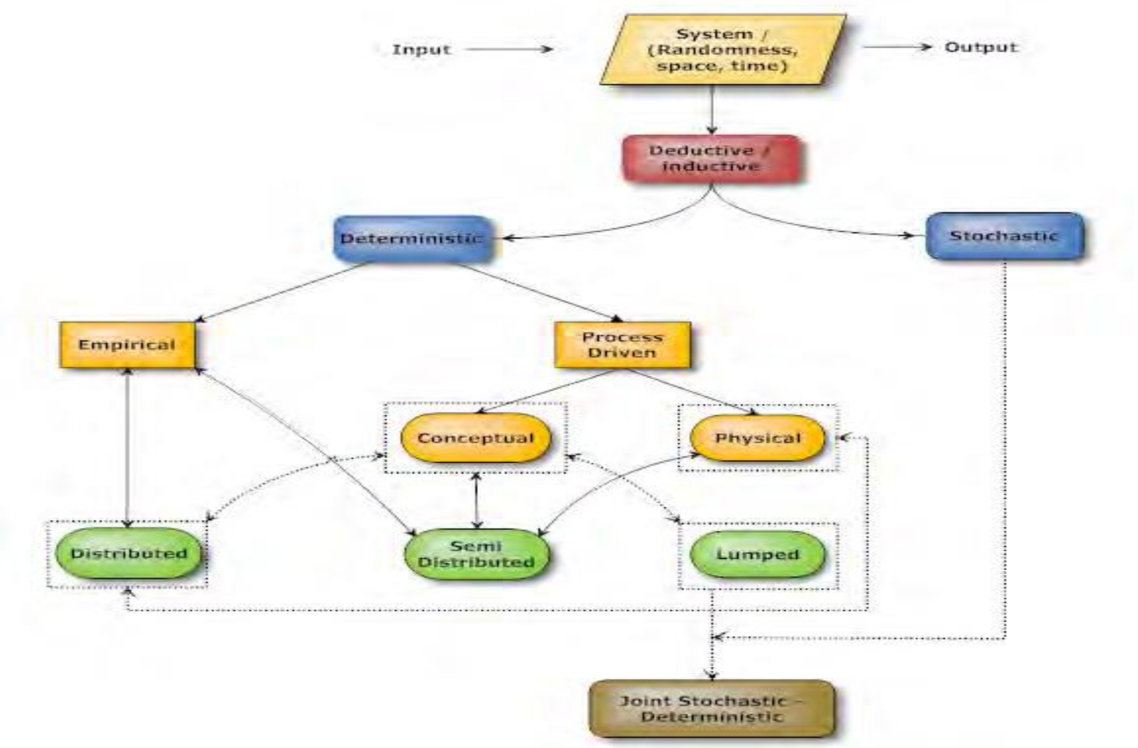
a) Black box models: sometimes called empirical models are determined by expression obtained /got from statistical examinations of measured data through correlation and regression and these types of the model don’t try to comprehend the physical procedures in the catchment.

b) White box model: these are mathematical models that utilize scientific (numerical way) approaches for explanations and are to great extent logical in nature. These models can be classified into theoretical and physical models, in which the former depends on theories to understand or construe regular phenomena instead of physical procedures while the latter is established on the nitty-gritty depiction of the procedures in the catchment and require quantifiable input data.

Several models are defined as ‘Grey box’ models with both empirical and physical compositions. Sometimes referred to as semi-empirical models. The above is further categorized considering the catchment characteristics. This is as follows:

a) Lumped models: are models which consider the catchment as a similar hydrological response unit (HRU) and ignore the spatial variations in parameters.

b) Distributed models: These models treat the catchment as different HRUs based on their characteristics and provide an explanation of catchment processes at geo-referenced computational grid points within the catchment.



c) Semi distributed models: are mixtures or amalgams of distributed & lumped models. For this situation, the evaluation of hydrological forms depends on semi-empirical equations. An appropriation is inferred, either in hydrological response units, or sub-catchments in which the regions with similar key functions are accounted as single units.

Figure 2.3: Basic Classification of Models (Haji Mtech)

Figure 2.3 defines the various forms of the model. The darts indicate probable blends of various sorts in modeling uses. Thus, it will be essential to future the interlaced idea of the sorts of model clarified in segment 2.3.2 For example, a theory can either be stochastic or deterministic in combined form. This is exhibited by the sediment transport model, which has combined parts of both deterministic and stochastics. One sample of deterministic experimental models is the dissemination of flood waves and Nash models. Model dependent on synthetic unit hydrographs describes the deterministic empirical combination (Ragunath, 2006). Thus, the categorization helps only to give the main basis of model types; the user states its real use.

2.4 Climate change and its effect on water resources

The hydrologic cycle will continuously be influenced by environmental change. The spatial circulation of rainfall combined with its sequential event will possibly experience adjustment. Hotter temperatures alter the quantity of rainfall, which will be transformed to snow and influence the timing and extent of ice melt. Also, there will be drier soils due to increases in evaporation. Continuous changes in CO_2 concentrations will also influence vegetation evapotranspiration thereby lead to more water loss. There will be an alteration to land cover due to drier soils which may result in longer droughts thus affecting the catchment runoff responses to precipitation. Similarly, the percolation rate is reduced thus affect the recharge of groundwater. This alteration will subsequently change the base flow from groundwater to streamflow Arnell (1999) and Miller et al., (2005).

Additionally, excessive rainfall will lead to runoff increment thus washing away contaminants from agricultural farmland and urban areas to nearby streams thereby affecting not only the quality but also, pose a physical risk to water infrastructures like dams, wastewater treatment systems due to overloads of contaminants and treatment difficulty and water supply. On the other hand, a decrease in stream flows and a reduction in volumes of water available in the water bodies will lead to an increment in contaminant concentrations. Additionally, a rise in the temperature of the water will affect the ecosystem, which perhaps, may base on a cooler environment Arnell (1999) and Miller et al., (2005).

2.5 The Water Evaluation and Planning (WEAP) Model

WEAP was developed by the Stockholm Environment Institute's (SEI) Boston Centre, it's a desktop tool for integrated water resource planning. For the past fifteen years since its first application carried out by Raskin and Zhu (1992) in the Aral Sea, there have been major improvements on the model like friendly graphical interface, a vigorous algorithm for water allocation, and the integration of hydrologic sub-modules that include a conceptual rainfall-runoff, water quality model for groundwater and surface water. Furthermore, additional combined choices to link to another model for example MODFLOW and QUAL2E. for instance if the inbuilt submodule is not enough. The model is an easily comprehensive tool that incorporates an integrated way to water resource management, which over the past ten years, has set more emphasis on demand-side management, the preservation, and protection of the ecosystem, and water quality. The model placed the demand-side issues for example. Water use pattern, reuse strategies, equipment efficiency, water allocation scheme, and costs on equivalent balance with supply-side resources (such as available surface and groundwater, reservoir storage, and transfer between basin), for integrates simulation of both the natural and engineered components. This gives the water resources manager the liberty of a detailed view of the results of various decisions on the system. The information provided herewith is to a great extent as extracted from the user guide provided by SEI.

2.5.1 Approach of WEAP model

WEAP model works or operate based on water balance accounting. It is useful or appropriate to agricultural and domestic systems, singular sub-basins and/ or complex river system. Additionally, the software addresses the extensive scope of concerns, for instance, investigation of demand of a region, water preservation, water rights and distribution (allocations) priorities, rainfall-runoff and baseflow, groundwater and streamflow simulation, hydropower generation, reservoir operations, water quality, ecosystem demands and project benefit-cost analysis (SEI, 2007).

The water system is characterized in agreement to its different supply sources, the process of retraction or withdrawal, and wastewater treatment facilities, ecosystem necessities, demands, and generation of pollution. The data assemblage and details can be personalized (such as, by combining demand sites) to the specific analysis required and limitations imposed by constrained. (SEI, 2007).

Generally, Water Evaluation and Planning model software applications comprise various stages. The study definition sets up the time frame, spatial limit, system components, and problem configuration. A baseline year is defined, known as the ‘current accounts’ in the model for which the factual data of assured quality is obtainable. Then substitute future assumptions are then established depending on for instance policies, demands, costs, pollution, supply, and hydrology. Afterward, a single or combination of different assumptions is used to construct scenarios and assessed with respect to the adequacy of wa**te**r, economic consideration, environmental sustainability. The area of study can be considered as a single or division of sub-entity based on available data/topography. The region in question is accordingly classified based on LULC. which is a determinant of runoff and infiltration. A one-dimensional, 2-store, theoretical water balance model calculates the hydrologic reaction of the area and partitions water into various components; evapotranspiration, surface runoff, interflow, and baseflow Yates et al., (2005).

2.5.2 Formulation for linear program in WEAP

WEAP maximizes the satisfaction of the requirement for demand sites, user-specified in-stream flows, and hydropower subject to constraints; as demand priorities, supply preferences, mass balance, and other constraints a user may set using Linear Program (LP). WEAP uses *LPSolve* which is an open-source linear program solver in solving equations. We will look into mass balance, coverage variables, and constraints, and constraints regarding demand priorities and supply preference as they are our main concerns regarding this work.

a. Mass Balance constraints

Mass balance equations (Equation 2.1) as the foundations of WEAP's monthly water

accounting such that every node and link in it(model) has a Mass balance equation, and each of these equations becomes a constraint in the LP.

$$\sum \boldsymbol{Inflow} = \sum \boldsymbol{Outflow} + \boldsymbol{Change\ in\ Storage} \qquad (\mathbf{2.1})$$

Equation 2.1 can be rewritten as Equation (2.2)

$$\boldsymbol{Inflow} - \boldsymbol{Outflow} - \boldsymbol{Change\ in\ Storage} = \mathbf{0} \qquad (\mathbf{2.2})$$

Addition to storage applies to reservoirs and aquifers and it is an addition or positive when there is an increase and also negative when there is a decrease. Outflow comprises losses and consumption. And every flow from one point to another is represented by a variable in LP.

If demand site let's say A is assumed to withdraw from supply site B & C, and their returned flow to these supplied sites after considerable consumptions, then, the water balance equation or expression would be written as Equation (2.3).

$$\boldsymbol{Inflow_{B,A} + Inflow_{C,A} - Outflow_{A,B} - Outflow_{A,C} - Consumption_A = 0} \quad (\mathbf{2.3})$$

B, A in Equation (2.3) is the inflow from supply B to demand site A. The LP constraint would be a row in the LP matrix, with coefficients of 1 for the inflow variables and -1 for the outflow variables. The entire row would be set to equal to 0.

b. Coverage Variables and Constraints

A new LP variable is created for each demand which will equal its “coverage” (percentage of demand satisfied). The Coverage for demand D cannot exceed 100% (Equation 2.4)

$$\boldsymbol{Coverage_D \leq 100\%} \qquad (\mathbf{2.4})$$

The inflow to a demand site (DS) from its entire transmission link (Src) will equal its supply requirement times its coverage (Equation 2.5)

$$\boldsymbol{\sum\nolimits_{Src} Inflow_{Src.Ds} = SupplyRequirement_{DS} * Coverage_{DS}} \qquad (\mathbf{2.5})$$

And Equation 2.5 can be rewritten as Equation (2.6)

$$\boldsymbol{\sum\nolimits_{Src} Inflow_{Src,DS} - SupplyRequirement_{DS} * Coverage_{DS} = 0} \qquad (\mathbf{2.6})$$

However, demand sites cannot take more water than their supply requirement, in-stream flow requirement (IFR) when applicable, can be exceeded by the actual flow. Therefore, the equation is written as an inequality (Equation 2.7)

$$\boldsymbol{Flow_{IFR} \geq SupplyRequirement_{IFR} * Coverage_{IFR}} \qquad (\mathbf{2.7})$$

Equation 2.7 can be rewritten as Equation (2.8)

$$\boldsymbol{Flow_{IFR} - SupplyRequirements_{IFR} * Coverage_{IFR} \geq 0} \qquad (\mathbf{2.8})$$

The LP constraint would be a row in the LP matrix, with coefficients of (1) for the flow variables (inflow to demand sites and streamflow at the in-stream flow requirement node), and (-1) times the supply requirement as the coefficient for the coverage variables. The entire row would be set equal to 0 (demand site) or greater than or equal to zero (in-stream flow and requirement).

c. Objective Function and Iterations

WEAP strives to maximize supply to demands sites, subject to all constraints and priorities. Allocations of water to demand sites are done based on the preferences of both demand and supply. WEAP iterates for each priority and reference, so that demands with priority 1 are allocated water before those with priority 2. Hence, the LP is solved at least once for each priority for each time step. When solving for priorit1, WEAP will temporarily turn off (in the LP) allocations to demand priority 2 and lower. Then, after priority 1 allocations have been made, priority 2 demands are turned on (but 3 and lower are still turned off). In cases where there is not enough water to satisfy all demands with the same priority, WEAP tries to satisfy all demands to the same percentage of their demands and satisfies coverage constraints.

If for instance, supply requirement of 100 and 50 is required by Site A and B with both demand sites having equal priority and there exit 60 units of water in the river in the time step, then demand site A will get 40% (40 units) and site B will have 40 % (20 units). On the other hand, a situation may arise such that one demand site will have more access to water than the others. For example, when there is a tributary with an inflow of 200units in between a withdrawal point A and B. such that there is always enough water for B. in such situations; demand site B should be able to withdraw its full requirement, even though demand site A cannot. In this case, the WEAP LP will iterate. The first time it solves, both A and B will get 60%; A gets all 60 (60%) units flowing past its withdrawal point, and demand site B gets 30 units (60%) 50 units that flowed in from the tributary. The equity constraints ensure that both demand sites get the same percentage coverage. The LP at this stage indicates that there is slack in the variable coverage variable in B because it could get more water than it is getting as opposed to A that cannot get any more water. Therefore, the allocation to demand site A is fixed at 60 (Equation 2.9), and the equity constraint is deleted. The LP runs again, and this time demand site B will get its full demand of 50 units (100%).

$$\boldsymbol{Coverage_{Final} = Coverage_{A}} \qquad (\mathbf{2.9})$$

d. Determination of Slack in WEAP

In the second scenario pointed out iteration above, the introduction of tributary inflow between withdrawal points of demand sites A and B makes demand site B able to receive a higher percentage of its demand than demand site A. For WEAP to determine which coverages are constrained from going higher due to unavailability of supply (e.g., 60% for Demand Site A), and which can get more water (e.g., 100% of demand site B); a new variable called *Epsilon* (which determines which demand site are supplied limited and which are not) is defined for each demand site and added to the coverage constraints as shown in Equations (2.10) and (2.11).

$$\mathbf{Coverage_{Final} = Coverage_{DS1} + Epsilon_{DS1}} \quad (\mathbf{2.10})$$

$$\mathbf{Coverage_{Final} = Coverage_{DS2} + Epsilon_{DS2}} \quad (\mathbf{2.11})$$

The epsilons are also added to the objective function, but with negative signs, so that they are minimized (Equation 2.12)

$$\boldsymbol{Maximise}: \boldsymbol{Coverage_{Final} - k * Epsilon_{DS2}} \quad (2.12)$$

e. Annual Demand

Water demand for demand site (DS) is calculated as the summation of all demand sites ‘bottom level branches (Br) demands. A branch without any branches below it is called the bottom-level branch. For example, in the structure that comprises, showers, toilets, washing and other (and four others underneath Multifamily that may not be shown) are the bottom-level branches for South City.

AnnualDemandDS = (TotalActivityLevelBr x WaterUseRateBr) *(*2.13)

The total activity level for a bottom-level branch is the product of the activity levels in all

branches from the bottom branch back up to the demand site branch (where Br is the bottom-level branch, Br' is the parent of Br, Br" is the grandparent of Br, etc.).

TotalActivityLevelBr = ActivityLevelBr x ActivityLevelBr' x ActivityLevelBr" x ... (2.14)

For the example above, this becomes

TotalActivityLevelShowers = ActivityLevelShowers x ActivityLevelSingleFamily x ActivityLevelSouthCity

= percent of people in single-family homes who have showers x percent of people who live in single-family homes x number of people in South City

The activity level for a branch, and the water use rate for a bottom-level branch, are entered as Data.

f. Monthly Demand

The demand for a month(m) equals that month's fraction (specified as data under Demand\Monthly Variation) of the adjusted annual demand.

$$\text{MonthlyDemandDS,m.} = \text{MonthlyVariationFractionDS, m.} \times \text{AdjustedAnnualDemandDS} \tag{2.15}$$

g. Monthly Supply Requirement

The water required in a month by demand site for utilization is represented by monthly demand. Whereas, supply requirement signifies the quantity needed from the source. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies for reducing demand, and internal losses. These three adjustment fractions are entered as data

$$\text{MonthlySupplyRequirementDS, m.} = (\text{MonthlyDemandDS, m.} \times (1 - \text{ReuseRateDS}) \times (1 - \text{DSMSavingsDS})) / (1 - \text{LossRateDS}) \tag{2.16}$$

2.5.3 Applications of WEAP (Model) software

The software has been extensively used around the universe since its development, in different Integrated Water Resources Management projects with varied objectives. Some of its applications are as follows:

Global Projects:

The first project was carried out in 1992 by Raskin and Zhu, (1992) on the Aral Sea which investigates water accounts and examining the management policies in the area in the former U.S.S.R.

Also, applied in hydrological modeling by Amato et al., (2006). In the United State of America, the studies on water usage and distribution or allocation (Yates et al., 2008) and the study of change in climate impacts in agricultural land (Purkey et al., 2008). Additionally, it has been applied incomparable water resources planning in many catchments in the state by Engineers of Centre for hydrological Engineering of U.S Army Corps.

WEAP was utilized to create substitute improvement on water distribution or allocation concerning Palestinian and Israeli. Furthermore, (Assaf and Saadeh, 2008) create or develop management plans for water quality of wastewater to control the discharge of Untreated one into the Upper Litani basin located in Lebanon.

In a program that took place in Beijing- Hebei WEAP was utilized to establish a baseline for achieving Cooperation on water-related issues that involve stakeholders of upstream and downstream. Also, it was used with other models for solid waste management to develop a master plan for Municipal Environmental Planning.

In Africa Continent:

In Kenya, WEAP was applied for modeling water resources management by Alfarra, (2004) in lake Naivasha. Also, its various water distribution works under WatManSup Project in Kitui Droogers et al., (2006) and the project tag “Green Water Programme” in Tana Basin by Hoff et al., (2007).

Haagan (2007). Make use of the software to examine the influence of small reservoirs in a semi-arid and arid part in Ghana.

Levite et al., (2003) used it to assess the ability of River (Steelport) to simultaneously meet demands for various uses and environmental reserve. This was done in the Olifants River Basin. Moreso, various water demand management strategies were examined through series of scenarios. Nevertheless, the streamflow from an earlier study was used in the setting of the hydrology of the area.

Additional research was carried out on the entire Olifants basin by Arranz and McCartney, (2007) used WEAP to assess the influence of three Scenarios created from water demand growth up to 2025, implementation of environmental reserve (ER), International Agreements (IA's), and strategies on water resources for conservations and demand management scheme. In simulating the basin hydrology, rainfall and naturalized streamflow were used. The model was calibrated through alteration of assumption of historical demand pattern, changing the demand priorities, and changing the reservoir operation rules. This was done to improve the fit between observed and simulated flows due consideration was given to the influence of climate variation on land use and water resources development. A further study was also done on conservation management plans and infrastructural development.

WEAP model was used in water resources management under environmental scenarios in Hirmand catchment for a period (2015-2030). In the study, the result shows that the average total demand in dust stabilization and animal-plant sustainable ecosystem scenarios increased about 238 and 231 million cubic meters compare to current account respectively and all unmet demand increases to 193 and 200 million cubic meters, approximately. According to the economic assessment calculations, benefit in dust stabilization scenario 160 milliards rials and in animal-plant sustainable ecosystem scenario 209 milliards rials decreased in agriculture sector. Therefore, in order to preserved and protect the wetlands,despite the reduction in benefit, policy making and water resources management should be given special attention (Shahraki et al., 2016).

In Nigeria:

Effects of probable water demands on the water resources of the Ogun river basin up to the year 2020 was evaluated with the WEAP model. In this work simulation of two scenarios were carried out: the first one involved the past and present feature of water demand in the basin from 2006 to 2011 while the second simulates the future water demand in the basin from 2012 to 2020. Various hydrological components, such as hydrological year cycles, precipitation, and dams were integrated to analyze the water demand utilization, unmet demand, demand site coverage, supply delivered, stream flows, and water storage for each scenario and some key assumptions for the gross domestic product, population growth rate, irrigation efficiency and complementary sources of water were made. the results of the model show that the total unmet water demand to be 4.1 x 10^9 m3 for previous and current scenarios and this increased to 6.9 x 10^{10} m3 after model prediction for years 2012-2020 with an average annual rate of 7.7 x 10^9 m3 this indicated that the basin, therefore, may not be able to satisfy the future water demand of water users in the basin. To reduce unmet demand, wastewater treatment, the introduction of water meters to check wastage, the building of new dams or increasing the capacities of existing ones, groundwater development, information dissemination, and development of manpower in the field of water resources are recommended. (Ojekunle et al., 2011)

A study of influences of climate change on water availability and basin responses to changes in climate, a case study of Sokoto rima river basin was carried out with WEAP software model. In this study the hydrological processes occurrence for six main rivers in the basin from 1970 to 2013 was successfully model. calibration was done through visual observation and it was done with twenty-two (22yrs) years' climatic data and validated with 8 years' data. consideration was given to Global climatic models' presumption and six climatic variation scenarios was developed for simulation that is, increase in temperature ;0, +0.5, + 1.0 ^{o}C combined with alteration in Precipitation (0, -10%, +10%).Thereafter, the output of the model was obtained and results indicated that an annual reduction in available water was about 1.70 billion cubic meters (BCM) and monthly demands were 17.11BCM for the driest month that is, April. This was linked to the effects of a 10% reduction in precipitation and an increase in evapotranspiration under a 1^{o}C rise in temperature. A sustainability method was suggested to ensure continuous availability Abdullahi et al., (2014).

CHAPTER THREE

MATERIALS AND METHODS

3.0 Description of the study area

3.1 The study area

The study area, Goronyo Reservoir, is situated between Latitudes 13°30'N to 14^{o}N and Longitudes 5^{o}30'E to 6^{o}E. The Reservoir has a length of about 20km with a width of about 10km and an area of about 200km^{2} with a storage capacity of 942 million cubic meters (Ita et al., 1982; Abubakar, et al., 2017). The study area is located in Goronyo Local Government Area, Sokoto State, Northwest Nigeria. The study area is part of the

Sokoto-Rima basin, which has a total catchment area of about 193,000km^2 distributed in Nigeria and the Niger Republic (Gill, 1974).

