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Presented by

John Faith Oyelakin

EVALUATION AND MODELING OF SUSTAINABLE URBAN WATER SUPPLY AND DEMAND IN IBADAN, NIGERIA

Defended on 15/11/2021 Before the following Committee:

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DECLARATION

STUDENT'S DECLARATION

I, John Faith Oyelakin, hereby declare that this thesis titled "Evaluation and Modeling of sustainable urban water supply and demand in Ibadan, Nigeria" is my original work to the best of my knowledge and has not been submitted to the University or any other institute or published earlier for the award of any degree or diploma. I also declare that all the information, materials and results from other works presented in this thesis have been duly cited and recognized as required of academic rules and ethics.

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SUPERVISOR'S DECLARATION

I, Professor Joseph Adelegan, hereby declare that I supervised the preparation of this Master thesis submitted therein in accordance with the guidelines on supervision of Master thesis laid down by the Pan African University Institute of Water and Energy Sciences, Algeria.

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ABSTRACT

Water scarcity is increasing in Ibadan, Nigeria due to increasing population, urbanization, increase in standard of living and increasing deteriorating state of urban water supply schemes thereby putting pressure on the available water sources. This research focused on trend analysis of past hydroclimatic data and modeling of future water demand. Two methods were used to achieve the objectives of this research, firstly, non-parametric statistics was used to determine the trend of rainfall and temperature for a period of 30 years while water evaluation and planning (WEAP) model was used to model the implication of external factors and management approaches on future water supply and demand deficit between 2021 and 2040. Result of the trend analysis revealed monotonic trend in rainfall time series data during wet and dry season while there was no trend in the annual rainfall at 5% significant level. The WEAP model result showed an increasing magnitude of all the external factors scenarios impacting on the available water while the two management approaches used show decreasing magnitude on the unsatisfied water demand when compared with the reference scenario. To prevent severe future water shortage in the study area, good management strategies and development of urban water supply infrastructures must be ensured.

RÉSUMÉ

La pénurie d'eau augmente à Ibadan, au Nigeria, en raison de l'augmentation de la population, de l'urbanisation, de l'augmentation du niveau de vie et de la détérioration croissante de l'état des systèmes d'approvisionnement en eau urbains, ce qui exerce une pression sur les sources d'eau disponibles. Cette recherche s'est concentrée sur l'analyse des tendances des données hydroclimatiques passées et la modélisation de la demande future en eau. Deux méthodes ont été utilisées pour atteindre les objectifs de cette recherche, premièrement, des statistiques non paramétriques ont été utilisées pour déterminer la tendance des précipitations et de la température pour une période de 30 ans tandis que le modèle d'évaluation et de planification de l'eau (WEAP) a été utilisé pour modéliser l'implication de facteurs externes et approches de gestion sur le futur déficit de l'approvisionnement et de la demande en eau entre 2021 et 2040. Le résultat de l'analyse des tendances a révélé une tendance monotone dans les données des séries chronologiques de précipitations pendant la saison sèche et humide alors qu'il n'y avait pas de tendance dans les précipitations annuelles à un niveau significatif de 5 %. Le résultat du modèle WEAP a montré une ampleur croissante de tous les scénarios de facteurs externes ayant un impact sur l'eau disponible, tandis que les deux approches de gestion utilisées montrent une ampleur décroissante de la demande en eau non satisfaite par rapport au scénario de référence. Pour prévenir une future grave pénurie d'eau dans la zone d'étude, de bonnes stratégies de gestion et le développement des infrastructures urbaines d'approvisionnement en eau doivent être assurés.

DEDICATION

This work is dedicated to the Almighty God, the giver of life and wisdom. I also dedicate this work to my parents, Mr and Mrs Olutayo Oyelakin for their support and encouragements, to my family members, friends and loved one for their support during this programme.

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LIST OF ABBREVIATIONS

ADB - African Development Bank

DEM - Digital elevation model

FAO - Food and Agriculture Organization of the United Nations

FMWR - Federal Ministry of Water Resources

FMWRRD - Federal Ministry of Water Resources and Rural Development

GIS - Geographic Information System

HPG - High population growth

IPCC - Intergovernmental Panel on Climate Change

IUFMP - Ibadan Urban Flood Management Project

LPCD - Litres per Capita per Day

LPG - Low population growth

MAE - Mean absolute error

MCM - Million cubic meters

MDGs - Millennium Development Goals

MESP - Ministry of Environment and Spatial Planning

MW - Mega Watt

NBS - National Bureau of Statistics

NEPAD - New Partnership for Africa's Development

NIMET - Nigerian Meteorological Agency

NSE - Nash-Sutcliffe Efficiency

PAU - Pan African University

PAUWES - Pan African University Institute of Water and Energy Sciences

QGIS - Quantum Geographic Information System

RBDA - River Basin Development Authorities

RMSE - Root mean square error

SDGs	-	Sustainable Development Goals
SEI	-	Stockholm Environment Institute
STRM	-	Shuttle Radar Topography Mission
SWAT	-	Soil and Water Assessment Tool
UN	-	United Nation
UNDP	-	United Nations Development Programme
USGS	-	United States Geological Survey
WCOS	-	Water Corporation of Oyo State
WEAP	-	Water Evaluation and Planning
WHO	-	World Health Organization
WMO	-	World Meteorological Organization

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

One of the most challenging global issues facing natural resources on earth is balancing the nexus between human demand and resource consumption. Water being the basis of life and the most abundant natural resource required to a large extent for various human activities, need to be judiciously managed to make its freshwater component sustainable. Stressing the importance of water sustainability and management would ensure continuous availability; successful water management will be the foundation for achieving Sustainable Development Goals (SDGs) 6 and other SDGs (Guppy and Anderson, 2017).

An increase in the human population and their activities, coupled with climate change, threaten spatial and temporal water availability and supply. It was estimated that four billion people face severe water shortages worldwide (Mekonnen and Hoekstra, 2016). Cities have been identified as water shortage hotspots due to high population concentrations that consume large amounts of water. In 2014, 54% of the world's population was estimated to live in cities, a statistic that is projected to rise to 66% by 2050; this will result in rapid urban population growth and a significant increase in the use of water resources in the world (Kou et al., 2018).

Likewise, climate change is also essential to water managers and planners because it can change the fundamental water management conditions, necessitating new water management systems and capital investments. To address climate change issues, understanding basin-specific patterns in water supply quantity and timing in the context of a changing climate can aid in determining the localized vulnerability of available water resources.

The planning and development of water resources have a long history in Nigeria. The government has been leading the process of developing water resources since the 1970s (Ajala, 2016). The then-Federal Ministry of Water Resources and Rural Development (FMWRRD) collaborated with the United Nations Food and Agriculture Organization (FAO) to create a national master plan for water resources management and development. However, due to a lack of funds, this work has not yet been completed. To complete the master plan, the FMWRRD asked the Japanese government to conduct a general water resource plan study. At the Nigerian government's request, the Japan International Cooperation Agency (JICA) has mobilized a team of consultants to come to Nigeria (Ajala, 2016). These plans are still rarely put into operation because many water resource systems are being evaluated. Recently, water scarcity has increased due to the growing need for irrigation, water supply, power generation due to population growth and economic development. As a result, water resources development and management have become an essential requirement to meet these needs and prevent environmental damage (Ajala, 2016). This study provides sustainable water resources management options and model sustainable urban water demand and supply using the Water Evaluation and Planning (WEAP) model. According to Mutiga et al. (2010), the WEAP model is used to compare water demand and supply, identify areas with potential water shortages under different scenarios, and forecast future water demand. The findings would serve as the basis for the decision-making process by engineers, hydrologists, and policymakers to distribute and manage water resources in Ibadan.

1.2 Problem Statement

The water demand is increasing; an increase in the population creates serious problems. The increasing demand for water due to population increase creates problems for agriculture, industry, domestic use. The only solution to water resources' complex problems is integrated planning and management based on modelling, simulation and optimization (Simonovic, 2009). Ibadan is a metropolitan city in southwest Nigeria with about 3.5 million people; due to urbanization, proximity to Nigeria's economic capital, and industrial development, the city is developing increasingly, putting pressure on the available water resources. Although the city falls in the tropical rain forest zone with an average rainfall of 1200mm per annum, it has 16 springs (Shridhar, 2001). The city has eight reservoirs with over 42.71 million m^3 capacity with two operational water treatment plants with a combined water capacity of 213,000m^3 /day. With this abundant resource, less than 10% of the population have access to the municipal water supply; this has led to people providing water sources to meet their water demand, thereby putting pressure on groundwater. Increasing pressure on groundwater resources due to increased water needs, urbanization, inadequate municipal water supply and the effects of climate change on water resources without planning are significant concerns in Ibadan. This study aims to model a sustainable urban water demand and supply, which can serve as a decision-making tool for optimizing water management in the study area.

1.3 Aim and Objectives of the study

This study evaluated and modeled urban water supply and demand on water resources in Ibadan. The specific objectives of the study are to:

i. Analyze the trend of past hydroclimatic data

ii. Determine the current water demand and supply in the study area

iii. Predict the future water demand under different management and external scenarios

1.4 Research Questions

The following are the research questions of the study.

i. What is the trend of rainfall and temperature in the past years in Ibadan?

ii. What is the current trend of water demand and supply in Ibadan?

iii. Is there relationship between future water demand under different management and external scenarios?

1.5 Working Hypothesis

i. There is no trend in monthly, seasonal and annual rainfall and temperature in Ibadan
ii. There is no trend in the current state of water demand and supply in Ibadan
iii. There is no relationship between future water demand under different management and external scenarios.