The Sokoto-Rima basin has a semi-arid tropical climate with a prolonged dry season from October to May and a short-wet season from the end of May to early October (Udo, 1970; Ogheneakpobo, 1988; Adeniyi,1993). Temperatures depict both seasonal and diurnal variations in the area (Davis, 1982). Two temperature maxima of over 35°C are common between April-May and between October-November, two minimum temperature periods below 20°C are also common between December-January and in August (Gill, 1974; Adeniyi, 1993). During the rainy season, the diurnal range of temperature in the area is low but during the dry season, it is high (Davis, 1982). Rainfall in the area shows both spatial and temporal variations (Udo, 1970; Adeniyi, 1993). The mean annual rainfall varies from about 700mm in the northern part of the Rima basin to about 1,100mm in the south (Gill, 1974; Davis, 1982; Adeniyi, 1993). The duration of the rainy season is also longer in the southern part (Davis, 1982) and According to Gill (1974), this was as a result of an early start and ends later than in the north. The study area has mostly sandy soil which have low organic matter and nutrients –nitrogen, phosphorus, and potassium (Swindell, 1986; Yelwa et al., 2012).

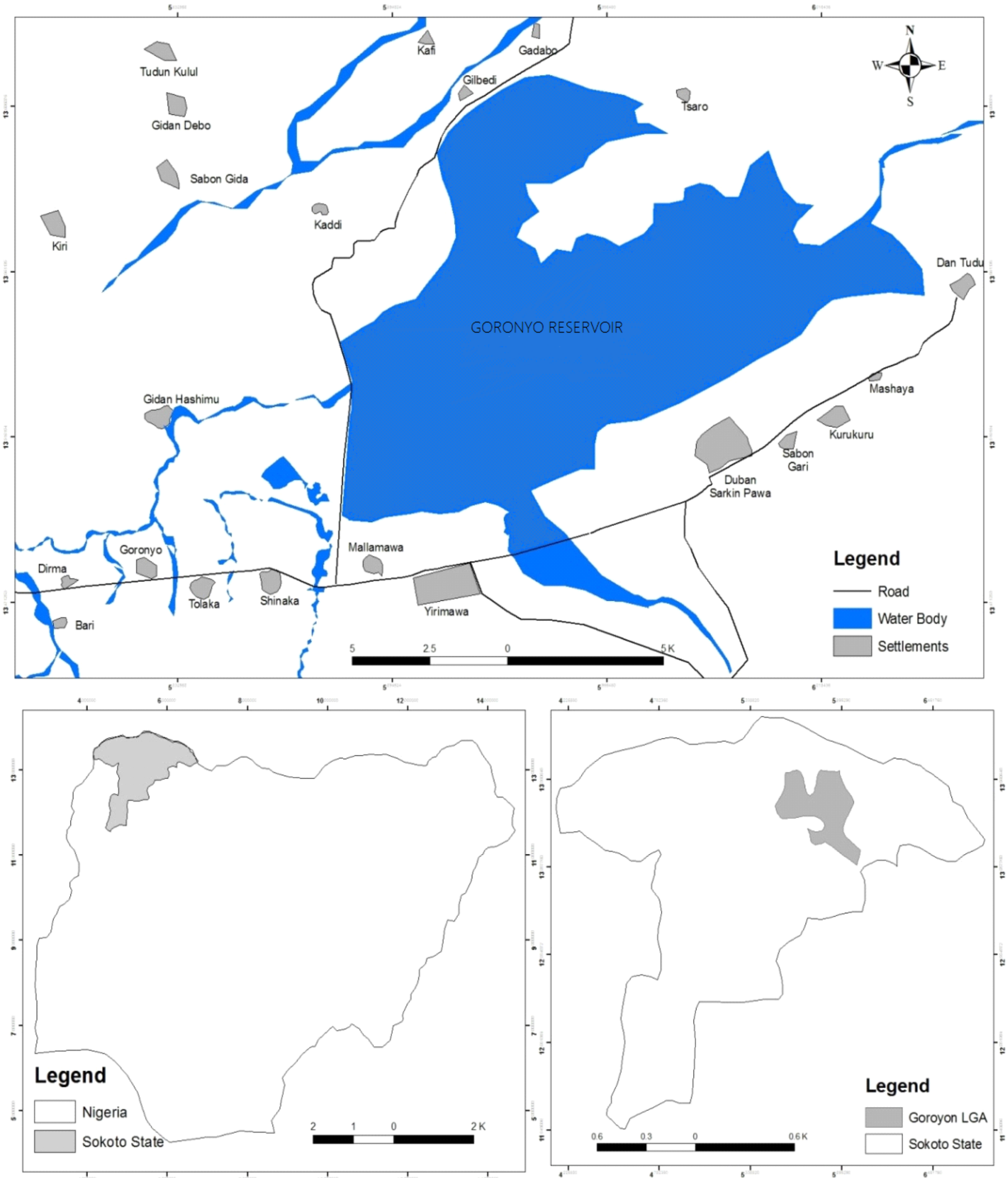


Figure 3.1: The Study Area (Goronyo Reservoir); Source: NASRDA, 2012

3.1.2 Climate

As it is common to West Africa, the atmosphere in this part is significantly constrained by the two main air masses influencing the sub-district. These are the dry, tropical-mainland air mass (which begins from the Sahara district), and warm, tropical-sea air mass (which starts from the Atlantic Ocean). The impact of both air masses on the area is resolved to a great extent by the development of the Inter-Tropical Convergence Zone (ITCZ), a zone portraying the surface boundary between the two air masses. The interaction of these air masses offers ascent to two distinct seasons inside the sub-area. The wet season is related to the tropical oceanic air mass, while the dry season is a result of the tropical mainland air mass. The impact and power of the wet season diminish from the west Africa coast northwards. In this way, precipitation in the entire sub-area of West Africa relies upon tempest action which happens along unsettling influence lines called ”line squall” and, around 80 percent of the all-out yearly precipitation for most places is related to line squall exercises which are predominant among June and September (Nicholson, 1980; Dennet, et al., 1985; Adefolalu, 1986; Kamara, 1986). As for climatic insights, the yearly precipitation for Sokoto extends between 300 mm and 800 mm. The mean yearly temperature is 34.5^0 C, albeit dry season temperatures in the district frequently surpass 40^0C (Ekpoh and Nsa, 2011).

3.1.2 Topography

The topography of Sokoto state is subjugated by the well-known Hausa plain of northern Nigeria. It includes broad tracts of practically level to the delicately undulating scene. This dullness is broken in the south and east by gatherings of rough slopes and inselbergs. The most elevated and most noteworthy massifs happen in the south-east. On the fields, the general stature contrast among valleys and adjoining vaults are just 10-20 meters. Regular cross-areas comprise an expansive vault territory; long, straight center slants of under 2^o and short, sharp lower inclines giving indications of physical weathering (Schultz, 1975). The immense floodplains (fadama) of Sokoto Rima River dismember the Hausa plain into rich alluvial soils that are appropriate for the development of an assortment of harvest. There are likewise segregated slopes and hill ranges that disperse everywhere throughout the state.

3.1.3 Demography

Generally, the growth in the Africa population shows a very swift rate more especially in the urban areas. In 1991, the population in Sokoto State is 2,397,000 people and comprised of rural and urban populations. While the total population according to the 2006 census is 3,702,676 people. Similarly, the local government area of interest with the village has the following populations as shown in Table 3.1. The whole areas within the study area have an average inter census growth rate of 3.03.in the year 2006.

Local Gov't Area	**Census 1991, Total Population**	**Census 2006, Total Population**			**2017 Total Population**
		Male	**Female**	**Both Genders**	
Wamako	140137	91466	87780	179246	248914
Sokoto North	-	124134	108878	233012	323578
Sokoto South	-	103207	94479	197686	274521

Table 3.1 Demography of the Area

(National Population Census, 2006)

3.1.4 Features of the dam

The Goronyo Dam (with a reservoir area of 200km^2) impounds Rima River in Goronyo local government area of Sokoto State. It was completed in 1984 and commissioned in 1992. The dam is a sand-fill structure with a height of 21 m and a total length of 12.5 km. It has a storage capacity of 942million cubic meters (MCM). The dam is controlling floods and releasing water in the dry season for the planned Zauro polder project downstream in Kebbi State.

3.1.5 Irrigation scheme within the area

Basically, there are three major existing irrigation schemes in the study area namely, Falalia, Taka Kume, and Mai Yali irrigation farmland. The crops cultivated in this area are; rice, cassava, onion, garlic, tomatoes, watermelon, cowpea, and vegetables. The total irrigable land as of present covers an area of 2,776 hectares of land and it is mainly fed by the flood irrigation system.

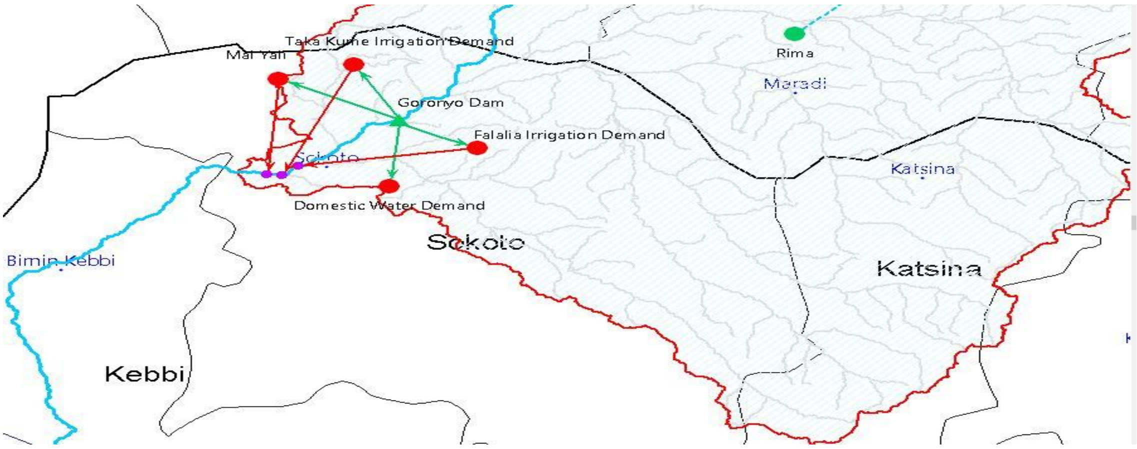


Figure 3.2: The Schematic (view) map of the area showing the reservoir and demands nodes.

3.2 Research procedure

Here the basic methods adopted to achieve the specific aim of this research were discussed. Firstly, the climatic data were obtained and used to simulate the surface water situation with the model. Secondly, the data was projected based on the initial model output and compared with the existing (observed) data. The comparison involved calibration and validation with the recorded data of river flow. Thirdly, the hypothetical climate change Scenarios were applied to the model to know what to be expected if climate changes. Thus, the model was used to analyze what happened to demand and water availability in Goronyo reservoir based on the water use of the area. Fourthly, a projection was done to observe and ascertain what may be the nature of the area in future time up to 2070 which is 52 years from 2018. Note, WEAP model software allows extending the trend data.

The following are detailed procedures adopted for the study:

(A) Preliminary investigation (i.e. Reconnaissance visit) was conducted to analyze the hydraulic nature and human activities related to water resources in the catchment.

The rainfall, temperature, evaporation, relative humidity, wind speed, and sunshine data was collected from NIMET from 1988 to 2017 and were analyzed statistically.

(B) The Catchment was delineated with WEAP inbuilt catchment delineation component and the inland waterway was digitized.

(C) The hypothetical climatic change scenarios were applied to the model to observe what happened if climate changes.

(D) The model was used to analyze the linkage between the water resources and the demand in the catchment.

3.3 Analysis of the temperature trend for generating climate scenarios

Statistical analysis of the annual average maximum temperature (1988 – 2017 obtained from NIMET) of the area was done. The maximum average annual temperature and minimum temperature with a mean and standard deviation of the data were determined. The linear trend was fit into the data and the gradient of the trend was determined. A linear equation obtained from the trend analysis was used for the projection of temperature increment for this region by considering temperature variation over four decades.

3.4 Analysis of the rainfall trend for generating climate scenarios

Similarly, the average annual rainfall (1988- 2017) of the region was analyzed statistically. The maximum average rainfall value and minimum average value with a mean and standard deviation of the data were determined. The linear trend was fit into the data and the gradient of the trend was determined. The trend analysis leads to a linear equation relating the rainfall to time. This was used for the projection of climate change effect on Precipitation for this region by considering average rainfall value variation over four decades.

3.5 Climate scenarios generation

The method adopted is the hypothetical scenario option which was adopted by scholars in climatic impact or influence studies (Islam et.al, 2005). Several published works were done in this method (e.g. Gleick, 1987; McCabe and Wolock, 1991; Skiles and Hanson, 1994; Yates, 1996; Boorman and Sefton, 1997; Bobba et.al, 1999; Hailemariam, 1999; Xu, 1999, 2000**;** Islam et.al, 2005; Abdullahi, 2014). From this perspective and aiming at the objective of the study to apply the WEAP model to the area to evaluate the influences of climate variability on water availability for current and future usage using water balance, the hypothetical scenario was chosen to generate scenarios. Whereas the linear trend was used in evaluating the pattern of temperature and rainfall.

The hypothetical scenarios are used in answering the question of what if the climate changes. Nine hypothetical scenarios were implemented as follows, first scenario considered an increase in temperature of about +0.4^{o}C over the entire area (Table 4.1), second scenario considered an increase in temperature of about +0.4^{o}C and an increase in rainfall of around +10% over the entire region(Table 4.2), third scenario considered an increase in temperature of about +0.4^{o}C and decrease in rainfall of around -10% over the entire area (Table 4.3), fourth scenario considered an increase in temperature of about +0.8^{o}C over the entire area (Table 4.4), fifth scenario considered an increase in temperature of about +0.8^{o}C and an increase in rainfall of around +10% over the entire area(Table 4.5), the sixth scenario consider increase in temperature of about +0.8^{o}C and decrease in rainfall of around -10% over the entire area(Table 4.6), the seventh scenario consider increase in temperature of about +1.2^{o}C over the entire area (Table 4.7),eighth scenario consider increase in temperature of +1.2^{o}C and increase in rainfall of around + 10% over the entire area (Table 4.8), and the ninth scenario consider increase in temperature of 1.2^{0}C and decrease in rainfall of around -10% over the entire area (Table 4.9). The nine (9) developed climate change scenarios are shown in tabular forms (Table 3.2). Meanwhile, Table 3.3 shows the reference scenario.

Table 3.2: Hypothetical climate change scenarios

Scenarios	**Change in Temperature $\Delta T(^{0}C)$**	**Change in Rainfall R(%)**
Reference	0	0
Scenario 1	+0.4	0
Scenario 2	+0.4	+10%
Scenario 3	+0.4	-10%
Scenario 4	+0.8	0
Scenario 5	+0.8	+10%
Scenario 6	+0.8	-10%
Scenario 7	+1.2	0
Scenario 8	+1.2	+10%
Scenario 9	+1.2	-10%

3.6 Inflow, Outflow and Storage volume

The reservoir capacity curve was used to determine the storage volume of the reservoir, this was obtained by tracing the elevation in meter to the volume for each month throughout the year, the average value is then obtained for each year as the average storage volume. The respective outflow or discharge data were obtained from the dam operator. Haven gotten the storage and outflow the water balance concept is then introduce to get the inflow to the reservoir.

3.7 Classification of water year

For the analysis of hydrological processes in the Goronyo Reservoir, all-natural hydrological watershed details and demand points for water resources management are represented in the WEAP model (Figure 3.2).

Well Characterized nine (9) scenarios were used to investigate the affectability of climate change. The reference account (Table 3.3) was embraced utilizing the Water Year Method to duplicate the hydrological variation as obtained from the historical records. The rest of the scenarios were adopted using the first as a beginning point, then modifying each water year type as indicated by anticipated impacts of climate change. (i.e. increment in temperature and increment or diminishing in rainfall).

The water-Year Method is the means to represent variation in climate data such as streamflow, rainfall, and groundwater recharged. The method first involves defining how different climate regimes e.g. very dry, dry, very wet, and wet years compare relatively to normal years. With the water year method, it is easier to present the effect of hydrological system change in the future through the use of the current account as the baseline based on the water year definition the available water can be modeled. Water year value (WYV) is expressed as the ratio of summation of water available per annum to annual average i.e. WYV$= \frac{\mathit{Summation\ of\ Annual\ Rainfall}}{\mathit{Annual\ Average}}$

Years	Temp. °C	Wind Speed (m/s)	Relative Humidity (%)	Rainfall (mm)	Water Year Value	Water Year Type
1988	33.37	3.15	41.17	641.4	1.067026	Normal
1989	32.96	3.20	39.60	614.7	1.022608	Normal
1990	33.98	2.80	40.95	505.1	0.840279	Very Dry
1991	33.23	2.68	45.58	712.4	1.185141	Wet
1992	32.87	3.05	42.01	535.0	0.89002	Dry
1993	33.75	2.79	40.61	498.8	0.829798	Very Dry
1994	32.54	3.01	45.06	779.6	1.296934	Very Wet
1995	33.13	2.87	44.68	459.6	0.764586	Very Dry
1996	33.67	2.71	42.27	544.6	0.905991	Dry
1997	33.18	2.76	44.10	520.7	0.866231	Dry
1998	34.07	2.77	41.91	654.1	1.088154	Normal
1999	34.3	2.62	40.44	716.3	1.191629	Wet
2000	34.01	2.87	42.70	512.4	0.852423	Dry
2001	34.66	2.89	37.82	509.6	0.847765	Very Dry
2002	34.83	2.65	40.28	558.0	0.928283	Dry
2003	34.63	2.74	41.36	652.6	1.085658	Wet
2004	34.58	2.69	41.91	516.0	0.858412	Dry
2005	34.75	2.78	42.16	697.3	1.160021	Very Wet
2006	35.08	2.61	38.82	651.3	1.083496	Wet
2007	34.63	2.80	38.82	583.2	0.970205	Normal
2008	34.04	2.94	38.17	657.8	1.094309	Wet
2009	34.78	2.60	40.73	544.7	0.906157	Dry
2010	34.46	2.72	42.02	701.1	1.166342	Wet
2011	34.52	2.88	38.03	478.9	0.796693	Very Dry
2012	33.86	2.23	42.75	553.7	0.921129	Dry
2013	34.22	2.42	42.60	506.2	0.842109	Very Dry
2014	32.45	2.70	41.07	582.7	0.969373	Normal
2015	34.11	2.83	39.31	532.2	0.885362	Dry
2016	35.06	2.76	42.05	958.1	1.593885	Very Wet
2017	34.58	2.86	38.60	655.2	1.089984	Wet

Table 3.3: Hypothetical climate change reference scenario data

The Table3.3 shows the Hypothetical Climate Change Reference Scenario Data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method.

3.7 Calibration and Validation of the WEAP model

According to (Abdullahi, 2014 and Trucano et al., 2006). Calibration can simply be interpreted as the adjustment of a set of parameters associated with a computational science and engineering code so that the model agreement is maximized for a set of experimental data. On the other hand, validation can simply be interpreted as quantifying our belief in the predictive capability of a computational code through comparison with a set of experimental data. The Calibration was done manually by using the sixteen years' climatological records (1988- 2004) in setting up the model. This calibration was done by visual check of the modeled versus observed streamflow graph (shown in chapter four) to ascertain the accuracy of the output. This adjusts the model structure to attain a representation of the streamflow that satisfies the measured/recorded streamflow data.

The model was validated with eight years of recorded data (2005 -2013) by using enabled statistical analysis describing the Correlation coefficient R^2, Nash-Sutcliffe coefficient of efficiency (CE) via Microsoft Excel, and the results were linked to WEAP analysis. Below is a summary of each objective function used:

a. Correlation Coefficient**:**

$$\boldsymbol{R^2} = \left[\frac{\sum_{i=1}^{n}\left(\boldsymbol{Q}_{obs,i} - \bar{Q}_{obs}\right)\left(\boldsymbol{Q}_{sim,i} - \bar{Q}_{sim}\right)}{\sqrt{\sum_{i=1}^{n}\left(\boldsymbol{Q}_{obs,i} - \bar{Q}_{obs}\right)^2} \cdot \sqrt{\sum_{i=1}^{n}\left(\boldsymbol{Q}_{sim,i} - \bar{Q}_{sim}\right)^2}}\right]^2 \qquad \textbf{(3.1)}$$

Where, Q obs, i =measured discharge at the ith time interval, $\bar{Q}_{obs}$ = mean of the measured discharge, Q sim, i = simulated discharge at the ith interval, $\bar{Q}_{sim}$ = mean of the simulated discharge n = number of observations. The range of R^2 lies between 0 and 1 for a perfect fit. The coefficient of determination is very important because it gives the proportion of the variance of one variable that is predictable from the other variable. It is a measure that allows us to determine how certain one can be in making predictions from a certain model.