1.6 Justification of the study

Due to overdependence on groundwater in Ibadan as a result of inadequate public water supply, there is a need to evaluate and model water demand and supply for proper urban management and development. The global trend of urbanization and population growth necessitates increased water extraction and transportation volumes (Hunt et al., 2010). As a result, securing adequate freshwater supplies for rising cities is a top priority and may be seriously hindered by the spatial and temporal variability of water demand and supply (Buytaert et al., 2012). Though readily available water resources have been used extensively across much of the planet, pressure from development, population growth and climate change put additional pressure on this vital resource (Baron et al., 2002). The report will add to the body of information by forecasting potential water demand and climate change on the water supply to manage the study area's water supplies better.

The findings of this study can be used as decision-making tools in the development of successful water management and future urbanization and climate change studies. This knowledge can be incorporated into the preparation of Ibadan's water supply networks to ensure sufficient potential amounts of potable water supply. As a result, this study is the first step toward delivering this evidence-based empirical and model data investigation.

1.7 Structure of the Thesis

The structure of this thesis is divided into five chapters as follow:

Chapter One: The chapter contains an overview of the study's background, problem statement, research aim and objectives, and the justification of the study. Chapter Two would review the literature on water supply, climate change and the WEAP model with various decision support system tools in water management used by researchers worldwide.

Chapter Three describes the research design, data collection and the research methodology.

Chapter Four describe the result and discussion of the findings

Chapter Five contains the research conclusions and recommendations based on the findings of the study's objectives

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Water is necessary for human survival. An adequate supply of drinking water is one of the most basic human needs, but it is not met for more than half of the world's population. According to various estimates, between half and two thirds of the world's population does not have access to sufficient amounts of drinking water, while two thirds of the surface of our planet is covered with water. Although there seems to be enough water in the world when you consider the mighty rivers and oceans, it would be a grave mistake to take the supply of water for human consumption for granted. Many developing countries face serious water problems in addition to population and pollution problems. Nigeria, the most populous country in Africa, has a limited water supply not only in the arid to semi-arid north, but also in the southern region along the Atlantic Ocean.

Nigeria is considered to be endowed with abundant water resources. However, the availability of water varies in time and space, with the north receiving only about 500 mm of precipitation in the northeast corner and the south receiving more than 4000 mm in the southeast. This great variability of rainfall in time and space is an important characteristic of the country's tropical climate belt, particularly the Sahel region, and must be taken into account in the management of the country's water resources (National Water Policy, 2004).

2.2 General Overview of Water Demand and Supply

Since air is essential for life, water is necessary for life and health. The human right to water is essential for a healthy and humane life, as it is a prerequisite for the realization of all other human rights. Globally, an estimated 1.2 billion people have no access to clean water (Klawitter and Qazzaz, 2005), which will always lead to the spread of water and sanitation-related diseases (Patrick, et al. 2004). When people do not have access to clean water, they suffer not only physically and emotionally, but also socio-economically. It is almost certainly the source of environmental degradation (UNDP 2006). The main causes of disease, especially in developing countries like Ethiopia, Nigeria and Sudan, are lack of access to clean water, poor hygiene and inadequate sanitation (Minten et al., 2002; Collick, 2008). In these cases, the provision of drinking water is essential.

Efforts have been made to improve access to drinking water for rural and urban households. However, many people, especially in sub-Saharan Africa, South Asia and East Asia, still have no access to water. In addition, the availability of water varies considerably; While some people pay a high price for domestic water, others have easy access to clean water and adequate sanitation because of their geographic location and social status in society. The United Nations Millennium Development Goals (MDGs) call for the population of people without permanent access to clean drinking water to be halved by 2015. Rural communities in several developing countries depend on untreated wells for their drinking water. Policy makers should consider the provision of drinking water for domestic use to be a necessity for people in rural and urban areas. This is not the case in developing countries, where people in rural areas are often overlooked in water supply projects.

2.3 Overview of Water Supply in Nigeria

Nigeria's annual surface water resources are projected to be over 267 billion m^3, with annual groundwater resources estimated to be around 92 billion m^3. There are almost 200 dams in the country, with a total storage capacity of 34 billion m^3 (Egbinola, 2017). Only 15% of surface water is utilised, while 85% is wasted because it flows into the oceans without being properly stored (ADB, 2007). However, there are no statistics on the actual use of groundwater. Groundwater resources (boreholes and hand-dug wells) have long been recognized as the principal source of public and private water in both urban and rural regions, encouraging widespread and unregulated use. Despite its vast water resources, the country is nevertheless designated as "water scarcity" due to its inability to meet domestic water needs. Furthermore, due to fast population expansion and urbanization, the need for drinking water is likely to rise.

The Lower Usuma Dam provides some drinking water to Abuja, Nigeria's capital. The Guara Dam, which began construction in 2012, is designed to improve Abuja's water supply while also protecting the city from drought. Lagos, Nigeria's largest metropolis, is surrounded by water and a lagoon. The drinking water supply in the city is roughly 81.32 %. The city, however, gets its water from the Ogun and Owo rivers because the lagoon's raw water is too contaminated. In 1910, the city erected its first water treatment plant in Iju, on the Ogun River. It increases to 45 million gallons per day overtime. Another smaller facility was developed in Ishashi on the Owo River in the 1970s while the largest facility to date has a daily capacity of 70 million gallons is situated at Adiyan. Furthermore, water is taken from the Owo River. In addition, there are seven micro hydraulic plants with a combined capacity of 18 million gallons per day that draw water from adjacent sources.

Makurdi, the state capital of Benue, has a shabby network that serves just 25-30% of the population, with locals collecting raw water from the contaminated Benue River with buckets. Authorities couldn't justify spending $ 6 million on an incomplete water treatment plant in 2008. The construction of a water treatment plant was part of the Grand Makurdi aqueduct project starting in 2012. Private water intake sites multiply as a result of a lack of public water supply, and their private operators profit. The Kaduna River provides drinking water for Kaduna, while the Eleyele Dam provides water for Ibadan.

In 1990, 47 % of Nigerians had access to water; by 2010, this figure had risen to 54 % (The Free Encyclopedia). In 2010, just 32% of the population had access to clean water. Only 87 million people, or 58 % of the population, have access to drinking water, while 63 million are excluded (Azubike, 2013). This differs between urban and rural areas, with the latter taking the brunt of the damage. However, the World Health Organization recommends that each individual consume 120 liters of water each day to guarantee proper drinking water consumption and function. Most individuals, however, would be unable to do so due to severe water supply issues.

Various administrations, on the other hand, have pursued numerous schemes to improve water supply and sanitation. Nonetheless, it was discovered that rural water and sanitation in Nigeria suffers from a lack of coordination, a lack of maintenance culture, an insufficient technical or institutional structure, insufficient funding, irregular grant payments, and insufficient infrastructure, as well as poor quality. Monitoring and assessment, a lack of a clear political orientation, and a lack of a goal orientation are all issues that need to be addressed.

Water supply infrastructure is still in its infancy in many rural villages in Nigeria, for example. Millions of people, mainly children in underdeveloped nations, are killed or injured by water-borne diseases. As a result, the World Health Organization (WHO) believes that better sanitation and hygiene could result in a considerable reduction in infant mortality.

According to a recent survey, 65 million Nigerians do not have access to safe drinking water. Given the larger share of the rural population, providing clean and reliable drinking water in rural regions remains a difficulty.

As a result, governments must spend in the provision of safe drinking water. Hand-dug wells, natural springs and streams, as well as rain collecting, are the most important sources of water for the rural population, which is often unreliable during dry seasons. Nigeria's rural development efforts, as well as the Water for All by 2020 target, have expanded the assessment, exploration, and exploitation of water resources in Nigeria, both on the surface and underground, as they have in other regions of the country. Despite the government's and non-governmental organizations' investments in delivering clean water to the state's rural population, there is still a long way to go. Improving access to safe drinking water and sanitation is a preventive intervention that will reduce diarrheal disease and, as a result, mortality. Water shortage in rural areas is reflected in poor health, particularly among small children, with a 170 per 1,000 live births infant mortality rate. Diarrhea and dysentery, malaria, and tetanus account for around 65 % of all infectious diseases that kill children under the age of five. The lack of precise data on available water sources and their sanitation has been one of the major roadblocks to increasing drinking water supply.

As a result, a comprehensive examination of the public health implications of rural access to safe drinking water is required. This necessitates precise and unbiased data on the number, quality, and dependability of the sources. The qualitative part of the assessment must come first, followed by the question of whether the quantity is sufficient to meet the population's needs. Water supply assessments have been carried out in rural communities throughout Nigeria's northern central states, but not in rural villages. The Nigerian government, like any other government in the globe, has done an excellent job in terms of water delivery projects in the country. Water supply initiatives aimed at ensuring that drinking water reaches every area of the country, on the other hand, have faced numerous obstacles. The development of rural water supply and sanitation has been patchy since Nigeria's independence in 1960.

2.3.1 Water Supply Management Policies in Nigeria

Water supply is on the concurrent legislative agenda in Nigeria, which is a considerable obstacle to cooperation and role and function defining (Goldface-Irokalibe, 2008). The Water Resources Act of 1993 grants the government the authority to utilize and manage all surface and groundwater resources in the country in order to develop, use, and safeguard them. Water that is shared by many states is the responsibility of the federal government; otherwise, each state is responsible for the water resources within its borders. The federal government is also in charge of most of the country's constructed dams and reservoirs. The Water Resources Act of 1993 ensures that everyone has access to safe drinking water from public sources. Water can be obtained from any groundwater source or stream by people with legal or customary land rights for residential use, animal irrigation, or personal irrigation systems. Furthermore, state-level water legislation and local water associations restrict usage (Boniface, 2000).

In each of the country's four major river basins, the Watershed Development Authorities Law of 1979 established and regulates 12 Watershed Development Authorities (RBDA). The watershed development authority are supervised by the Federal Ministry of Agriculture and Rural Development (Egboka, 1981).

Within their borders, each states have jurisdiction over water resources, and the majority of them do.