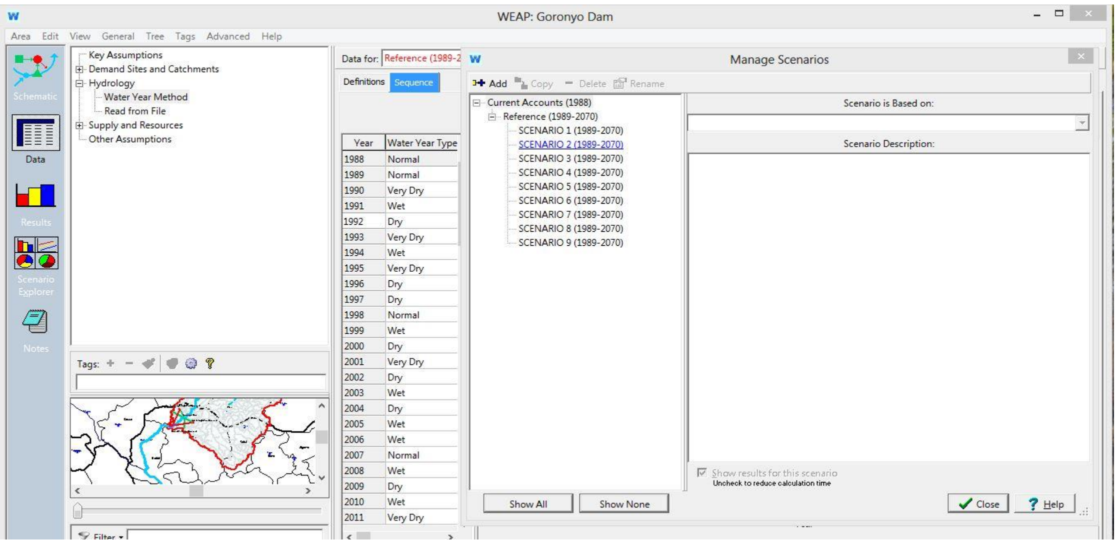
b. Nash-Sutcliffe coefficient of efficiency (CE) .

$$\boldsymbol{CE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} \ - \bar{Q}_{obs,i}\right)^2} * 100} \tag{3.2}$$

Where: CE is the Nash-Sutcliffe coefficient of efficiency; Qobs, i is the observed discharge at the time step I, Qobs is the mean of the observed discharge; Q sim, I = the simulation discharge at the time step I, and n is the number of observations. The Nash-Sutcliffe coefficient of efficiency indicates how well the plot of observed versus simulated value fits the 1:1 line and is commonly used in most or all hydrologic model evaluations. If the measured variable is estimated mostly accurately by the model, then CE is close to or equal to (1) one; if the CE is negative, it shows or indicates that the quality of the model results is smaller than the average value of the measured variables (Nash and Sutcliffe 2012).

3.8 Analysis of climate change impact on water availability

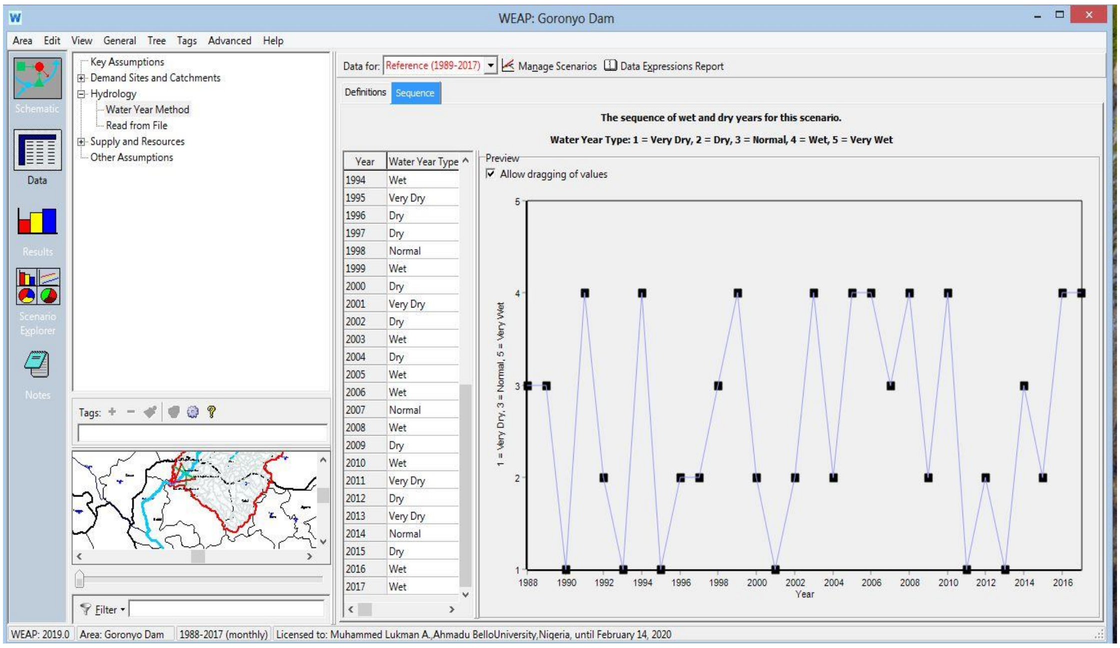
At this stage, the scenarios set up was carried out following prescribed climate variability and the water availability of all scenarios was analyzed (Figure 3.3). The water availability for different scenarios adopted was obtained by using the water year values as shown in Figure 3.4



Current Accounts (1988)
- Reference (1989-2070)
  - SCENARIO 1 (1989-2070)
  - SCENARIO 2 (1989-2070)
  - SCENARIO 3 (1989-2070)
  - SCENARIO 4 (1989-2070)
  - SCENARIO 5 (1989-2070)
  - SCENARIO 6 (1989-2070)
  - SCENARIO 7 (1989-2070)
  - SCENARIO 8 (1989-2070)
  - SCENARIO 9 (1989-2070)

Year	Water Year Type
1988	Normal
1989	Normal
1990	Very Dry
1991	Wet
1992	Dry
1993	Very Dry
1994	Wet
1995	Very Dry
1996	Dry
1997	Dry
1998	Normal
1999	Wet
2000	Dry
2001	Very Dry
2002	Dry
2003	Wet
2004	Dry
2005	Wet
2006	Wet
2007	Normal
2008	Wet
2009	Dry
2010	Wet
2011	Very Dry

Figure 3.3: Setting up of all scenarios



The sequence of wet and dry years for this scenario.

Water Year Type: 1 = Very Dry, 2 = Dry, 3 = Normal, 4 = Wet, 5 = Very Wet

Year	Water Year Type
1994	Wet
1995	Very Dry
1996	Dry
1997	Dry
1998	Normal
1999	Wet
2000	Dry
2001	Very Dry
2002	Dry
2003	Wet
2004	Dry
2005	Wet
2006	Wet
2007	Normal
2008	Wet
2009	Dry
2010	Wet
2011	Very Dry
2012	Dry
2013	Very Dry
2014	Normal
2015	Dry
2016	Wet
2017	Wet

Figure 3.4: Water year values

The obtained values for each scenario generate runoff based on its climatic water year value. These values are shown in chapter (4) four. The water availability was evaluated based on the difference between the total available water within the catchment under scenarios and total water demand from the catchment of the model, the water availability in each scenario is then analyzed to evaluate the sensitivity and reliability of the study based on climate change scenario. The impact of climate change on water demand and supply can easily be analyzed based on the availability of water within the area.

3.9 Water demand

In 2010, the Food and Agricultural Organization of the United Nations, online Water use database, indicate that the water use in Nigeria ranges from 78.67 to 118.6 liters per capita per day. Therefore, the value of 120 liters per capita per day was used as the approximate maximum water use-value. The demographic data of the area was projected by using the inter census growth rate of the 1991 and 2006 population census. Therein, the Global Rice Science Partnership (GRIP),2013: Norton *et al.*,2018 indicate that for flood irrigation system, the water use for rice per hectare is 10750MCM. Therefore, the value of 10750MCM was adopted as the water use rate per hectare. since in the area, rice is the most water-demanding crop plant.

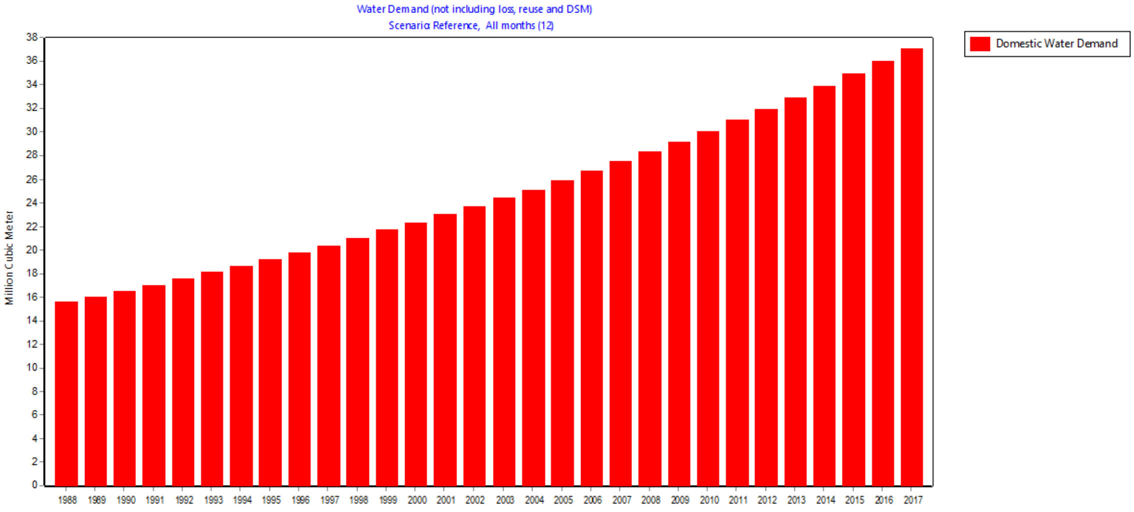


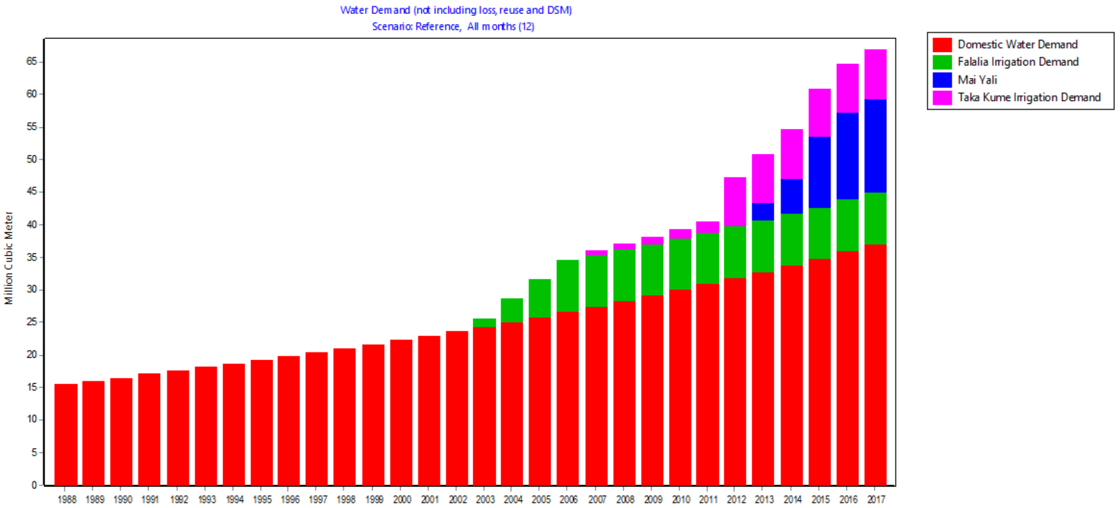
Figure 3.5 Domestic water demand of reference account

Figure 3.6 Water demand including all branches of reference account

Figure 3.6 shows the image of the water demand of the reference account involving all branches i.e. domestics and agricultural demands.

3.10 Questionnaire analysis

A survey was conducted which demanded a response of people in the study area in respect to their water consumptives uses. According to the result analysis considering various water consumptive activities, 135 liters per capita per day was adopted for the study area. The breakdown is shown in table 3.4 this was done after consulting different journals. For instance, WHO (1996) reported that in Europe average of 200 liters per person a day, and according to WHO technical report on minimum water quantity needed for domestics uses for developed countries is a 220-liter person a day. Finally, according to Nema (2011), he reported that for developing countries like India the average water requirement per person a day is 135 liters under normal conditions. Therefore, this was chosen to justify the result from the responses of the study area via questionnaires.



Domestic water uses	Average daily uses (Litres)
Drinking	5
Toilets	30
Bathing	30
Laundry	30
Cooking	15
Cleaning (Others)	25
Total	135

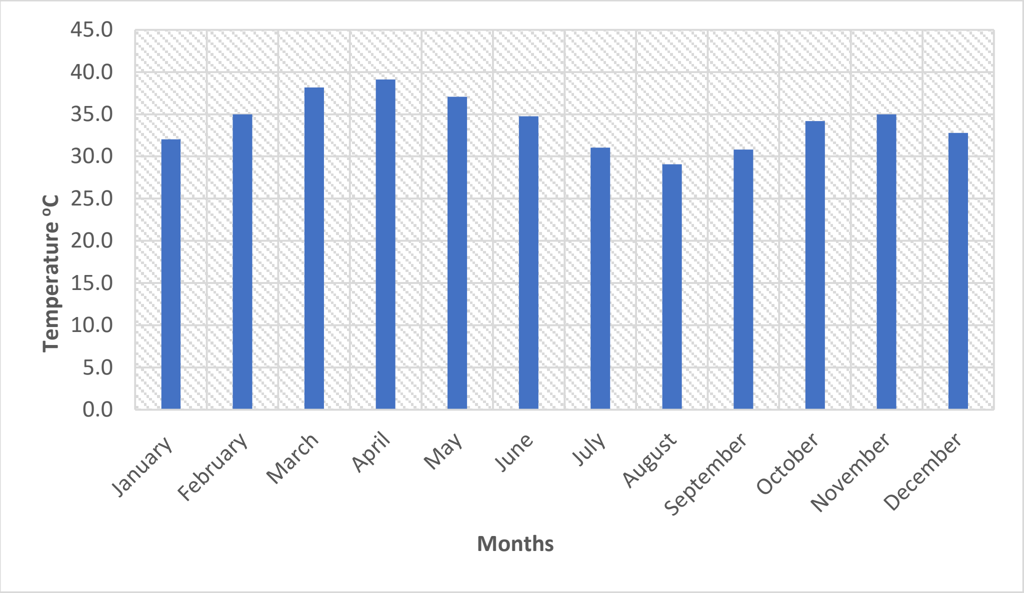
Table 3.4: Domestic water uses per capita per day

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This section displays an outline of the model results, the summary of the various parameters analyses as it is essential to effective recreation of the hydrology of the area, the strategies utilized in parameter data preparation, and the results of the calibration are also presented.



4.2 Trend analysis

Figure 4.1 The mean monthly temperature of the area.

The average monthly temperature value for Sokoto station is 34.1°C, the maximum value is 39.1°C in April, the minimum value is 29.1°C. The standard deviation and variance of this data are 3.1 and 9.43 respectively.

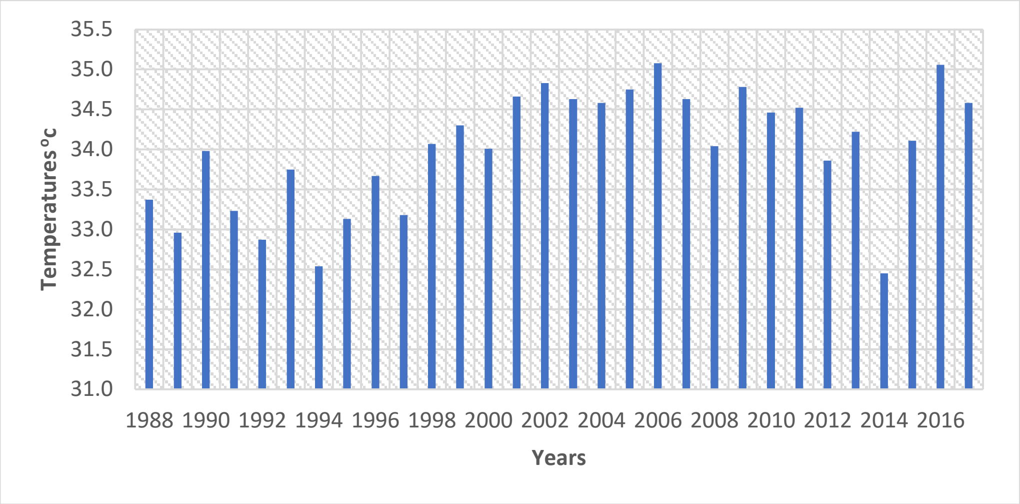


Figure 4.2 The annual average temperature of the area

The annual average temperature range of the area has an average temperature value of 34.0°C, the minimum value is 32.5°C in the year 1994 and 2014, with the maximum value of 35.1°C in the year 2006. The standard deviation and variance of the data are 0.75 and 0.56 respectively.

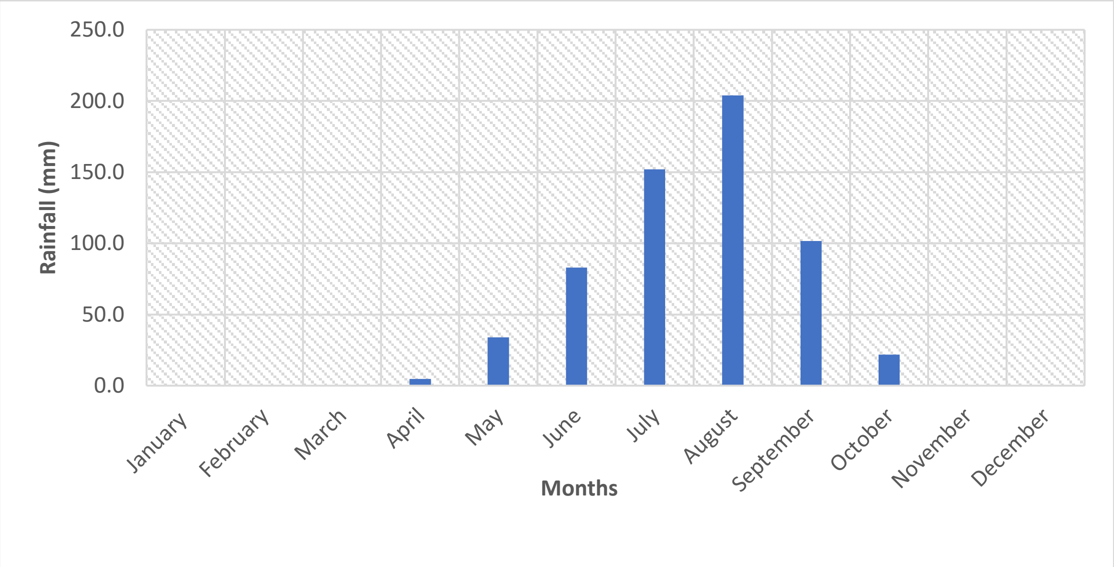


Figure 4.3. The chart of the mean monthly rainfall of the area.

The average monthly rainfall value of 50.1mm, with a maximum value of 203.9mm in August, the months of January, February, November, and December have no rainfall. The standard deviation and variance of the data in this station are 69.7 and 4857.2 respectively.

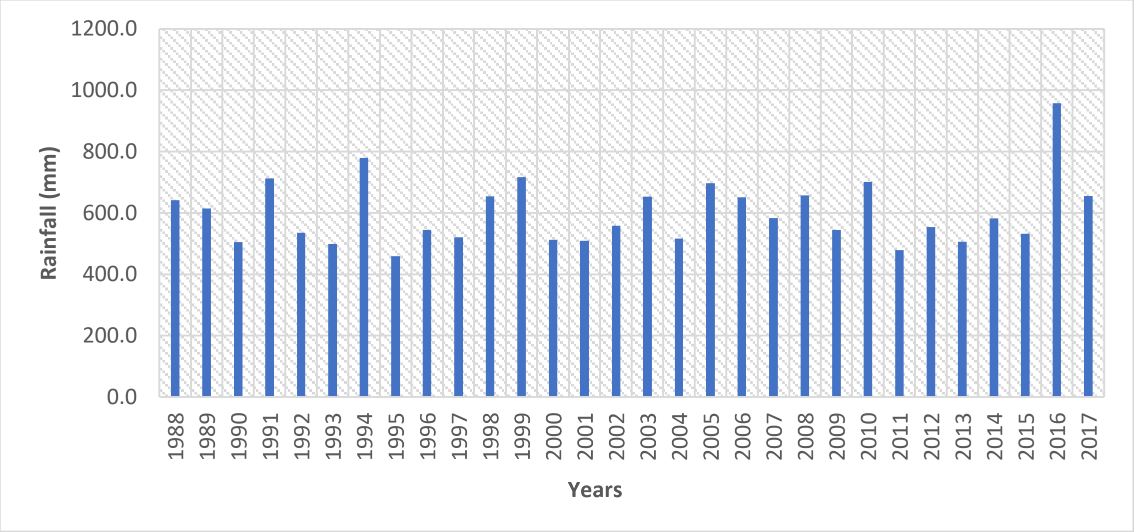


Figure 4.4 The annual rainfall data of the area.

The mean annual rainfall of the area is as shown in Figure 4.4, this displays the annual average pattern of rainfall in the area from 1988 to 2017. The maximum and minimum average values of 958.1mm and 459.6mm are in the years 2016 and 1995 respectively.

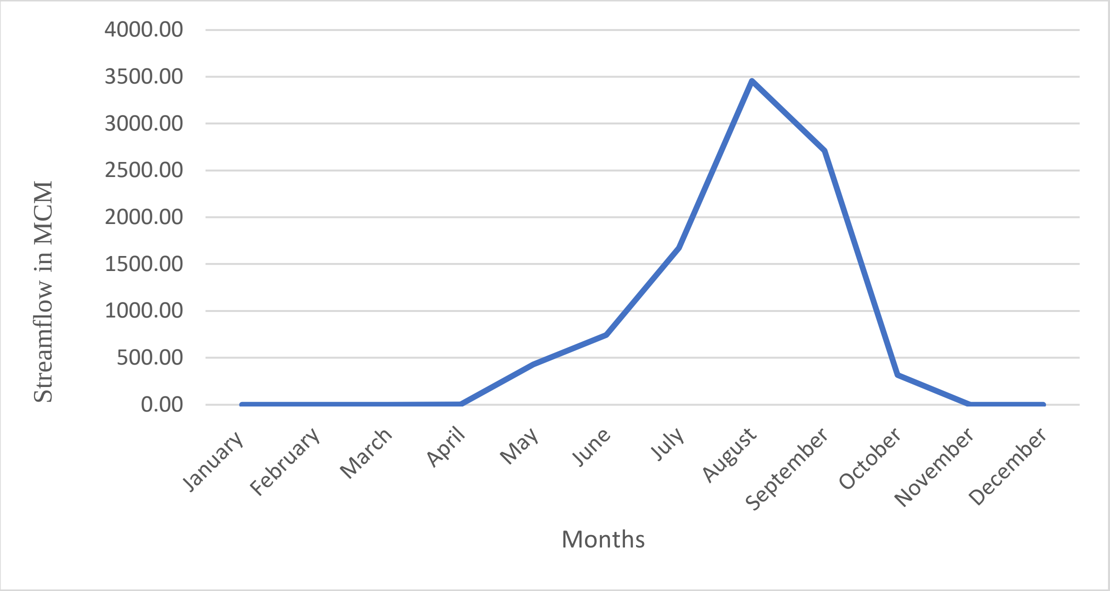


Figure 4.5 Monthly Average Streamflow Measured for Rima River

The streamflow data used was obtained from literature are the historical data this was done due to lack of adequate hardcopy data. The monthly average measured streamflow patterns of Rima rivers are shown in Figure 4.5. which is the main river dam (i.e.