The Federal Ministry of Water Resources (FMWR) is the water sector's most important national coordination office. Water resource management is a broad term that encompasses regulatory, operational, and support functions. Government institutions like the Federal Ministry of Water Resources and state water authorities, as well as non-governmental organizations and funders like CBO, NGO, UNDP, UNEP, EU, and World Bank, collaborate in Nigeria. as well as UNICEF (Emoabino and Alayande, 2007). The federal and state ministries of agriculture and the environment are two other government entities that are not directly involved in the development of water resources but are indirectly involved (Kévin, 2015).

2.3.2 Water Supply Infrastructure

The following is a list of the Nigerian institutions in charge of water supply. Water services are decentralized at the local level so that the private sector can build, operate, and maintain the water supply infrastructure; and each level of government (local, state, and federal) is empowered to develop, treat, and distribute surface and groundwater to users, as well as build and maintain a water supply infrastructure. In Nigeria, the following service companies are currently involved in providing water delivery services.

• Federal Ministry of Water Resources: This government agency performs both primary and secondary functions in the development of Nigeria's water resources (Aderogba 2005). This authority is in charge of developing and implementing national water supply policies, legislation, regulations, and programs. However, aside providing logistical support, sponsoring specialized programs (rehabilitation), and ensuring that all water actors behave on an equitable footing, the agency is not directly involved in the supply of rural water services (Adeleye et al. 2014; Adeoye et al. 2013). It also supervises and oversees policy, offers technical advice and support to state water agencies, conducts studies and research, manages and monitors development partner engagement, and provides financial aid and assistance. It assists state and local governments, as well as organizing and funding facility repair programs around the country.

• Water authorities/companies in each state: In their respective legal systems, these state entities are responsible for the complete provision of rural water services (Adeleye et al. 2014). They oversee the licensing and registration of private water service providers and water user associations, as well as the planning, development, operation, maintenance, and repair of rural water infrastructure. Setting standards, assigning money, and selecting technology are among the other responsibilities. Recruit, train, pay, and deploy personnel; Monitoring water quality; ensuring replacement parts availability; building the capacity of community service providers; Conducting research and studies, as well as providing additional services as needed.

• Local governments: Local governments are in charge of the development and management of water resources in their jurisdiction (Nzeadibe, Ajaero 2010). They serve as regulators, service providers, and fundraisers, all with the goal of making it easier to supply locally sustainable water infrastructure inside their borders.

• Non-governmental organizations (NGOs): Many NGOs, as well as bilateral and multilateral organizations, have invested in the construction and rehabilitation of Nigeria's rural water infrastructure (Adekayi et al. 1991). Examples include the World Bank, the World Health Organization, and UNICEF. These non-governmental groups work on developing rural water supply infrastructure, disseminating innovative technologies within existing systems, and repairing ailing water supply infrastructure. They develop, finance, and construct municipal water supply systems, as well as providing technical help and support to increase family access to safe drinking water, particularly in water-scarce areas.

• In Nigeria, the private sector plays a critical role in the development and management of private water infrastructure. Individuals, communities, enterprises, and community-based organizations (CBOs) are increasingly participating in public water distribution in Nigeria, thanks to a range of private-sector efforts (Chitonye, 2011). Despite the efforts of the aforementioned organizations, Nigerian rural communities continue to face water scarcity and shortages (Omole et al. 2015). Consumers of water confront significant and long-term issues in meeting their water needs (Adeleye et al. 2014). They mostly concentrate on the construction, operation, and maintenance of privately held facilities. They collect water rates from customers and supply operation and maintenance tool kits so that private water projects can get spare parts and be monitored.

2.3.3 The National Water Policy (NWP) Document of 2004

The National Water Policy governs water abstraction for public water supply. To fulfill Nigeria's water supply demand, policy objectives and implementation guidelines were developed. The Millennium Development Goals (MDGs), the NEPAD Objectives, and the outcomes of various water policy conferences, conventions, and meetings inspired the development of the water resources policy. International trends and agreements on water policy have emphasized the importance of participatory water management and development, with decision-making taking place at the lowest appropriate level. The concepts of national water policy are founded on the goal of protecting the nation's water resources in order to ensure long-term balanced social and economic progress.

2.3.4 Factors Affecting Supplying of Potable Water in Nigeria

The elements that contribute to massive failures in water systems in Nigeria have been thoroughly examined by Ofoezie (2003), Ulocha (2005), Gbadegesin and Olorundemi (2007), Abaje et al. (2009) and Omole et al. (2015). These are the factors they highlighted:

• Pollution from industry and cities: Environmental degradation has harmed drinking water, water resources, vegetation, and animal life, as well as soil fertility, in the Niger Delta area, which comprises the states of Rivers, Bayelsa, Cross River, Delta, Edo, Akwa Ibom, Abia, Imo, and Ondo. One of the region's catastrophic effects of oil spills and gas flaring was this. Oil spills are becoming more regular in the area. Pipelines carrying crude oil to refineries traverse across farmland, lakes, and fishing grounds, and some of them degrade and burst over time. The melancholy has been accentuated by unpatriotic behaviors such as oil bunkering. According to Ukase (2009), Shell Petroleum alone leaked about 1.6 million gallons of oil into the environment between 1982 and 1992. In today's world, the same firm logs 200 spills per year. He also shows that between 1999 and 2004, oil companies spilled approximately 2,300 cubic meters of crude oil into the river in 300 distinct occurrences. Ukase (2009; Ukase, 2009; Ukase, 2009). Gas flaring has contributed to the poisoning of fresh water in the Niger Delta region, alongside oil spills.