Goronyo Reservoir). The measured monthly average streamflow volume data indicates a total volume of 9.33 billion cubic meters (BCM)or 9331.9MCM, with a mean of 777.7 million cubic meters (MCM).

4.3 Analysis of the temperature trend for generating climate scenarios

The annual average maximum temperature of the area was analyzed. It indicates a maximum average annual temperature of 35.1^{0}C and minimum temperature of 29.1^{0}C and a standard deviation of 0.75. The linear trend analysis in Figure 4.6 below indicates a gradient of 0. 044. This designates a decadal increase of about 0.40^{0}C. Therefore, the value of 0.4^{0}C to 1.2^{0}C was selected as the projection of temperature increase for this region by considering temperature variation over four decades.

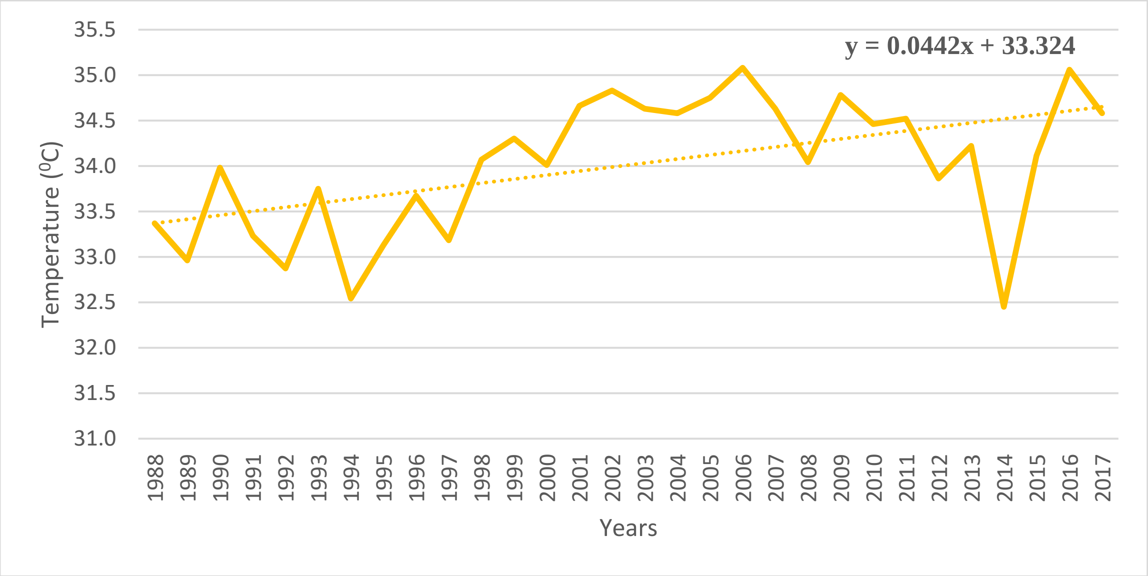


Figure 4.6 Temperature Trend Analysis

4.4 Analysis of the rainfall trend for generating climate scenarios

The average annual rainfall of the area was also analyzed. It indicates a maximum average rainfall value of 958.1mm and a minimum average value of 459mm with a mean of 601.1mm and a standard deviation of 107.32. The linear trend analysis as shown in Figure 4.7 indicates a gradient of 10.0. This designates an annual increase of about 10%. Therefore, the value of 10% increase in rainfall and 10% decrease in rainfall was selected as the projection for climate change for this region by considering average rainfall value variation over four decades.

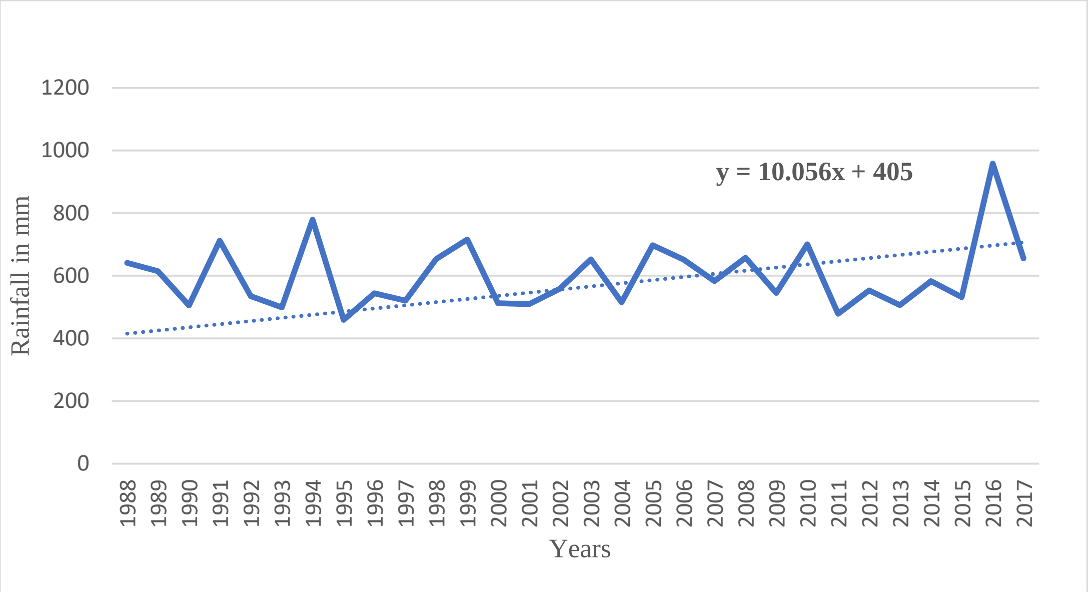


Figure 4.7 Rainfall in mm Trend Analysis

Table 4.1: Hypothetical climate change scenario One (1) data

SCENARIO 1: +0.4 °C						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	33.77	3.15	41.17	641.4	1.067026002	Normal
1989	33.36	3.20	39.60	614.7	1.022608175	Normal
1990	34.38	2.80	40.95	505.1	0.840278818	Very Dry
1991	33.63	2.68	45.58	712.4	1.185140823	Wet
1992	33.27	3.05	42.01	535.0	0.890020129	Dry
1993	34.15	2.79	40.61	498.8	0.829798207	Very Dry
1994	32.94	3.01	45.06	779.6	1.296934005	Very Wet
1995	33.53	2.87	44.68	459.6	0.764585517	Very Dry
1996	34.07	2.71	42.27	544.6	0.905990584	Dry
1997	33.58	2.76	44.10	520.7	0.866230806	Dry
1998	34.47	2.77	41.91	654.1	1.088153583	Normal
1999	34.70	2.62	40.44	716.3	1.19162882	Wet
2000	34.41	2.87	42.70	512.4	0.852423017	Dry
2001	35.06	2.89	37.82	509.6	0.847764968	Very Dry
2002	35.23	2.65	40.28	558.0	0.928282677	Dry
2003	35.03	2.74	41.36	652.6	1.085658199	Wet
2004	34.98	2.69	41.91	516.0	0.858411938	Dry
2005	35.15	2.78	42.16	697.3	1.160020629	Very Wet
2006	35.48	2.61	38.82	651.3	1.083495533	Wet
2007	35.03	2.80	38.82	583.2	0.970205121	Normal
2008	34.44	2.94	38.17	657.8	1.094308862	Wet
2009	35.18	2.60	40.73	544.7	0.906156943	Dry
2010	34.86	2.72	42.02	701.1	1.166342267	Wet
2011	34.92	2.88	38.03	478.9	0.796692785	Very Dry
2012	34.26	2.23	42.75	553.7	0.921129244	Dry
2013	34.62	2.42	42.60	506.2	0.842108765	Very Dry
2014	32.85	2.70	41.07	582.7	0.969373326	Normal
2015	34.51	2.83	39.31	532.2	0.88536208	Dry
2016	35.46	2.76	42.05	958.1	1.593884647	Very Wet
2017	34.98	2.86	38.60	655.2	1.08998353	Wet

Table 4.1 shows the hypothetical climate change scenario 1 data of average annual temperature, wind speed, relative humidity, and rainfall with the equivalent water year type, derived based on the description of the water year method. The +0.4^{0}C increase in temperature is within the range of expected climate change and is expected to increase evaporation and evapotranspiration,

this will afterward affect the runoff obtained from the rainfall and thereby affect water available in the area, with all other parameters being equal. This scenario will help to answer the question of what if the temperature should increase by +0.4°C due to climate change.

Table 4.2: Hypothetical climate change scenario two (2) data

SCENARIO 2: +0.4 °C & +10%R						
	Temp. °C	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	33.77	3.15	41.17	705.54	1.173729	Wet
1989	33.36	3.20	39.60	676.17	1.124869	Wet
1990	34.38	2.80	40.95	555.61	0.924307	Dry
1991	33.63	2.68	45.58	783.64	1.303655	Wet
1992	33.27	3.05	42.01	588.5	0.979022	Normal
1993	34.15	2.79	40.61	548.68	0.912778	Dry
1994	32.94	3.01	45.06	857.56	1.426627	Wet
1995	33.53	2.87	44.68	505.56	0.841044	Very Dry
1996	34.07	2.71	42.27	599.06	0.99659	Normal
1997	33.58	2.76	44.10	572.77	0.952854	Wet
1998	34.47	2.77	41.91	719.51	1.196969	Wet
1999	34.7	2.62	40.44	787.93	1.310792	Wet
2000	34.41	2.87	42.70	563.64	0.937665	Dry
2001	35.06	2.89	37.82	560.56	0.932541	Dry
2002	35.23	2.65	40.28	613.80	1.021111	Normal
2003	35.03	2.74	41.36	717.86	1.194224	Wet
2004	34.98	2.69	41.91	567.60	0.944253	Dry
2005	35.15	2.78	42.16	767.03	1.276023	Wet
2006	35.48	2.61	38.82	716.43	1.191845	Wet
2007	35.03	2.80	38.82	641.52	1.067226	Wet
2008	34.44	2.94	38.17	723.58	1.20374	Wet
2009	35.18	2.60	40.73	599.17	0.996773	Normal
2010	34.86	2.72	42.02	771.21	1.282976	Wet
2011	34.92	2.88	38.03	526.79	0.876362	Dry
2012	34.26	2.23	42.75	609.07	1.013242	Normal
2013	34.62	2.42	42.60	556.82	0.92632	Dry
2014	32.85	2.70	41.07	640.97	1.066311	Wet
2015	34.51	2.83	39.31	585.42	0.973898	Normal
2016	35.46	2.76	42.05	1053.91	1.753273	Very Wet
2017	34.94	2.86	38.60	720.72	1.198982	Wet

Table 4.2 shows the hypothetical climate change scenario 2 data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The +0.4 ^{0}C increase in temperature is within the range of expected climate change and is expected to increase evaporation and evapotranspiration, this will subsequently affect the runoff obtained from the rainfall, with all other parameters being equal. The 10% increase in rainfall is assigned due to the ambiguity in the change caused by climate change in the rainfall. A similar uncertainty effect was described by the IPCC (2014) and emphasis was made on this by Abdullahi (2014). This scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by +0.4^{o}C and 10% rainfall due to climate change.

Table 4.3: Hypothetical climate change Scenario three (3) data

SCENARIO 3: +0.4°C, - %10R						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	33.77	3.15	41.174	577.26	0.960323	Normal
1989	33.36	3.20	39.6	553.23	0.920347	Dry
1990	34.38	2.80	40.95	454.59	0.756251	Dry
1991	33.63	2.68	45.58	641.16	1.066627	Wet
1992	33.27	3.05	42.01	481.5	0.801018	Dry
1993	34.15	2.79	40.61	448.92	0.746818	Very Dry
1994	32.94	3.01	45.06	701.64	1.167241	Wet
1995	33.53	2.87	44.68	413.64	0.688127	Very Dry
1996	34.07	2.71	42.27	490.14	0.815392	Dry
1997	33.58	2.76	44.10	468.63	0.779608	Dry
1998	34.47	2.77	41.91	588.69	0.979338	Normal
1999	34.7	2.62	40.44	644.67	1.072466	Wet
2000	34.41	2.87	42.70	461.16	0.767181	Dry
2001	35.06	2.89	37.817	458.64	0.762988	Dry
2002	35.23	2.65	40.283	502.2	0.835454	Dry
2003	35.03	2.74	41.361	587.34	0.977092	Normal
2004	34.98	2.69	41.913	464.4	0.772571	Dry
2005	35.15	2.78	42.158	627.57	1.044019	Normal
2006	35.48	2.61	38.821	586.17	0.975146	Normal
2007	35.03	2.80	38.824	524.88	0.873185	Dry
2008	34.44	2.94	38.174	592.02	0.984878	Normal
2009	35.18	2.60	40.731	490.23	0.815541	Dry
2010	34.86	2.72	42.017	630.99	1.049708	Normal
2011	34.92	2.88	38.028	431.01	0.717024	Very Dry
2012	34.26	2.23	42.753	498.33	0.829016	Dry
2013	34.62	2.42	42.602	455.58	0.757898	Dry
2014	32.85	2.70	41.069	524.43	0.872436	Dry
2015	34.51	2.83	39.308	478.98	0.796826	Dry
2016	35.46	2.76	42.049	862.29	1.434496	Very Wet
2017	34.98	2.86	38.604	589.68	0.980985	Normal

Table 4.3 shows the hypothetical climate change scenario 3 data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The +0.4^{0}C increase in temperature is within the range of expected climate

change and is expected to increase evaporation and evapotranspiration, this will subsequently affect the runoff obtained from the rainfall, with all other parameters being equal. The 10% decrease in rainfall is assigned due to the ambiguity in the change caused by climate change in the rainfall. A similar uncertainty effect was described by the IPCC (2014) and emphasis was made on this by Abdullahi (2014). This scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by $+0.4^0C$ and a 10% decrease in rainfall due to climate change.

Table 4.4: Hypothetical climate change scenario four (4) data

SCENARIO 4: +0.8 °C						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	34.17	3.15	41.174	641.4	1.067026	Normal
1989	33.76	3.20	39.6	614.7	1.022608	Normal
1990	34.78	2.80	40.95	505.1	0.840279	Very Dry
1991	34.03	2.68	45.58	712.4	1.185141	Wet
1992	33.67	3.05	42.01	535	0.89002	Dry
1993	34.55	2.79	40.61	498.8	0.829798	Very Dry
1994	33.34	3.01	45.06	779.6	1.296934	Very Wet
1995	33.93	2.87	44.68	459.6	0.764586	Very Dry
1996	34.47	2.71	42.27	544.6	0.905991	Dry
1997	33.98	2.76	44.1	520.7	0.866231	Dry
1998	34.87	2.77	41.905	654.1	1.088154	Normal
1999	35.1	2.62	40.4425	716.3	1.191629	Wet
2000	34.81	2.87	42.7	512.4	0.852423	Dry
2001	35.46	2.89	37.817	509.6	0.847765	Very Dry
2002	35.63	2.65	40.283	558	0.928283	Dry
2003	35.43	2.74	41.361	652.6	1.085658	Wet
2004	35.38	2.69	41.913	516	0.858412	Dry
2005	35.55	2.78	42.158	697.3	1.160021	Very Wet
2006	35.88	2.61	38.821	651.3	1.083496	Wet
2007	35.43	2.80	38.824	583.2	0.970205	Normal
2008	34.84	2.94	38.174	657.8	1.094309	Wet
2009	35.58	2.60	40.731	544.7	0.906157	Dry
2010	35.26	2.72	42.017	701.1	1.166342	Wet
2011	35.32	2.88	38.028	478.9	0.796693	Very Dry
2012	34.66	2.23	42.753	553.7	0.921129	Dry
2013	35.02	2.42	42.602	506.2	0.842109	Very Dry
2014	33.25	2.70	41.069	582.7	0.969373	Normal
2015	34.91	2.83	39.308	532.2	0.885362	Dry
2016	35.86	2.76	42.049	958.1	1.593885	Very Wet
2017	35.38	2.86	38.604	655.2	1.089984	Wet

Table 4.4 shows the hypothetical climate change scenario four (4) data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The +0.8^{0}C increase in temperature is within the range of expected climate change and is expected to increase evaporation and

evapotranspiration, this scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by $+0.8^0$C due to climate change.

Table 4.5: Hypothetical climate change scenario five (5) data

SCENARIO 5: +0.8°C, +10%R						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	34.17	3.15	41.174	705.54	1.17373	Wet
1989	33.76	3.20	39.6	676.17	1.12487	Wet
1990	34.78	2.80	40.95	555.61	0.92431	Dry
1991	34.03	2.68	45.58	783.64	1.30365	Wet
1992	33.67	3.05	42.01	588.5	0.97902	Normal
1993	34.55	2.79	40.61	548.68	0.91278	Dry
1994	33.34	3.01	45.06	857.56	1.42663	Wet
1995	33.93	2.87	44.68	505.56	0.84104	Very Dry
1996	34.47	2.71	42.27	599.06	0.99659	Normal
1997	33.98	2.76	44.1	572.77	0.95285	Wet
1998	34.87	2.77	41.905	719.51	1.19697	Wet
1999	35.1	2.62	40.4425	787.93	1.31079	Wet
2000	34.81	2.87	42.7	563.64	0.93767	Dry
2001	35.46	2.89	37.817	560.56	0.93254	Dry
2002	35.63	2.65	40.283	613.8	1.02111	Normal
2003	35.43	2.74	41.361	717.86	1.19422	Wet
2004	35.38	2.69	41.913	567.6	0.94425	Dry
2005	35.55	2.78	42.158	767.03	1.27602	Wet
2006	35.88	2.61	38.821	716.43	1.19185	Wet
2007	35.43	2.80	38.824	641.52	1.06723	Wet
2008	34.84	2.94	38.174	723.58	1.20374	Wet
2009	35.58	2.60	40.731	599.17	0.99677	Normal
2010	35.26	2.72	42.017	771.21	1.28298	Wet
2011	35.32	2.88	38.028	526.79	0.87636	Dry
2012	34.66	2.23	42.753	609.07	1.01324	Normal
2013	35.02	2.42	42.602	556.82	0.92632	Dry
2014	33.25	2.70	41.069	640.97	1.06631	Wet
2015	34.91	2.83	39.308	585.42	0.9739	Normal
2016	35.86	2.76	42.049	1053.91	1.75327	Very Wet
2017	35.38	2.86	38.604	720.72	1.19898	Wet

Table 4.5 shows the hypothetical climate change scenario 5 data of average annual temperature, wind speed, relative humidity, and rainfall with the

corresponding classification of the year type, derived based on the description of the water year method. The +0.8^{0}C increase in temperature is within the range of expected climate change and is expected to increase evaporation and evapotranspiration. This will subsequently affect the runoff obtained from the rainfall, with all other parameters being equal. The 10% increase in rainfall is assigned due to the ambiguity in the change caused by climate change in the rainfall. A similar uncertainty effect was described by the IPCC (2014) and emphasis was made on this by Abdullahi (2014). This scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by +0.8^{0}C and 10% rainfall due to climate change.

Table 4.6: Hypothetical climate change scenario Six (6) data

SCENARIO 6: +0.8°C, -10%R						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	34.17	3.15	41.174	577.26	0.960323	Normal
1989	33.76	3.20	39.6	553.23	0.920347	Dry
1990	34.78	2.80	40.95	454.59	0.756251	Dry
1991	34.03	2.68	45.58	641.16	1.066627	Wet
1992	33.67	3.05	42.01	481.5	0.801018	Dry
1993	34.55	2.79	40.61	448.92	0.746818	Very Dry
1994	33.34	3.01	45.06	701.64	1.167241	Wet
1995	33.93	2.87	44.68	413.64	0.688127	Very Dry
1996	34.47	2.71	42.27	490.14	0.815392	Dry
1997	33.98	2.76	44.1	468.63	0.779608	Dry
1998	34.87	2.77	41.905	588.69	0.979338	Normal
1999	35.1	2.62	40.4425	644.67	1.072466	Wet
2000	34.81	2.87	42.7	461.16	0.767181	Dry
2001	35.46	2.89	37.817	458.64	0.762988	Dry
2002	35.63	2.65	40.283	502.2	0.835454	Dry
2003	35.43	2.74	41.361	587.34	0.977092	Normal
2004	35.38	2.69	41.913	464.4	0.772571	Dry
2005	35.55	2.78	42.158	627.57	1.044019	Normal
2006	35.88	2.61	38.821	586.17	0.975146	Normal
2007	35.43	2.80	38.824	524.88	0.873185	Dry
2008	34.84	2.94	38.174	592.02	0.984878	Normal
2009	35.58	2.60	40.731	490.23	0.815541	Dry

SCENARIO 6: +0.8°C, -10% R Continue						
2010	35.26	2.72	42.017	630.99	1.049708	Normal
2011	35.32	2.88	38.028	431.01	0.717024	Very Dry
2012	34.66	2.23	42.753	498.33	0.829016	Dry
2013	35.02	2.42	42.602	455.58	0.757898	Dry
2014	33.25	2.70	41.069	524.43	0.872436	Dry
2015	34.91	2.83	39.308	478.98	0.796826	Dry
2016	35.86	2.76	42.049	862.29	1.434496	Very Wet
2017	35.38	2.86	38.604	589.68	0.980985	Normal

Table 4.6 shows the hypothetical climate change scenario 6 data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The +0.8^{0}C increase in temperature is within the range of expected climate change and is expected to increase evaporation and evapotranspiration, this will subsequently affect the runoff obtained from the rainfall, with all other parameters being equal. The 10% decrease in rainfall is assigned due to the ambiguity in the change caused by climate change in the rainfall. A similar uncertainty effect was described by the IPCC (2014) and emphasis was made on this by Abdullahi (2014). This scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by +0.8^{0}C and a 10% decrease in rainfall due to climate change.