Nigeria produces over 1.8 billion standard cubic meters of gas per day, which is flared into the atmosphere on a daily basis (Emordi and Azelaman, 2009). As a result, acid rain forms and fresh water sources become acidified, rendering them unsafe for human use. And, if not for the Amnesty program, it was precisely this degradation of the environment that fostered youth rebellion in the region and constituted a severe threat to national growth in the twenty-first century. Untreated industrial fluid waste and chemical pollutants have contaminated several sources of fresh water, such as streams, rivers, and lakes, in addition to oil spills and gas flaring. The significance of fertilizer firms and other chemical industries in this regard cannot be emphasized. The National Fertilizer Company of Nigeria (NAFCON), for example, was discovered to have contaminated the River Kaduna in Northern Nigeria, rendering it unsafe for human consumption and drinking for an extended length of time (Akpan, 2009).

• Infrastructure Decay: Infrastructure decay has worsened the issues associated with water delivery in some parts of Nigeria, in addition to water contamination. Several water treatment plants have been decommissioned and are in a condition of disrepair, resulting in aesthetic figures. According to the World Bank, due to malfunctioning equipment, Nigerian water production facilities were rarely running at full capacity in 2010. There are numerous manually controlled taps across the country that have remained dry for the majority of the time. Intriguingly, erratic water supply hastens the failure of water equipment. It damages pipes, produces rust, and causes leaks, compounding the water supply issue (Yunusa, 2001).

• Inadequate Power Supply: Providing adequate potable water to the public requires electricity. This, however, is a long cry from the unpredictable power supply that urban and rural residents have to contend with. Nigerian water production facilities, according to the World Bank, were rarely running at full capacity in 2010 due to faulty equipment or a lack of power or fuel for pumping. Due to the irregular nature of power supply, water agencies' running costs are raised by the need to rely on diesel generators or even develop their own power plants. Intermittent delivery and large volumes of non-revenue water are the result of poor equipment and pipe maintenance. According to studies, Nigeria's power station has a capacity of 5400 Megawatts

(MW), however only 1,600 (29%) of that capacity has been generated. It also showed that 37,500 MW was needed to fulfill the global standard, but only slightly less than 3000 MW was achieved in the fourth and first quarters of 2007 and 2008. This equates to a per capita consumption rate of 27 kW/hr, but the worldwide per capita consumption rate is set at 2500 KW/hr (Mawali and Aminu, 2010). A steady power supply is essential for a variety of socioeconomic operations, including water generation and distribution, and its absence has negative effects for the country. In a research on the water situation in Zaria, Yunusa (2001) argues concisely that water plants demand a minimum of 22.4 hours of electricity every day. Only around ten hours of power are provided daily by the public utility that delivers electricity to water treatment plants and pump stations. As a result, the city's whole water supply is severely depleted, and the water machinery is idle.

• Inadequate Funding: A major component of enabling water supply is funding, which is chronically inadequate. For example, funds are needed to refurbish or build additional laboratories for the purpose of implementing water quality and control initiatives; to establish hydrometer data collection centers and refurbish existing ones in accordance with WMO specifications; and to provide chlorine and water treatment plants, as well as water treatment plants. A closer look at the Nigerian scenario indicates that the water sector's infrastructure has collapsed due to a lack of investment.

• Corruption: It's also worth noting that corruption in the granting of water contracts has played a significant role in the widespread water scarcity that currently affects the majority of Nigerians. As resources that may be used to improve the functionality of other areas of the economy are wasted or diverted, the result is increased water shortage.

• Demographic Changes: Another serious impediment to the provision of appropriate water to the populous is the exponential rise of the population. Nigeria's population may be regarded as modest for the first decade after political independence. According to the National Population Commission, Nigeria's population increased from 88 million in 1991 to over 140 million in 2006. This shows that our population has more than quadrupled to 52 million people in the 15 years since the 1991 census (Mamman,1994). Nigeria's population has swelled to almost 200 million people, resulting in increased daily water usage.