Table 4.7: Hypothetical climate change scenario seven (7) data

SCENARIO 7: +1.2 °C						
Year	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	34.57	3.15	41.174	641.4	1.06703	Normal
1989	34.16	3.20	39.6	614.7	1.02261	Normal
1990	35.18	2.80	40.95	505.1	0.84028	Very Dry
1991	34.43	2.68	45.58	712.4	1.18514	Wet
1992	34.07	3.05	42.01	535	0.89002	Dry
1993	34.95	2.79	40.61	498.8	0.8298	Very Dry
1994	33.74	3.01	45.06	779.6	1.29693	Very Wet
1995	34.33	2.87	44.68	459.6	0.76459	Very Dry
1996	34.87	2.71	42.27	544.6	0.90599	Dry
1997	34.38	2.76	44.1	520.7	0.86623	Dry
1998	35.27	2.77	41.905	654.1	1.08815	Normal
1999	35.5	2.62	40.4425	716.3	1.19163	Wet
2000	35.21	2.87	42.7	512.4	0.85242	Dry
2001	35.86	2.89	37.817	509.6	0.84776	Very Dry
2002	36.03	2.65	40.283	558	0.92828	Dry
2003	35.83	2.74	41.361	652.6	1.08566	Wet
2004	35.78	2.69	41.913	516	0.85841	Dry
2005	35.95	2.78	42.158	697.3	1.16002	Very Wet
2006	36.28	2.61	38.821	651.3	1.0835	Wet
2007	35.83	2.80	38.824	583.2	0.97021	Normal
2008	35.24	2.94	38.174	657.8	1.09431	Wet
2009	35.98	2.60	40.731	544.7	0.90616	Dry
2010	35.66	2.72	42.017	701.1	1.16634	Wet
2011	35.72	2.88	38.028	478.9	0.79669	Very Dry
2012	35.06	2.23	42.753	553.7	0.92113	Dry
2013	35.42	2.42	42.602	506.2	0.84211	Very Dry
2014	33.65	2.70	41.069	582.7	0.96937	Normal
2015	35.31	2.83	39.308	532.2	0.88536	Dry
2016	36.26	2.76	42.049	958.1	1.59388	Very Wet
2017	35.78	2.86	38.604	655.2	1.08998	Wet

Table 4.7 shows the hypothetical climate change scenario 7 data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The +1.2^{0}C increase in temperature is within the range

of expected climate change and is expected to increase evaporation and evapotranspiration, this scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by +1.2^{0}C due to climate change.

Table 4.8: Hypothetical climate change scenario eight (8) data

SCENARIO 8: +1.2 °C &+10% R						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	34.57	3.15	41.174	705.54	1.17373	Wet
1989	34.16	3.20	39.6	676.17	1.12487	Wet
1990	35.18	2.80	40.95	555.61	0.92431	Dry
1991	34.43	2.68	45.58	783.64	1.30365	Wet
1992	34.07	3.05	42.01	588.5	0.97902	Normal
1993	34.95	2.79	40.61	548.68	0.91278	Dry
1994	33.74	3.01	45.06	857.56	1.42663	Wet
1995	34.33	2.87	44.68	505.56	0.84104	Very Dry
1996	34.87	2.71	42.27	599.06	0.99659	Normal
1997	34.38	2.76	44.1	572.77	0.95285	Wet
1998	35.27	2.77	41.905	719.51	1.19697	Wet
1999	35.5	2.62	40.4425	787.93	1.31079	Wet
2000	35.21	2.87	42.7	563.64	0.93767	Dry
2001	35.86	2.89	37.817	560.56	0.93254	Dry
2002	36.03	2.65	40.283	613.8	1.02111	Normal
2003	35.83	2.74	41.361	717.86	1.19422	Wet
2004	35.78	2.69	41.913	567.6	0.94425	Dry
2005	35.95	2.78	42.158	767.03	1.27602	Wet
2006	36.28	2.61	38.821	716.43	1.19185	Wet
2007	35.83	2.80	38.824	641.52	1.06723	Wet
2008	35.24	2.94	38.174	723.58	1.20374	Wet
2009	35.98	2.60	40.731	599.17	0.99677	Normal
2010	35.66	2.72	42.017	771.21	1.28298	Wet
2011	35.72	2.88	38.028	526.79	0.87636	Dry
2012	35.06	2.23	42.753	609.07	1.01324	Normal
2013	35.42	2.42	42.602	556.82	0.92632	Dry
2014	33.65	2.70	41.069	640.97	1.06631	Wet
2015	35.31	2.83	39.308	585.42	0.9739	Normal
2016	36.26	2.76	42.049	1053.91	1.75327	Very Wet
2017	35.78	2.86	38.604	720.72	1.19898	Wet

Table 4.8 shows the hypothetical climate change scenario 8 data of average annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The $+1.2^0$C increase in temperature is within the range of expected climate change and is expected to increase evaporation and evapotranspiration, this will subsequently affect the runoff obtained from the rainfall, with all other parameters being equal. The 10% increase in rainfall is assigned due to the ambiguity in the change caused by climate change in the rainfall. A similar uncertainty effect was described by the IPCC (2014) and emphasis was made on this by Abdullahi (2014). This scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by $+1.2^0$C and 10% rainfall due to climate change.

Table 4.9: Hypothetical climate change scenario nine (9) data

SCENARIO 9: +1.2°C & -10%R						
Years	**Temp. °C**	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Water Year Value**	**Water Year Type**
1988	34.57	3.15	41.174	577.26	0.96032	Normal
1989	34.16	3.20	39.6	553.23	0.92035	Dry
1990	35.18	2.80	40.95	454.59	0.75625	Dry
1991	34.43	2.68	45.58	641.16	1.06663	Wet
1992	34.07	3.05	42.01	481.5	0.80102	Dry
1993	34.95	2.79	40.61	448.92	0.74682	Very Dry
1994	33.74	3.01	45.06	701.64	1.16724	Wet
1995	34.33	2.87	44.68	413.64	0.68813	Very Dry
1996	34.87	2.71	42.27	490.14	0.81539	Dry
1997	34.38	2.76	44.1	468.63	0.77961	Dry
1998	35.27	2.77	41.905	588.69	0.97934	Normal
1999	35.5	2.62	40.4425	644.67	1.07247	Wet
2000	35.21	2.87	42.7	461.16	0.76718	Dry
2001	35.86	2.89	37.817	458.64	0.76299	Dry
2002	36.03	2.65	40.283	502.2	0.83545	Dry
2003	35.83	2.74	41.361	587.34	0.97709	Normal
2004	35.78	2.69	41.913	464.4	0.77257	Dry
2005	35.95	2.78	42.158	627.57	1.04402	Normal
2006	36.28	2.61	38.821	586.17	0.97515	Normal
2007	35.83	2.80	38.824	524.88	0.87318	Dry
2008	35.24	2.94	38.174	592.02	0.98488	Normal
2009	35.98	2.60	40.731	490.23	0.81554	Dry
2010	35.66	2.72	42.017	630.99	1.04971	Normal
2011	35.72	2.88	38.028	431.01	0.71702	Very Dry
2012	35.06	2.23	42.753	498.33	0.82902	Dry
2013	35.42	2.42	42.602	455.58	0.7579	Dry
2014	33.65	2.70	41.069	524.43	0.87244	Dry
2015	35.31	2.83	39.308	478.98	0.79683	Dry
2016	36.26	2.76	42.049	862.29	1.4345	Very Wet
2017	35.78	2.86	38.604	589.68	0.98099	Normal

Table 4.9 shows the hypothetical climate change scenario 9 data of average

annual temperature, wind speed, relative humidity, and rainfall with the corresponding classification of the year type, derived based on the description of the water year method. The $+1.2^0$C increase in temperature is within the range of expected climate change and is expected to increase evaporation and evapotranspiration, this will subsequently affect the runoff obtained from the rainfall, with all other parameters being equal. The 10% decrease in rainfall is assigned due to the ambiguity in the change caused by climate change in the rainfall. A similar uncertainty effect was described by the IPCC (2014) and emphasis was made on this by Abdullahi (2014). This scenario will tend to answer the question of what will happen to the surface water under an increase in temperature by $+1.2^0$C and a 10% decrease in rainfall due to climate change.

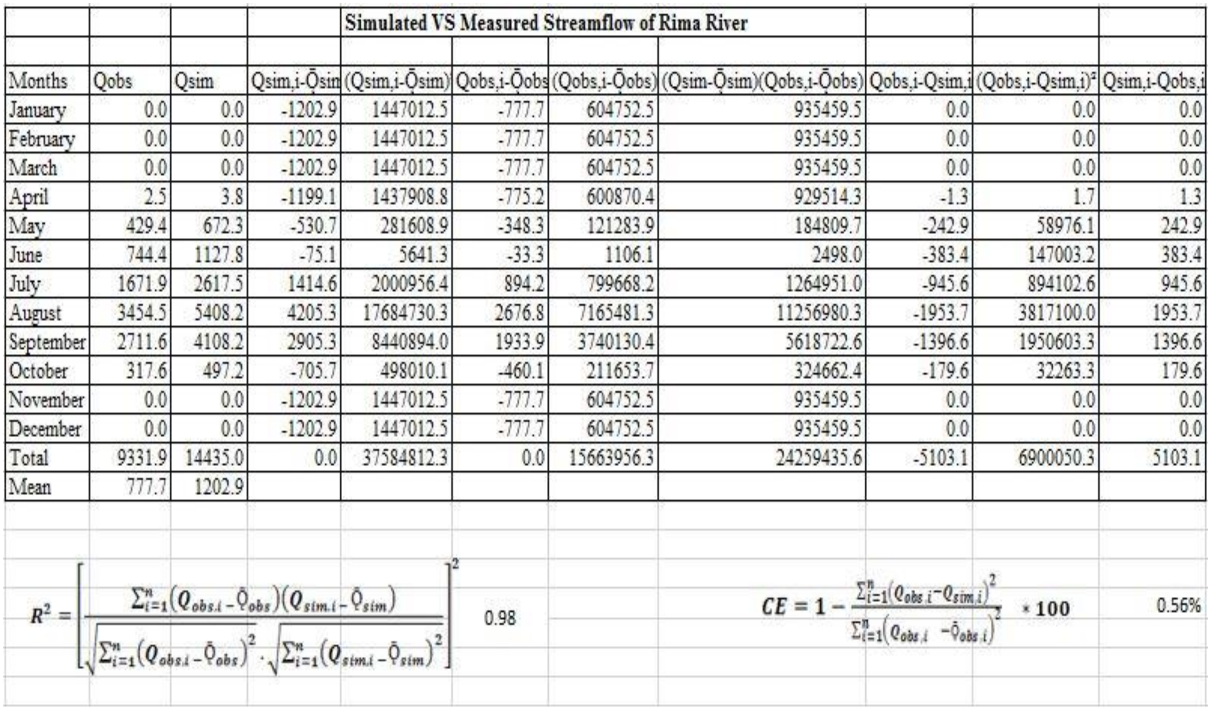
4.5 Streamflow simulation

The average simulated streamflow volume of the Rima river using WEAP software is shown in Table 4.1 and Figure 4.8, the total mean average of the volume of water was found to be 14.4BCM and has maximum streamflow of 5.4 BCM in August and at the beginning of the rainy years, the average mean monthly value was 3.79MCM. This shows a little increment from what was gotten by Abdullahi 2015. He obtained the overall streamflow volume to be 11.6BCM for the rima river which drains both rivers buguru and gagere.

4.6 Calibration and validation result

After a successful model Set up and Calibration with historical values. An obvious validation was first made by comparing graphically the simulated values with the observed values. Some efficiency criteria such as the Coefficient of regression (R^2) and Coefficient of efficiency (C.E) were employed to access how fit the model reproduces the observed measurement using excel. Table 4.10 shows the calculations of objective functions that were used for the determination of efficiency parameters of rima river streamflow simulation. The obtained values for the Coefficient of determination R^2 is 0.98 and Nash- Sutcliffe coefficient (C.E) is 0.56% the value obtain lies within the specified ranges (i.e. 0 -1) to prove that the model performed well.

Table 4.10: The simulated versus measured average monthly streamflow of rima river analysis.



				Simulated VS Measured Streamflow of Rima River					
Months	Qobs	Qsim	Qsim,i-Q̄sin	(Qsim,i-Q̄sim)	Qobs,i-Q̄obs	(Qobs,i-Q̄obs)	(Qsim-Q̄sim)(Qobs,i-Q̄obs)	Qobs,i-Qsim,i	(Qobs,i-Qsim,i)²	Qsim,i-Qobs,i
January	0.0	0.0	-1202.9	1447012.5	-777.7	604752.5	935459.5	0.0	0.0	0.0
February	0.0	0.0	-1202.9	1447012.5	-777.7	604752.5	935459.5	0.0	0.0	0.0
March	0.0	0.0	-1202.9	1447012.5	-777.7	604752.5	935459.5	0.0	0.0	0.0
April	2.5	3.8	-1199.1	1437908.8	-775.2	600870.4	929514.3	-1.3	1.7	1.3
May	429.4	672.3	-530.7	281608.9	-348.3	121283.9	184809.7	-242.9	58976.1	242.9
June	744.4	1127.8	-75.1	5641.3	-33.3	1106.1	2498.0	-383.4	147003.2	383.4
July	1671.9	2617.5	1414.6	2000956.4	894.2	799668.2	1264951.0	-945.6	894102.6	945.6
August	3454.5	5408.2	4205.3	17684730.3	2676.8	7165481.3	11256980.3	-1953.7	3817100.0	1953.7
September	2711.6	4108.2	2905.3	8440894.0	1933.9	3740130.4	5618722.6	-1396.6	1950603.3	1396.6
October	317.6	497.2	-705.7	498010.1	-460.1	211653.7	324662.4	-179.6	32263.3	179.6
November	0.0	0.0	-1202.9	1447012.5	-777.7	604752.5	935459.5	0.0	0.0	0.0
December	0.0	0.0	-1202.9	1447012.5	-777.7	604752.5	935459.5	0.0	0.0	0.0
Total	9331.9	14435.0	0.0	37584812.3	0.0	15663956.3	24259435.6	-5103.1	6900050.3	5103.1
Mean	777.7	1202.9								

$$R^2 = \left[\frac{\sum_{i=1}^{n}\left(Q_{obs.i} - \bar{Q}_{obs}\right)\left(Q_{sim.i} - \bar{Q}_{sim}\right)}{\sqrt{\sum_{i=1}^{n}\left(Q_{obs.i} - \bar{Q}_{obs}\right)^2} \cdot \sqrt{\sum_{i=1}^{n}\left(Q_{sim.i} - \bar{Q}_{sim}\right)^2}}\right]^2 \quad 0.98$$

$$CE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs.i} - Q_{sim.i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs.i} - \bar{Q}_{obs.i}\right)^2} * 100 \quad 0.56\%$$

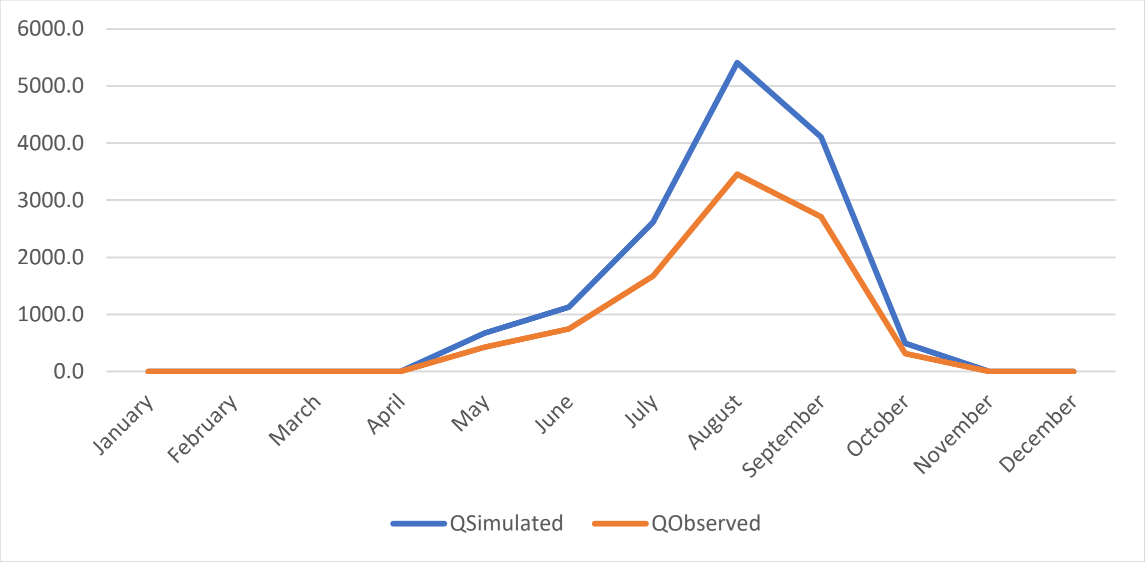
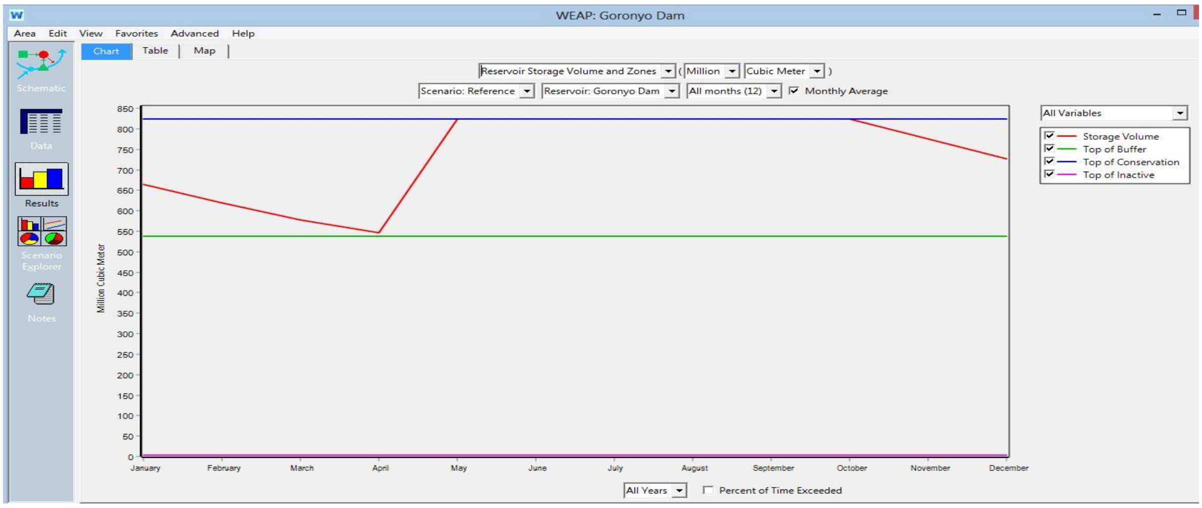


Figure 4.8: Comparison of simulated and measured streamflow of River

Figure 4.8 The comparison of simulated and measured streamflow of River Rima. The visual evaluation of the graph indicates a similar pattern and coincidence in some values.

4.7 Simulated storage volume

The simulated reservoir storage volume of Goronyo dam using the WEAP model is shown in Figure 4.9. The mean monthly average volume of water storage was found to be 737.9MCM and has a maximum storage volume of 824.3 in May, June, July, August, September, October respectively, and a minimum in the volume of 546.6MCM in April.



Reservoir Storage Volume and Zones (Million Cubic Meter)

Scenario: Reference

Reservoir: Goronyo Dam

All months (12)

☑ Monthly Average

All Variables

☑ Storage Volume
☑ Top of Buffer
☑ Top of Conservation
☑ Top of Inactive

All Years

☐ Percent of Time Exceeded

Figure 4.9: Reservoir storage volume.

4.8 Impact of climate change on water availability

According to the simulation and comparison of the storage volume and zone of the reservoir reaches for reference scenario and scenarios 1 to 9, it was observed/detected that the impact varied. The difference in water availability based on simulation as a result of prescribed climate scenarios is as shown in Table 4.11. The reference scenario shows the total average mean volume of water to be 737.9MCM in the reservoir. while scenario 2 gives the highest mean average value of 703.2MCM as compared to other prescribed scenarios. The minimum available mean average under scenario 9 (assumed to be worst scenario) of 1.2^{o}C increase in temperature and 10% decrease in rainfall is 698.7MCM.

Table 4.11 Effect of different climate scenarios on the volume of water storage in the reservoir

Amount of Water Available in MCM

Scenarios	**Reference**	**Scenario1 +0.4^{o}C**	**Scenario2 +0.4^{o}C, +10%R**	**Scenario3 +0.4^{o}C, -10%R**	**Scenario4 +0.8^{o}C**	**Scenario5 +0.8^{o}C, +10%R**	**Scenario6 +0.8^{o}C, -10%R**	**Scenario7 +1.2^{o}C**	**Scenario8 +1.2^{o}C, +10%R**	**Scenario9 +1.2^{o}C, -10%R**
Mean Average Storage volume (MCM)	737.9	703.2	703.7	703.1	701.0	701.0	700.9	698.8	698.8	698.7

4.9 Demand sites

The average annual domestic water demand of the population of 389,79 people based on the 1991 census of the area served by the reservoir was 17.1million cubic meters (MCM). while the 2006 census indicated that the population was 609,944 people. The average domestic water demand was 26.72 MCM. However, projecting the population to 2070 reveals that the future population will be 4,120,660 and their domestic water demand will be 180.5MCM. The annual average water demand for the area under the reference scenario is shown in Figure 4.10.

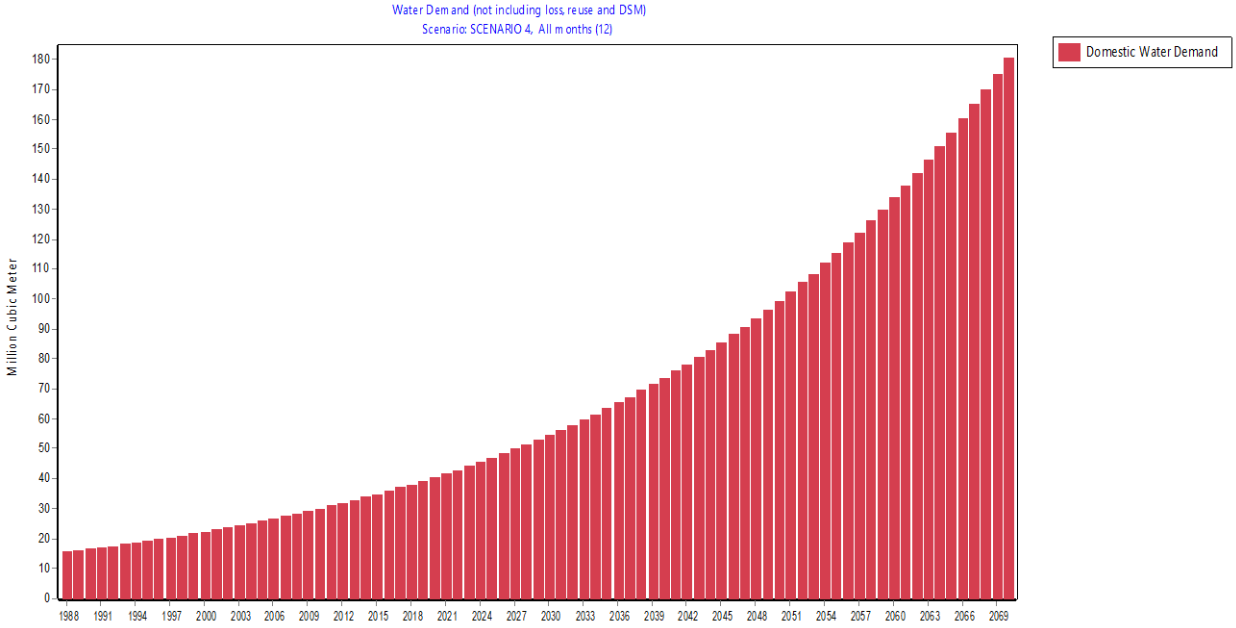


Figure 4.10**.** Domestic water demand for the reference scenario

The annual irrigation demand dated back to 2003 when the Falalia irrigation scheme kicked off occupying an irrigable land of 120ha and a demand of 1.3million cubic meters (MCM), in 2005, the scheme occupied an irrigable land of 530ha and water demand of 5.7million cubic meters (MCM). Finally, in 2006, the scheme came to an end with total irrigable land of 736ha and having a constant water demand of 7.9MCM till 2017. However, in 2007 the Taka Kume irrigation scheme kicked off, occupying an irrigable land of 50ha and the demand was 0.5MCM, in 2010, the scheme occupied an irrigable land of 125ha and water demand of 1.3MCM. Finally, in the year 2012 the overall available land (690ha) in this scheme was occupied and demand of 7.4MCM. While, in 2013, the Mai Yali irrigation scheme kicked off occupying an irrigable land of 250ha and water demand of 2.7MCM, in 2015, the scheme occupied an irrigable land of 1000ha and water demand of10.8MCM.Finally, in 2017, the scheme came to an end with total irrigable land of 1350ha and having a water demand of 14.5MCM. The overall irrigation demand from initiation till the present is 202.1MCM. The future projection shows that the demand will be 1783.7MCM. Figures 4.11,4.12 and 4.13 show the annual irrigation water demand under the reference scenario.

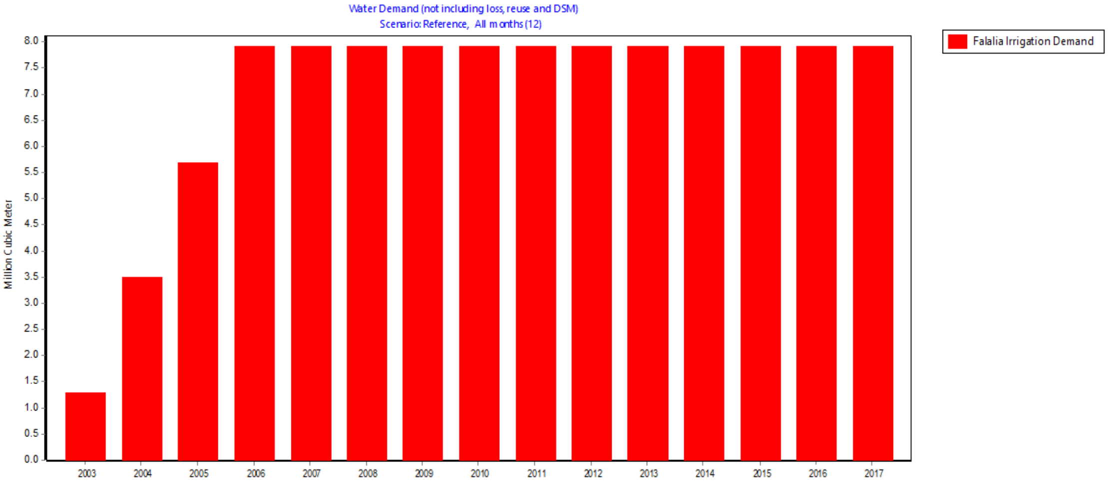


Figure 4.11**.** Falalia Irrigation water demand for the reference scenario

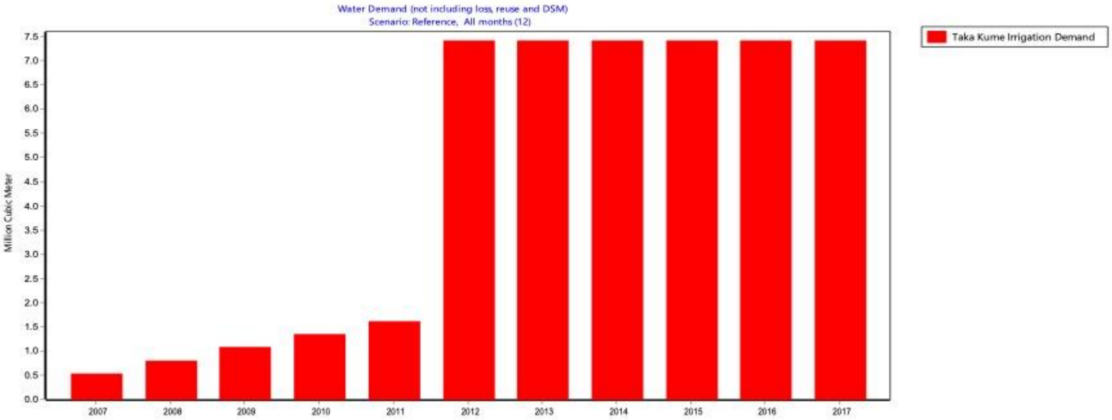


Figure 4.12**.** Taka Kume irrigation water demand for the reference scenario

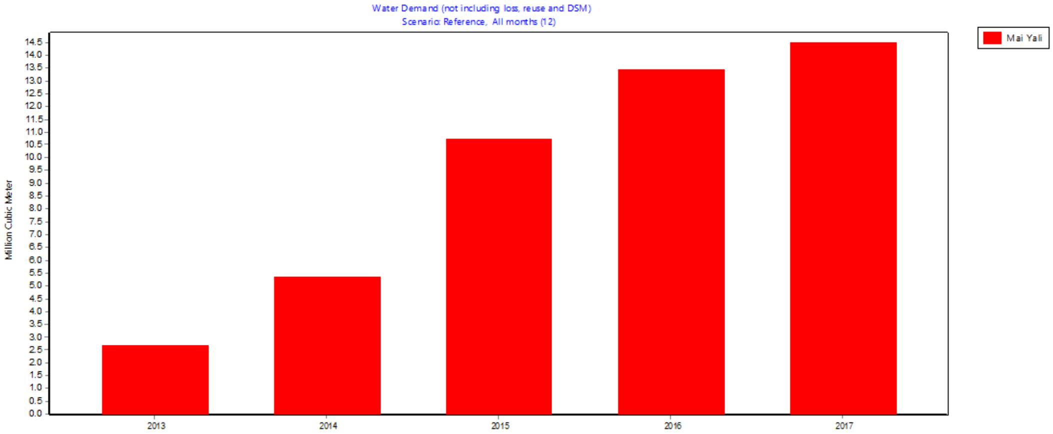


Figure 4.13. Mai Yali irrigation water demand for reference scenario.

4.9 Demand site reliability on water availability

The demand site reliability of the available water for all branches under all scenarios before projection is shown in Figure 4.14 before projection. and Appendix B1. which shows the demand site reliability under climate change influence where a site like Mai Yali shows 91.7% reliability and others ranges from 51.9- 82.7%. while Appendix D. shows the projected water availability reliability under all scenarios due to the influence of climate change with the summary in Appendix B2.

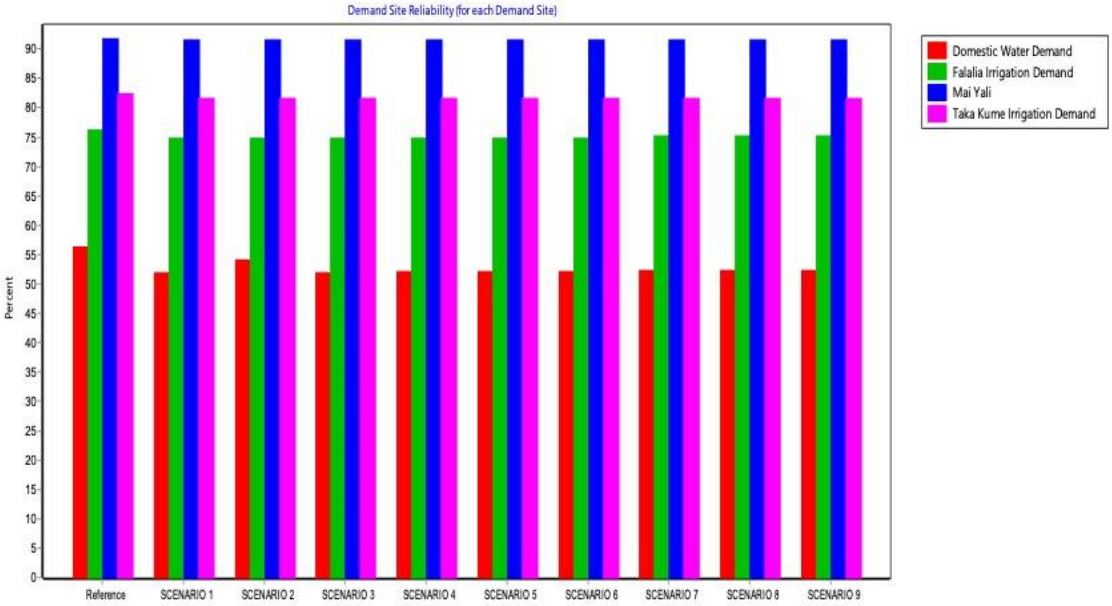


Figure 4.14. Demand site reliability before projection

4.10 Comparison of scenarios on water availability

The streamflow for each node and reaches for both the river and reservoir (i.e. all branches) is shown in Figure 4.15 in this, Scenario two (2) appear to have the highest volume of available water, while scenario 1, scenario 4, and scenario 7 appear to have the same volume, similarly, scenario 3 and 6 have nearly similar value with a slight difference. Scenario 9 has a lower volume than all other scenarios.

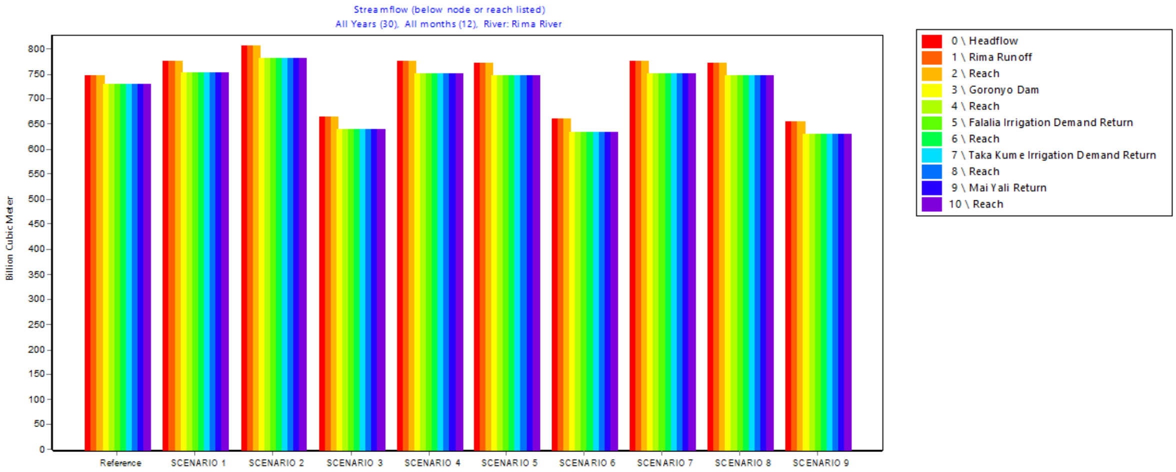


Figure 4.15: Streamflow below node and reach

The reference scenario was compared with all the other scenarios as shown in Figure 4.16. Appendix A1. gives the summary of the minimum and maximum monthly average volume for each scenario difference with the reference scenario shown in Figure 4.16. scenarios 3,6, and 9 show a very high negative volume that occurs under 0.4^{o}C, 1.2^{o}C rise in temperature, and 10% reduction in precipitation. Scenario 2 illustrates or depicts higher positive volume; this may be attributed to a 10% increase in rainfall.

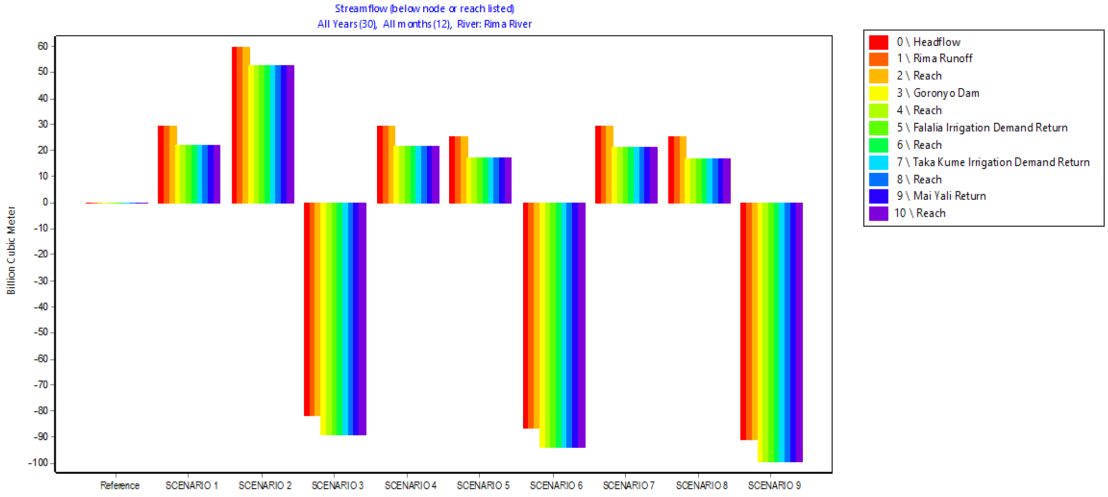


Figure 4.16 Streamflow of all scenarios compares with reference scenario.

The comparison of all other scenarios with scenario 1 is shown in Figure 4.17 and Appendix A2. gives the summary of the minimum and the maximum monthly average volume of each scenario difference with scenario 1. Scenario 2 shows positive and higher volume due to a 10% increase in rainfall over that scenario. The reference scenario,3,4,5,6,7,8, and 9 all show negative volume. However, scenario 3,6 and 9 depicts the high negative volume with scenario 9 shows the highest negative volume due to increase in temperature and reduction in precipitation. While scenarios 4 and 7 have **a** lower negative volume with scenario 4 have a slight negative volume.

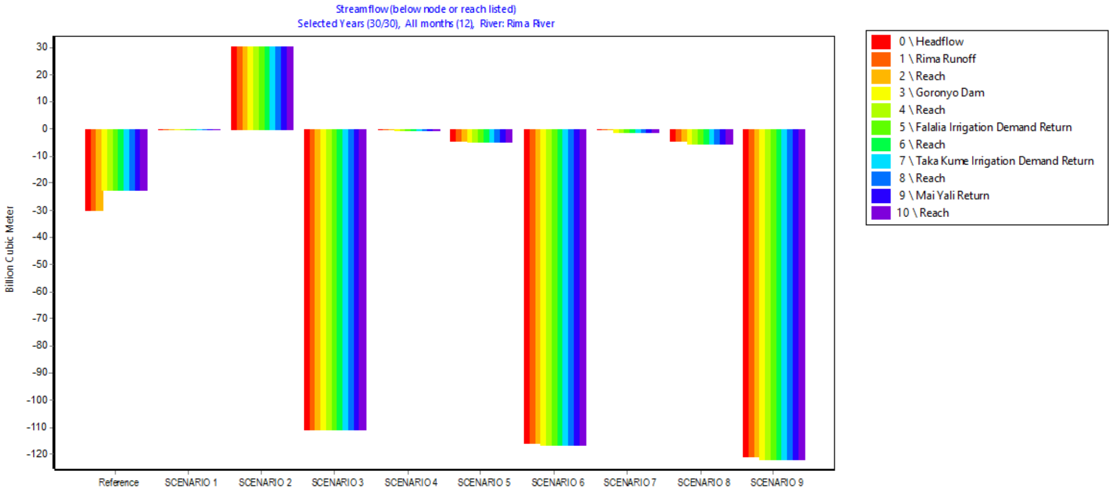


Figure 4.17: Streamflow for all scenarios compared with scenario 1

A graphical comparison of all other scenarios with scenario 2 is shown in Figure 4.18 and summarized in Appendix A3. All the scenarios indicate negative volume difference, which makes it clear that scenario 2 influences all other scenarios negatively. If scenario2 were to use as the reference scenario, all other scenarios will portray a deficit in total available water.

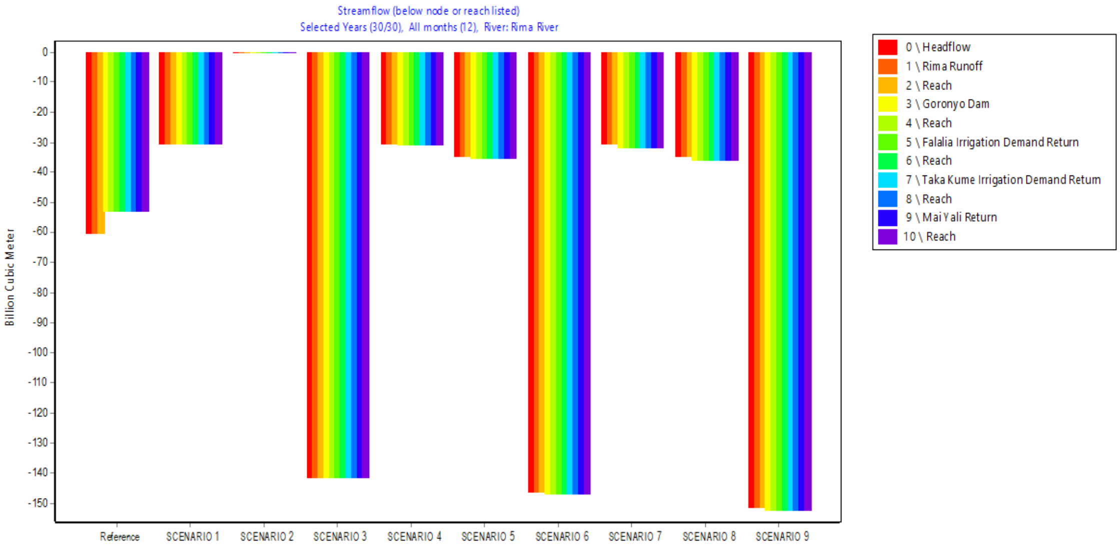


Figure 4.18: Streamflow for all scenarios compared with scenario 2

The graphical comparison of scenario 3 with all other scenarios is also shown in Figure 4.19 and summarized in Appendix A4. All the scenarios indicate positive volume difference except scenario 6 and 9, which shows that scenario 3 influence all other scenarios positively, but scenario 6 and 9 shows a deficit in total available water.

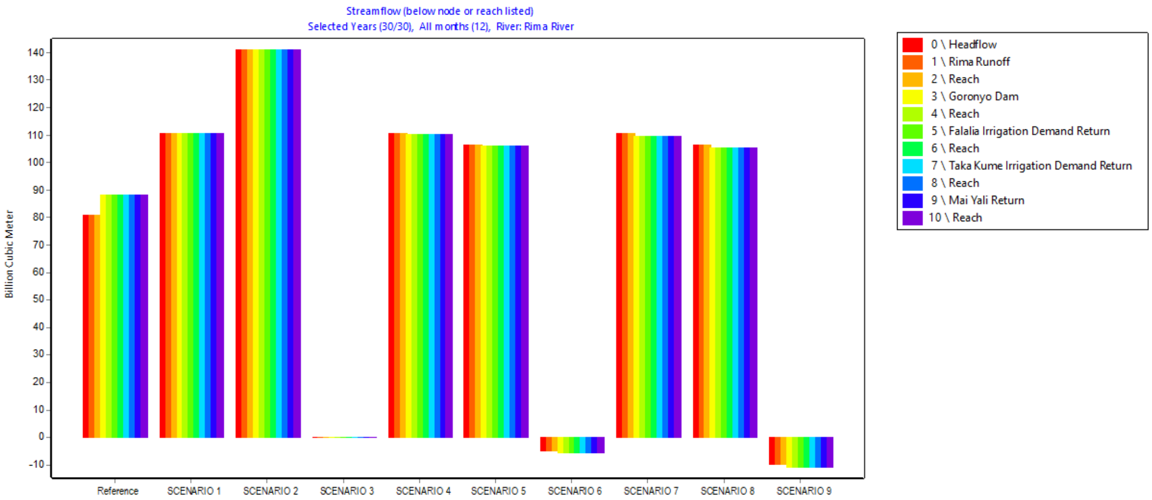


Figure 4.19: Streamflow for all scenarios compared with scenario 3

Comparing scenario 4 with other scenarios as shown in Figure 4.20. Scenarios 1 and 2 depict positive volume with scenario 2 having the higher volume due to the 10% increase in precipitation, while, scenarios 5,7, and 8 shows very small negative volume due to an increase in temperature. Scenarios 3,6 and 9 shows very high negative volume indicating the difference between the scenario and decrease in volume that occurs under a 10% reduction in precipitation and also an increase in temperature most especially in the worse scenario (9). The summary is shown in Appendix A5.