2.3.5 Consequences of Inadequate Water Supply in Nigeria

The incapacity of industries that rely on water as an input in the creation of industrial goods to function, and when they do, the resulting commodities will be expensive, are among the economic implications of water scarcity. As a result, the general public is experiencing significant economic difficulty. On a social level, water scarcity has a disastrous effect on sanitation and personal hygiene. Apart from that, most people get water-borne diseases like cholera, diarrhoea, guinea worm, river blindness, and skin ailments as a result of their efforts to consume untreated water. Water supply challenges have political ramifications for any government, democratic or military, in terms of creating an impression of poor governance, denial of basic human rights, corruption, and a lack of accountability to the citizenry, necessitating the need for politicians to change their behavior in order to effectively combat the Nigerian water crisis

2.4 Water Demand and Supply in Ibadan

There are various major types of water use, each with its own set of quantity and quality criteria. These categories include drinking and cooking water, waste disposal, crop production, aquaculture, livestock, industrial usage, recreational use, navigational use, and ecological values such the survival of natural lake, riverine, and wetland communities. Climate and precipitation variables play a big role in determining how much water is needed for each of these activities.

The method by which governmental utilities, business companies, communities, and individuals distribute water, usually through a network of pumps and pipes, is known as water supply. Household connections or other enhanced techniques such as standpipes, water kiosks, spring supplies, and covered wells are needed to provide adequate access to safe and clean water for public consumers. The single most significant predictor of public health is the availability of potable water, specifically unpolluted (impurity-free) water. As the world continues to urbanize, providing safe and reliable water to the urban population is becoming increasingly important.

The escalation of strain on water supplies is influenced by demographic, social, and economic changes. Water availability, management, and waste water disposal are three significant concerns surrounding water supply in urban areas. Small and medium-sized towns are likely to see the most urban growth. In the face of rising demand and limited ability to operate such services, some communities lack the necessary money to maintain the existing rate of infrastructure development. Because of their slow rate of infrastructure development, unplanned peri-urban areas are particularly vulnerable (Anna Norstrom et al, 2009; UN Habitat, 2006).

Even without accounting for climate change, the globe as a whole is on its way to becoming increasingly water-scarce, as seen in Ibadan township, where pure-water sachets and table water are the most convenient sources of potable drinking water. Water shortage is already severe, and existing water has been polluted and rendered unsafe for human consumption. The Eleyele dam, which is unable to meet demand due to the city's rising population, provides drinking water to Ibadan. As societies grow, water usage patterns change; global trends in the use of various water sources indicate a shift toward piped water on premises, especially in metropolitan areas. This kind of water supply is only available in older portions of most Nigerian cities (for example, Ibadan), as recently constructed regions have not been linked into the water supply network, requiring residents to find other ways to meet their water demands.

2.4.1 Water supply scheme in Ibadan

Water is obtained in a variety of methods by the people in Ibadan. They are:

• Pipeborne Water: The State Water Corporation provides pipeborne water and has been the primary source of water supply for many years, but it is no longer as functional as it once was due to a lack of funds and insufficient maintenance, and it is unable to keep up with the city's rapid rate of development and urbanization, forcing inhabitants to seek water through alternative methods.

• Boreholes: These are found mostly in individual homes, commercial and health-care buildings, and sometimes constructed for the local communities by politicians and Non-governmental Organization.

• Wells: Due to a lack of public water, average residents could only afford to provide water for its households from wells

• Rivers/streams: In some of the city's peri-urban areas, where there is no access to piped water and no wells, residents rely only on water from rivers and streams for household uses.

2.5 Climate Trends in Nigeria

Since 1901, research in Nigeria have showed an upward trend in air temperature. The average air temperature in Nigeria was 26.6°C between 1901 and 2005, an increase of 1.1°C over 105 years. This is higher than the global mean temperature increase of 0.74 degrees Celsius (Akpodiogaga-a & Odjugo, 2010). Furthermore, the rainfall trend in Nigeria from 1901 to 2005 shows a downward trend. Between 1901 and 2005, rainfall in Nigeria fell by 81 millimeters, according to Akpodiogaga-a & Odjugo (2010). Odjugo (2007) also discovered a 53 percent reduction in rainy days in northeastern Nigeria and a 14 percent reduction in the Niger Delta coastal areas. Aside from the brief dry season, August Break is now more common in July than it was in August before the 1970s. Significant disturbances in Nigeria's climate patterns were attributed to this, demonstrating indications of climate change (Akpodiogaga-a & Odjugo, 2010).

There is considerable evidence that average climatic conditions, as measured by rainfall and temperature, are radically shifting. The humid tropical zone of southern Nigeria, which is already abnormally hot and wet, is anticipated to see an increase in both precipitation (especially during the rainy season's peak) and temperature, according to IPCC forecasts. Already, temperature increases of 0.20°C to 0.30°C each decade have been reported across the country's numerous biological zones, while the Sudan-Sahel region has been plagued by drought since the late 1960s. In Nigeria's tropically humid zones, precipitation increases of about 2% to 3% per degree of global warming should be expected. As a result, in the most humid sections of the forest and southern savanna, an increase in precipitation of between 5% - 20% is realistic to expect.

In instance, the savanna parts of northern Nigeria would likely receive less rainfall, resulting in decreasing soil moisture availability when combined with rising temperatures. The expected decrease in rainfall, which would result in greater drought probabilities and interannual variability, may exacerbate this (Akpodiogaga-a & Odjugo, 2010)..