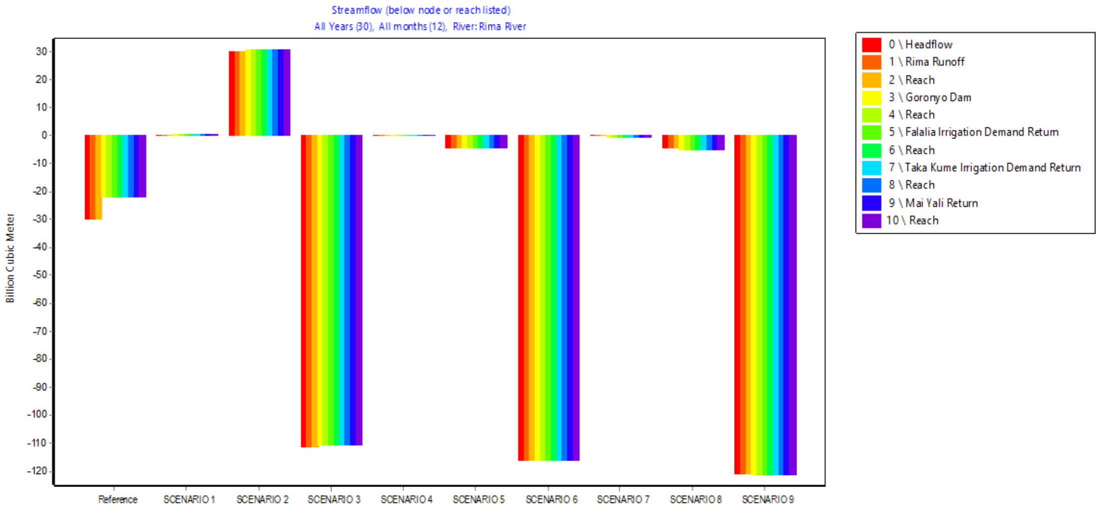
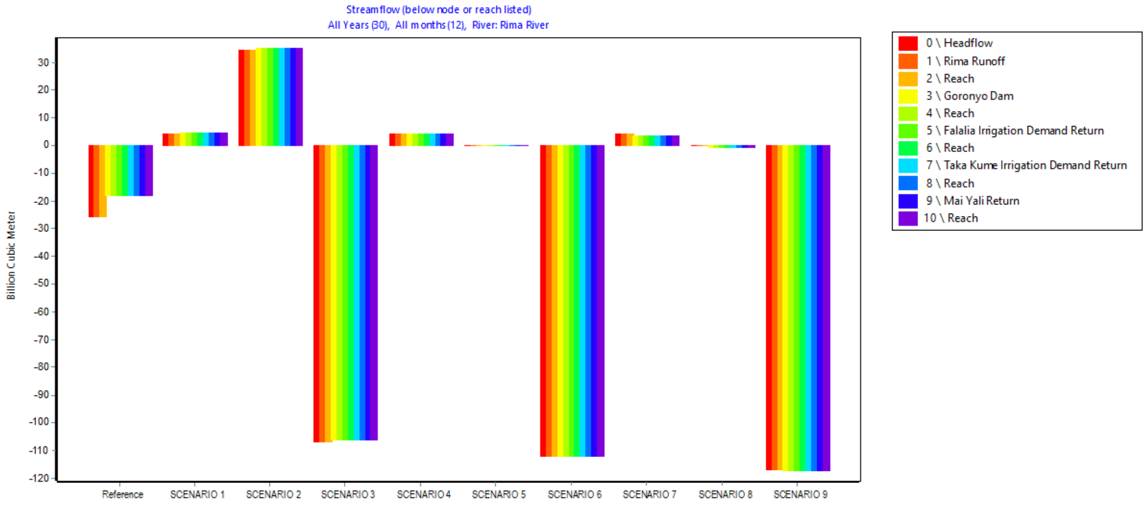


Figure 4.20: Streamflow for all scenarios compared with scenario 4

The comparison of scenario 5 with all other scenarios is also shown in Figure 4.21 and summarized in Appendix A6. four of the scenarios show negative volume. scenario,1,2,4, and 7 showing positive values with scenario 2 showing higher volume, scenarios 1,4, and 7 show close volume. which shows that scenario 5 negatively



influence scenario 3,6 and 9 respectively.

Figure 4.21: Streamflow for all scenarios compared with scenario 5

The graphical comparison of scenario 6 with all other scenarios is also shown in Figure 4.22 and summarized in Appendix A7. All the scenarios indicate a positive volume difference except scenario 9 with 1.2°C and a 10% reduction in precipitation. This shows that scenario 6 influences other scenarios positively. If scenario 6 is used as the reference scenario, all other scenarios show an increase in total available water. Except for the case where the temperature increases with a reduction in precipitation.

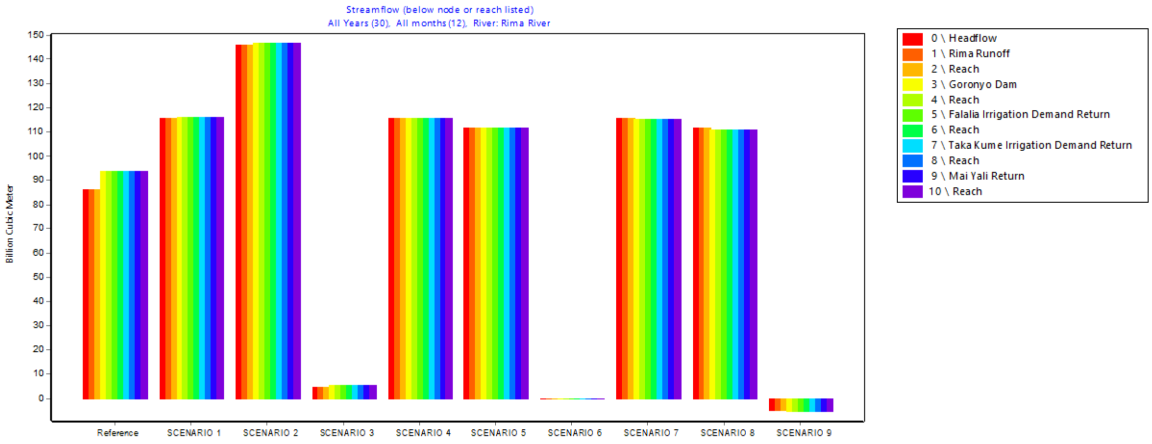
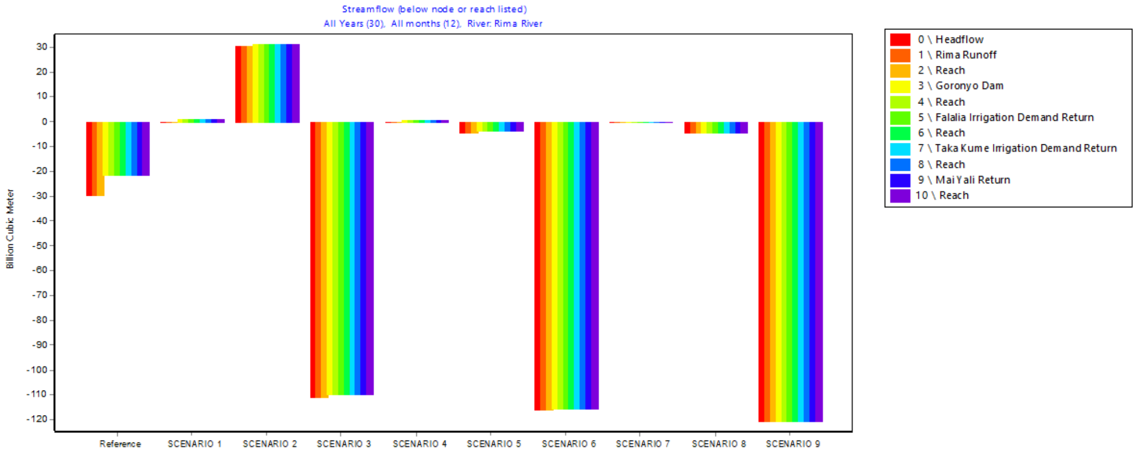


Figure 4.22: Streamflow for all scenarios compared with scenario 6

Comparing scenario 7 with other scenarios (Figure 4.23) shows that Scenarios 3, 6, and 9 depict Very high negative volume due to a 10% reduction in precipitation while Scenario 1,2, and 4 show positive volume due to an increase in precipitation by 10%. Scenarios 5 and 8 shows very small negative volume indicating decreasing volume that



occurs under 0.8°C and 1.2°C increase in temperature. A summary is shown in Appendix A8.

The comparison of scenario 8 with all other scenarios is also shown in Figure 4.24 and summarized in Appendix A9. Four of the scenarios show negative volume i.e. reference scenario,3,6, and 9. While scenarios 1,2,4,5 and 7 showing positive volume, though scenario two still have the higher volume. This shows that scenario 8 negatively influences four scenarios.

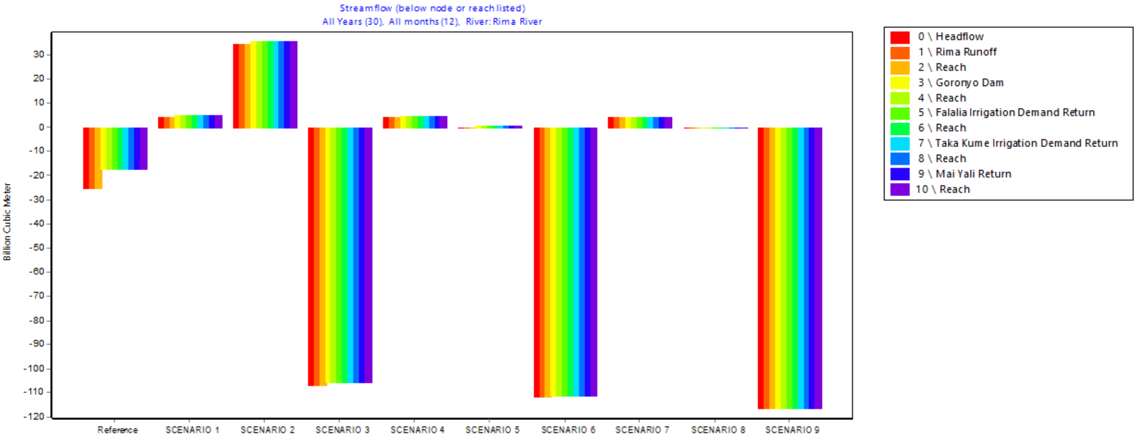


Figure 4.24: Streamflow for all scenarios compared with scenario 8

The graphical comparison of scenario 9 with all other scenarios is also shown in Figure 4.25 and summarized in Appendix A10. All the scenarios indicate a positive volume difference. This shows that scenario 9 influences all other scenarios positively. If scenario 9 is used as the reference scenario, all other scenarios show an increase in total available water.

Figure 4.25: Streamflow for all scenarios compared with scenario 9

4.11 Forecasting the future available water

The climate change impact on future water availability to meet the demand requirements was assessed for Goronyo Reservoir utilizing nine scenarios-based climate datasets. The situation was projected/forecasted up to the year 2070, which is 51 years from 2019. The result indicates a similar trend of climate change with the previous outcome as shown in Figure 4.26. It indicates higher future streamflow in Scenario 1, 2,4 & 7 with Scenario 2 having the highest volume.

Similarly, the storage volume of the reservoir under different scenarios was observed to vary as it is affected by the scenarios. Table 4.13 shows the summary of all the storage volumes for all scenarios.

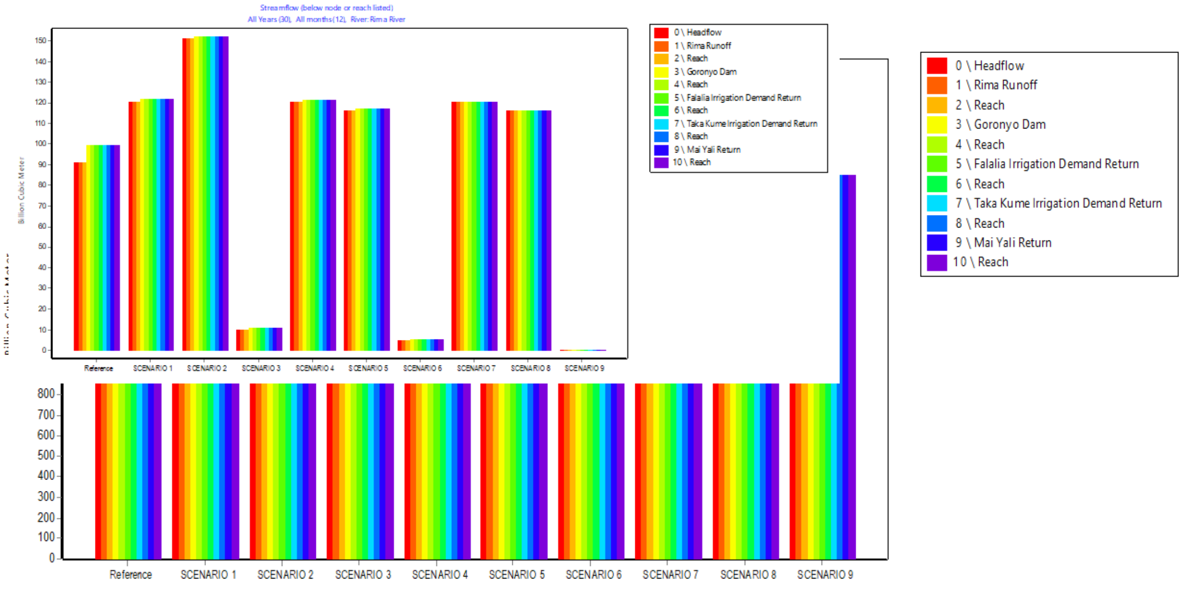
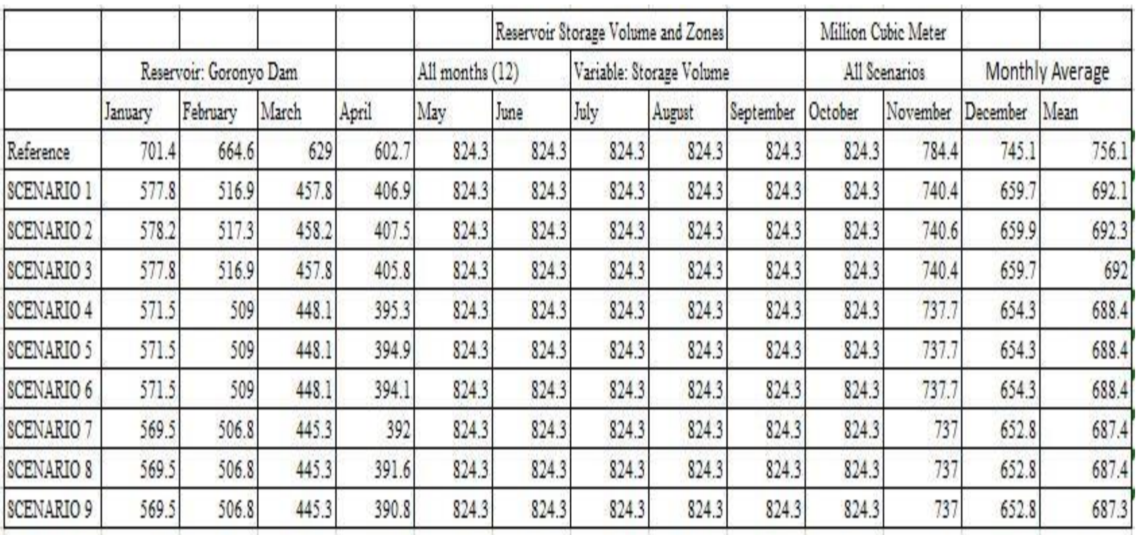


Figure 4.26: Streamflow of Rima river for all scenarios projected to 2070.



						Reservoir Storage Volume and Zones				Million Cubic Meter			
	Reservoir: Goronyo Dam				All months (12)		Variable: Storage Volume			All Scenarios		Monthly Average	
	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Reference	701.4	664.6	629	602.7	824.3	824.3	824.3	824.3	824.3	824.3	784.4	745.1	756.1
SCENARIO 1	577.8	516.9	457.8	406.9	824.3	824.3	824.3	824.3	824.3	824.3	740.4	659.7	692.1
SCENARIO 2	578.2	517.3	458.2	407.5	824.3	824.3	824.3	824.3	824.3	824.3	740.6	659.9	692.3
SCENARIO 3	577.8	516.9	457.8	405.8	824.3	824.3	824.3	824.3	824.3	824.3	740.4	659.7	692
SCENARIO 4	571.5	509	448.1	395.3	824.3	824.3	824.3	824.3	824.3	824.3	737.7	654.3	688.4
SCENARIO 5	571.5	509	448.1	394.9	824.3	824.3	824.3	824.3	824.3	824.3	737.7	654.3	688.4
SCENARIO 6	571.5	509	448.1	394.1	824.3	824.3	824.3	824.3	824.3	824.3	737.7	654.3	688.4
SCENARIO 7	569.5	506.8	445.3	392	824.3	824.3	824.3	824.3	824.3	824.3	737	652.8	687.4
SCENARIO 8	569.5	506.8	445.3	391.6	824.3	824.3	824.3	824.3	824.3	824.3	737	652.8	687.4
SCENARIO 9	569.5	506.8	445.3	390.8	824.3	824.3	824.3	824.3	824.3	824.3	737	652.8	687.3

Table: 4.12 Storage volume of Goronyo Reservoir for all Scenario after Projection.

From Table 4.12, it is observed that Scenario 9 still shown the least mean monthly storage compared to the reference scenario. The water demand from the area was projected, as shown in Figure 4.27 indicating or showing that the demand will be approximately 6 times higher in 50 years to come and that the supply deficit is on the increasing order (61%).

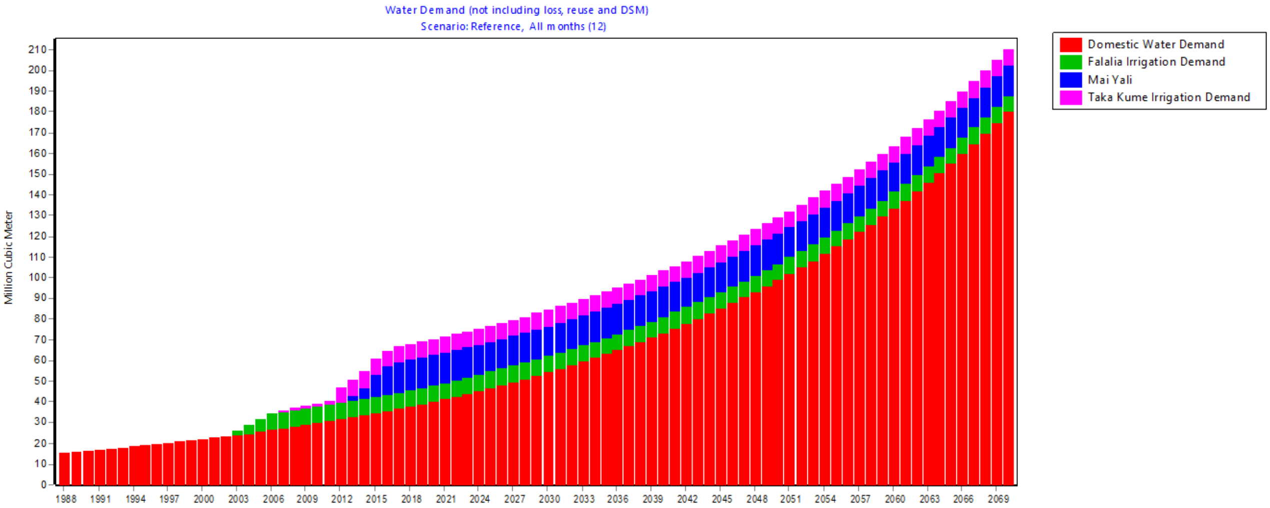


Figure 4.27: Water Demands projected to 2070.

The unmet demand projected into the future is shown in Figure 4.28. it shows that all the scenarios have a similar trend of not satisfying the demand. However, the domestic demands can be source from alternatives sources most especially during the dry seasons. Hence, it is clearly shown in Figures 4.29 & 4.30 that the unmet demand is more pronounced during the dry season for both the reference and even all scenarios.

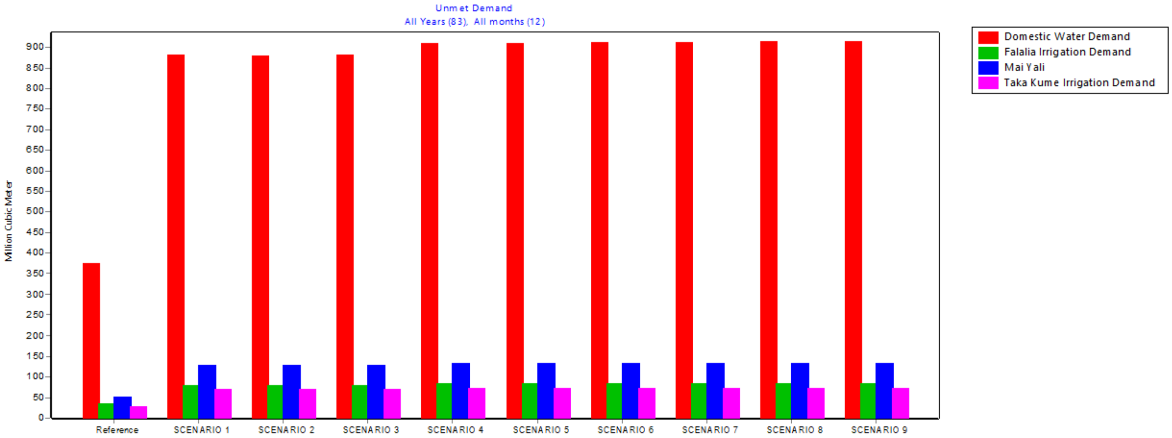
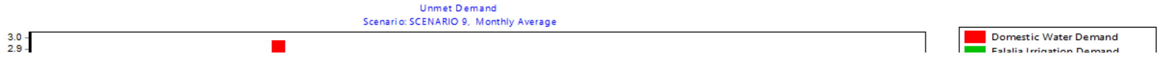


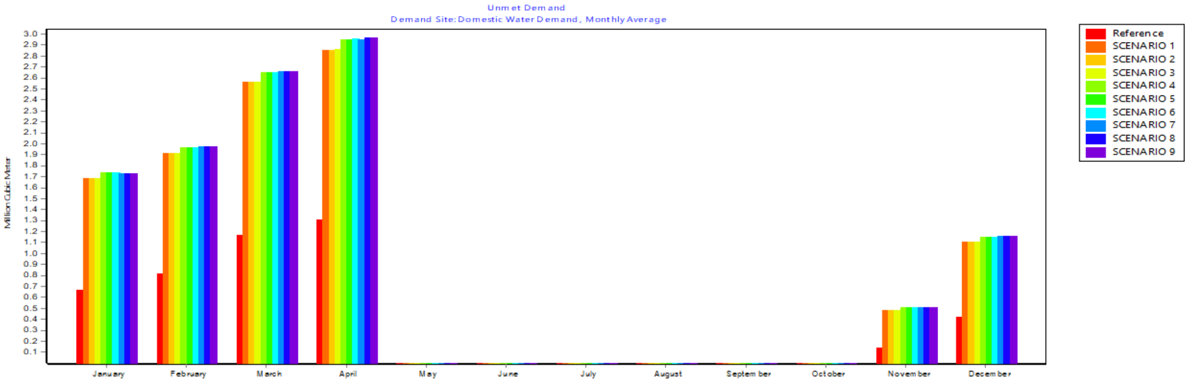
Figure 4.28: Unmet Demand for all Demands.

Figure 4.29: Average Monthly Unmet Demands for reference scenario.

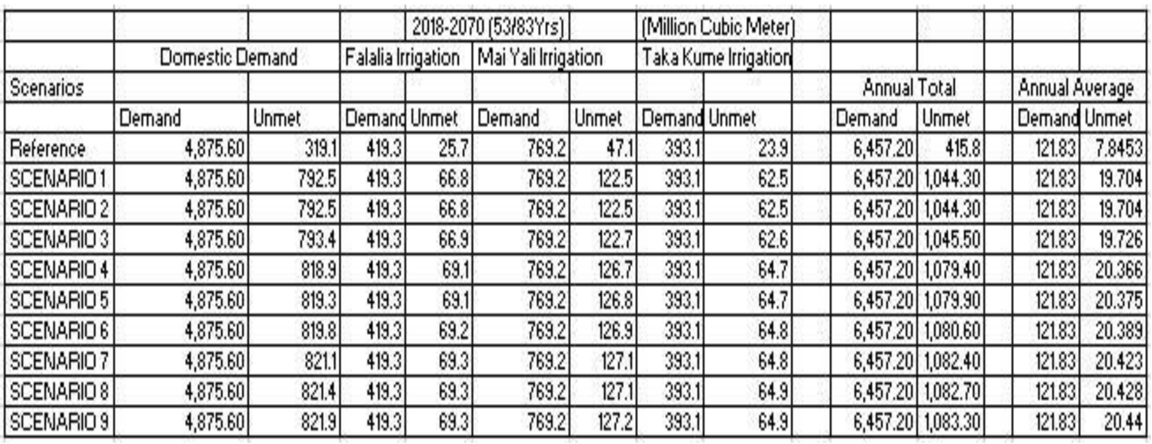
Figure 4.30: Average Monthly Unmet Demands for all scenarios.

Comparing demand, supplied delivered, and unmet demand, it is seen that there has being a deficit in supply to meet demand right from the reference scenario, however, the situation becomes worsen under scenario 9 with the higher overall volume of unmet





demand. Table 4.13 shows the summary of projected demands and unmet for all branches from 2018- 2070.



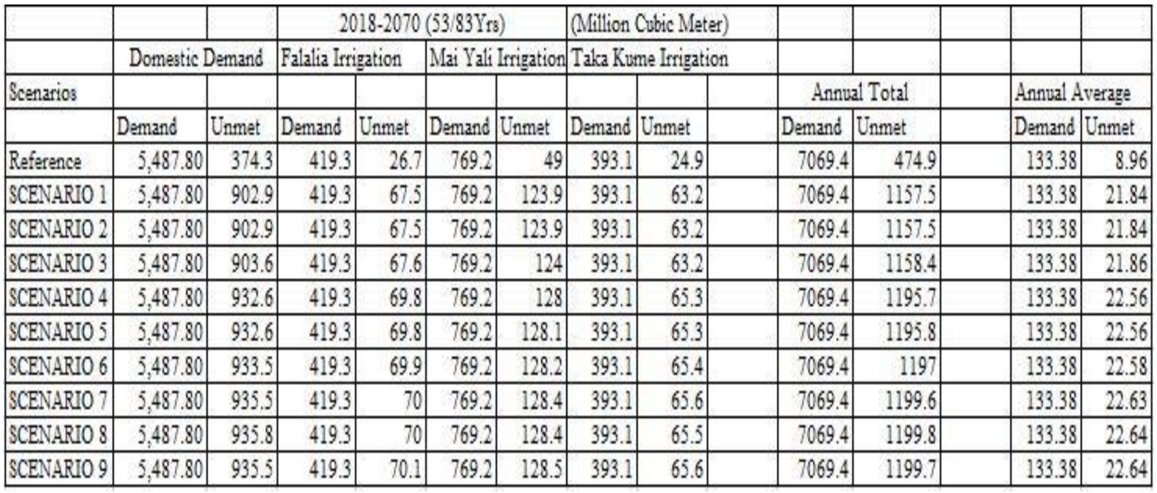
				2018-2070 (53/83Yrs)			(Million Cubic Meter)							
	Domestic Demand		Falalia Irrigation		Mai Yali Irrigation		Taka Kume Irrigation							
Scenarios										Annual Total			Annual Average	
	Demand	Unmet	Demand	Unmet	Demand	Unmet	Demand	Unmet		Demand	Unmet		Demand	Unmet
Reference	4,875.60	319.1	419.3	25.7	769.2	47.1	393.1	23.9		6,457.20	415.8		121.83	7.8453
SCENARIO 1	4,875.60	792.5	419.3	66.8	769.2	122.5	393.1	62.5		6,457.20	1,044.30		121.83	19.704
SCENARIO 2	4,875.60	792.5	419.3	66.8	769.2	122.5	393.1	62.5		6,457.20	1,044.30		121.83	19.704
SCENARIO 3	4,875.60	793.4	419.3	66.9	769.2	122.7	393.1	62.6		6,457.20	1,045.50		121.83	19.726
SCENARIO 4	4,875.60	818.9	419.3	69.1	769.2	126.7	393.1	64.7		6,457.20	1,079.40		121.83	20.366
SCENARIO 5	4,875.60	819.3	419.3	69.1	769.2	126.8	393.1	64.7		6,457.20	1,079.90		121.83	20.375
SCENARIO 6	4,875.60	819.8	419.3	69.2	769.2	126.9	393.1	64.8		6,457.20	1,080.60		121.83	20.389
SCENARIO 7	4,875.60	821.1	419.3	69.3	769.2	127.1	393.1	64.8		6,457.20	1,082.40		121.83	20.423
SCENARIO 8	4,875.60	821.4	419.3	69.3	769.2	127.1	393.1	64.9		6,457.20	1,082.70		121.83	20.428
SCENARIO 9	4,875.60	821.9	419.3	69.3	769.2	127.2	393.1	64.9		6,457.20	1,083.30		121.83	20.44

Table 4.13 Projected demand and unmet for all branches using 120 l/c/d.

From Table 4.13 it can be deduced that the unmet demand increased by 61% that is, reference scenario to scenario 9 which is the worst scenario and with a higher volume annual total of 1,083.30 MCM unmet and annual average of unmet 20.44MCM.

However, considering the water usage analyses and the per capita daily demand of 135 liters per capita per day. as shown in Table 4.14. it can be seen that the demand increases and unmet also increases with scenarios 9 given an annual total of 1,199.7 MCM unmet demand and an annual average of 22.64MCM. Now comparing these two it can be stated that the unmet demand increases with an annual average of 2.20MCM.

Table 4.14 Projected demand and unmet for all branches using 135l/c/d



			2018-2070 (53/83Yrs)				(Million Cubic Meter)							
	Domestic Demand		Falalia Irrigation		Mai Yali Irrigation		Taka Kume Irrigation							
Scenarios										Annual Total			Annual Average	
	Demand	Unmet	Demand	Unmet	Demand	Unmet	Demand	Unmet		Demand	Unmet		Demand	Unmet
Reference	5,487.80	374.3	419.3	26.7	769.2	49	393.1	24.9		7069.4	474.9		133.38	8.96
SCENARIO 1	5,487.80	902.9	419.3	67.5	769.2	123.9	393.1	63.2		7069.4	1157.5		133.38	21.84
SCENARIO 2	5,487.80	902.9	419.3	67.5	769.2	123.9	393.1	63.2		7069.4	1157.5		133.38	21.84
SCENARIO 3	5,487.80	903.6	419.3	67.6	769.2	124	393.1	63.2		7069.4	1158.4		133.38	21.86
SCENARIO 4	5,487.80	932.6	419.3	69.8	769.2	128	393.1	65.3		7069.4	1195.7		133.38	22.56
SCENARIO 5	5,487.80	932.6	419.3	69.8	769.2	128.1	393.1	65.3		7069.4	1195.8		133.38	22.56
SCENARIO 6	5,487.80	933.5	419.3	69.9	769.2	128.2	393.1	65.4		7069.4	1197		133.38	22.58
SCENARIO 7	5,487.80	935.5	419.3	70	769.2	128.4	393.1	65.6		7069.4	1199.6		133.38	22.63
SCENARIO 8	5,487.80	935.8	419.3	70	769.2	128.4	393.1	65.5		7069.4	1199.8		133.38	22.64
SCENARIO 9	5,487.80	935.5	419.3	70.1	769.2	128.5	393.1	65.6		7069.4	1199.7		133.38	22.64

4.12 Analysis of questionnaire

The questionnaire analysis is detailed in the subheadings below

4.12.1 Water consumptive use.

The Figure 4.31. Shows the chart of water usage against the frequency, the detailed table is in appendix C1 which describes the variation in usage, it can be seen that the response to uses such as Watering of the garden, washing of cars, etc. shows more negative response than the positive which implies few percent or numbers of people using the water for such purposes. Reversed is the case as regards basic necessities such as drinking, bathing, and cooking, etc. the frequency ranges from 386- 396.

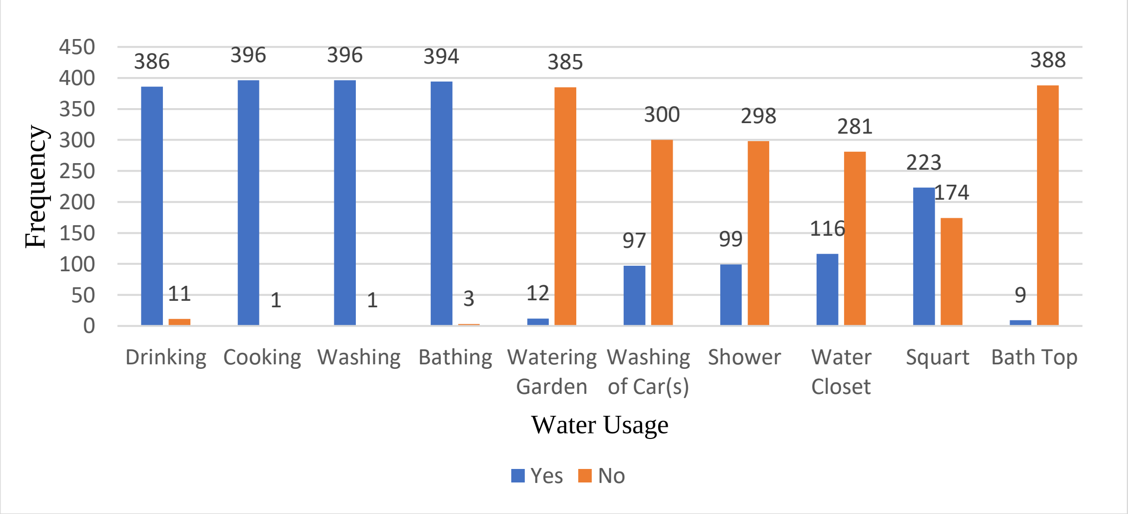


Figure 4.31. Water Usage versus Frequency

4.12.2 Domestic water demand

Table 4.15 present the water usage and percentage of their responses per combination of different consumptive uses. For instance, those that are used for both Drinking and cooking have a percentage of 97.48% Drinking, Cooking, Washing, and Bathing with 97.23 and Soon.

Domestic Water Usages (DWU)	Percentages
Drinking Cooking	97.48
Drinking Cooking Washing	97.48
Drinking Cooking Washing Bathing	97.23
Drinking Cooking Washing Bathing Bathtub	5.04
Drinking Cooking Washing Bathing Bathtub Water Closet	69.27
Drinking Cooking Washing Bathing Bathtub Water Closet Squat	81.36
Drinking, Cooking, Washing, Bathing, Bathtub, Water Closet, Squat, Shower	0
Drinking, Cooking, Washing, Bathing, Bathtub, Water Closet, Squat, Shower, Washing car	75.57
Drinking, Cooking, Washing, Bathing, Bathtub, Water Closet, Squat, Shower, Washing car, Watering Garden	22.42

Table 4.15 Domestic water uses

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The WEAP model software was successfully applied to estimate or assess the water availability in the area of study and scenarios analyses were carried out under possible climate change variability. The results indicate that the water available in the reservoir

(Goronyo Reservoir) with the mean average volume of 737.9MCM, Maximum of 824.3 MCM mainly in the wet period ranges from May – October, and the minimum mean average volume of 546.6 MCM mostly in a dry month i.e. April.

Meanwhile, under the influence of prescribed climate change, it was detected after simulation and comparison of storage volume and zone of reservoir for reference scenario and Scenarios 1 to 9 that impact varied in respect to water availability. The reference scenario shows a total average mean volume of 737.9MCM while scenario 2 gives the highest mean average value of 703.2MCM as compared to other prescribed scenarios. The minimum available mean average under scenario 9 of 1.2^{o}C increase in temperature and 10% decrease in rainfall is 698.7MCM, therefore, the average storage volume is expected to be reduced by 5.6% as a result of the forecast increase in temperature by 1.2 ^{o}C and decreased rainfall of 10%.

The water demand was further analyzed using a questionnaire and projection was made from 2018 to 2070 and the annual total demand is 7069.4 MCM and the annual average demand of 133.4 MCM. Meanwhile, the unmet demand under various prescribed scenarios ranges from 21.84MCM to 22.64MCM.

Generally, the WEAP software model is a desktop tool for combined water resource planning and displays its suitability for water resources availability forecast.

5.2 Recommendations

Owing to the research carried out the following recommendations are proposed:

1. Demand Management Strategies such as rainwater harvest at the household level, wastewater reuse within the commercial facilities, etc. these would help in mitigating increasing demand and pressure on the water resources.

2. There may be a need to develop other sources of water for irrigation such as the use of groundwater to reduce the growing pressure on the available source.
3. The irrigation practice in the area is a furrow irrigation system, therefore, the use of improved irrigation systems such as sprinkler or drip (metered) irrigation systems would be of greater advantage.
4. Further study could be carried out on Developmental Management Scenarios Such as Demand Management scenarios.

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APPENDICES

APPENDIX A

APPENDIX A: Comparison of Scenarios on Water Availability

A1 Streamflow from rima for all scenarios compared with reference scenario.

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	0	23.3	60	-88.6	21.8	17.6	-94.0	21.3	17.1	-99.4
Max	0	29.0	54.1	-81.2	29.6	25.4	-86.2	29.6	25.4	-91.1

A2 Summary of Streamflow for all scenarios Compared with Scenario1

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	-29.6	0	30.4	-110.9	-0.5	-4.7	-116.3	-5.1	17.1	-121.7

Max	-22.3	0	30.5	-110.9	0.0	-4.2	-115.8	0.0	25.4	-120.8

A3 Summary of Streamflow for all scenarios Compared with Scenario 2

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	--60.0	-30.5	0	-141.4	-31.0	-35.2	-146.3	-31.4	-35.6	-152.2
Max	-52.8	-30.4	0	-141.3	-30.4	-34.6	-146.2	-30.4	-34.6	-151.1

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	81.2	110.9	141.3	0	110.4	106.2	-5.4	109.9	105.7	-10.8
Max	88.6	110.9	141.4	0	110.9	106.7	-4.9	110.9	106.0	-9.9

A4 Summary of Streamflow for all scenarios Compared with Scenario 3

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	-29.6	0.0	30.4	-110.9	0.0	-4.2	-115.8	-0.5	-4.7	-121.2
Max	-21.8	0.5	31.0	-110.4	0.0	-4.2	-115.8	0.0	-4.2	-120.8

A5 Summary of Streamflow for all scenarios Compared with Scenario4

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	-25.4	4.2	34.6	-106.7	4.2	0.0	-111.6	3.7	-0.5	-117.0
Max	-17.6	4.7	35.2	-106.7	4.2	0.0	-111.6	4.2	-0.0	-116.6

A6 Summary of Streamflow for all scenarios Compared with Scenario 5

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	86.2	115.8	146.2	4.9	115.8	111.6	0.0	115.4	111.2	-5.4
Max	94.0	116.3	146.8	5.4	115.8	111.6	0.0	115.8	111.6	-4.9

A7 Summary of Streamflow for all scenarios Compared with Scenario 6

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	-29.6	0.0	30.4	-110.9	0.0	-4.2	-115.8	0.0	-4.2	-120.8
Max	-21.3	0.9	31.4	-109.9	0.5	-3.7	-115.4	0.0	-4.2	-120.8

A8 Summary of Streamflow for all scenarios Compared with Scenario 7

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	-25.4	4.2	34.6	-106.7	4.2	0.0	-111.6	4.2	0.0	-116.6
Max	-17.1	5.1	35.6	-105.7	4.7	0.5	-111.2	4.2	0.0	-116.6

A9 Summary of Streamflow for all scenarios Compared with Scenario 8

All Nodes and Reaches, River, All Years 30/30, All months (12) (Billion Cubic Meter)

	Reference	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9
Min	91.1	120.8	151.1	9.9	120.8	116.6	4.9	120.8	116.6	0.0
Max	99.4	121.7	152.2	10.8	121.2	117.0	5.4	120.8	116.6	0.0

A10 Summary of Streamflow for all scenarios Compared with Scenario 9

APPENDIX B

APPENDIX B: Demand Sites Reliability for all Demands Before and After Projection

	Domestic Demand	**Falalia Irrigation**	**Mai Yali Irrigation**	**Taka Kume Irrigation**

Reference	56.4	76.4	91.9	82.5
Scenario 1	51.9	75.0	91.7	81.7
Scenario 2	54.2	75.0	91.7	81.7
Scenario 3	51.9	75.0	91.7	81.7
Scenario 4	52.2	75.0	91.7	81.7
Scenario 5	52.2	75.0	91.7	81.7
Scenario 6	52.2	75.0	91.7	81.7
Scenario 7	52.5	75.3	91.7	81.7
Scenario 8	52.5	73.3	91.7	81.7
Scenario 9	52.5	75.3	91.7	81.7

B1 Demand sites reliability for all demands before projection

Demand Site Reliability(for each Demand Site)(Percent)
Selected Demand Sites (4/5)

	Reference	SCN1	SCN2	SC3	SCN3	SCN3	SCN6	SCN7	SCN8	SCN9
Domestic Water Demand	52.6	50.7	51.5	50.7	50.8	50.8	50.9	50.9	50.9	50.9
Falalia Irrigation	59.8	59.0	59.0	59.0	59.0	59.0	59.1	59.1	59.1	59.1
Mai Yali Irrigation	65.5	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1	65.1
Taka Kume Irrigation	62.0	61.4	61.4	61.4	61.4	61.4	61.4	61.4	61.4	61.4

B2 Demand Site Reliability for all sites projected to 2070.

SCN: Scenario

APPENDIX C

C1 The Responses of Water Usage with Frequencies and Percentages

			Frequency	Percent	Valid Percent	Cumulative Percent
Drinking	Valid	No	11	2.8	2.8	2.8
		Yes	386	97.2	97.2	100.0
Cooking	Valid	No	1	.3	.3	.3
		Yes	396	99.7	99.7	100.0
Washing	Valid	No	1	.3	.3	.3
		Yes	396	99.7	100.0	100.0
Bathing	Valid	No	3	.8	.8	.8
		Yes	394	99.2	99.2	100.0
Watering Garden	Valid	No	385	97.0	97.0	97.0
		Yes	12	3.0	3.0	100.0
Washing Car(s)	Valid	No	300	75.6	75.6	75.6
		Yes	97	24.4	24.4	100.0
Shower	Valid	No	298	75.1	75.1	75.1
		Yes	99	24.9	24.9	100.0
Water Closet	Valid	No	281	70.8	70.8	70.8
		Yes	116	29.2	29.2	100.0
Squirt	Valid	No	174	43.8	43.8	43.8
		Yes	223	56.2	56.2	100.0
Bath Top	Valid	No	388	97.7	97.7	97.7
		Yes	9	2.3	2.3	100.0
Washing Machine	Valid	No	351	88.4	88.4	88.4
		Yes	46	11.6	11.6	100.0

APPENDIX D

APPENDIX D: Representation of demands site Reliability for all demands

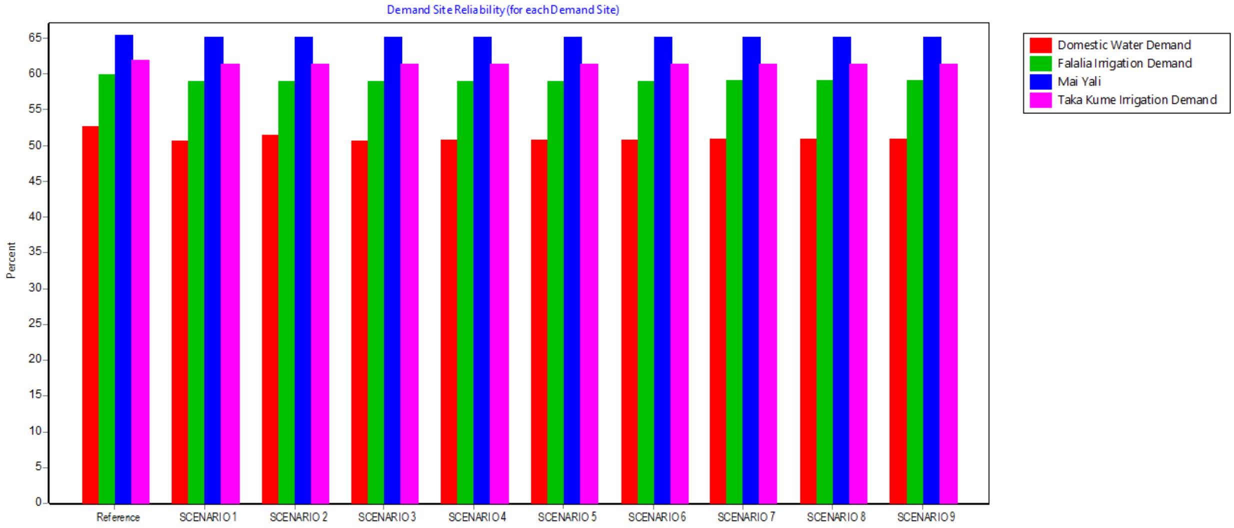

Figure:4.28: Demand Sites Reliability for each Demand.