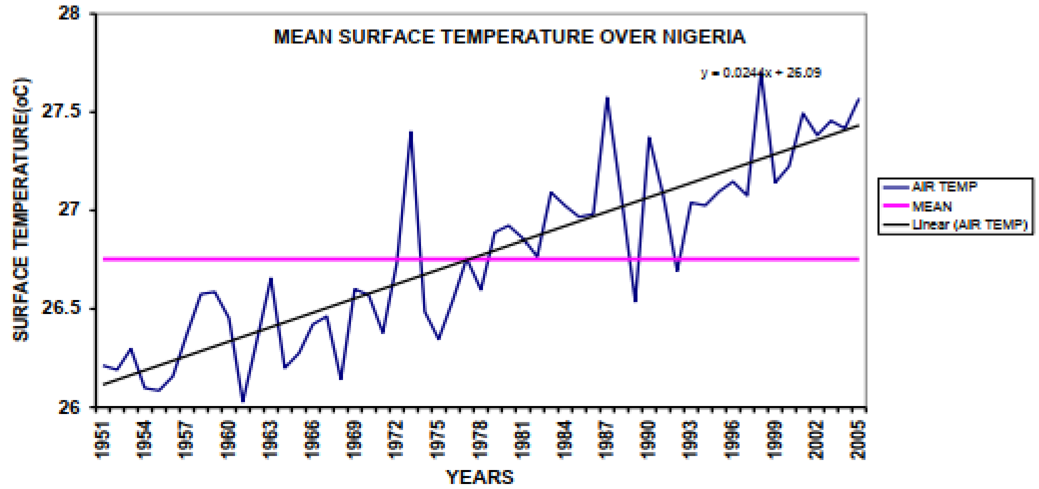

Fig 2.1: Mean surface temperature in Nigeria from 1951-2005 (Fashae and Onafeso, 2011)

2.5.1 Impacts on Climate Change on Water Resources in Nigeria

Because of its geographical location, limited technological and institutional capacity to adapt to rapid environmental changes, and heavy reliance on climate-sensitive renewable natural resource sectors such as water and agriculture, Nigeria, like the rest of Sub-Saharan Africa, is suffering the devastating effects of climate change (Eboh, 2009).

One of the most significant effects of climate change is the hydrological cycle, which includes everything from evaporation to precipitation, runoff, and discharge (McGuire et al., 2002). According to Akpodiogaga-a and Odjugo (2010), global warming and decreased rainfall cause the depletion of groundwater resources, wells, lakes, and rivers in the majority of the world's areas, mainly Africa, culminating in a water crisis. Users' natural desire to cluster around scarce water sources will be exacerbated by the approaching water crisis. The risk of further contamination of finite water resources and disease transmission increases in such conditions.

Lagos State, in southern Nigeria, is the largest metropolitan agglomeration in Sub-Saharan Africa, with Lagos as its capital. Lagos' coastal lowlands are already susceptible, and as sea levels rise, they will become ever more vulnerable. Flooding and the incursion of sea water into freshwater sources and ecosystems are predicted to worsen as a result of coastal inundation, intensifying the region's already boiling social tensions (Fashae and Onafeso, 2011).

In portions of northern Nigeria, drought-related conditions have resulted in a water deficit. Rainwater harvesting accounts for more than half of rural households' total water usage, and northern groundwater tables have plunged in the previous 50 years, owing in part to reduced rain (Sayne, 2011).

Changes in river flow timing and rising air temperatures can have a range of effects on water quality and use. Flood peaks, on the other hand, may cause greater erosion, turbidity, and concentrated pollutant pulses. This makes it more difficult for water treatment plants to produce safe drinking water. Reduced flow, heat, and eutrophication, on the other hand, impede the spread of floods and occasionally result in water stagnation in some areas. Floating weeds impair fishing, shipping, irrigation scheme functioning, and hydroelectric development. They also encourage the spread of vectors for water-borne diseases like malaria. The water hyacinth has spread swiftly across the Volta's Otti sub-catchment in recent years, while the Typha has spread widely in Northern Nigeria's Komadugu Yobe Basin. Water quality degradation and the development of water-borne infections are exacerbated by the discharge of untreated wastewater into rivers from large metropolitan areas and the increased use of agricultural inputs.

2.6 Non-Parametric Trend Analysis

2.6.1 Man-Kendall Trend Analysis

The Mann-Kendall test is a frequently used statistical test for trend analysis in climatological and hydrologic time series (Mavromatis and Stathis, 2011, Onoz and Bayazit, 2012). It is mostly utilized to find monotonic trends in data sets with meteorological, hydrologic, and environmental factors.

The Mann Kendall test has several advantages, according to Tabari et al. (2011), including being a non-parametric test that does not require data to have a normal distribution and being insensitive to sudden breaks in time series due to inhomogeneity. Both null and alternative hypotheses are considered in the Mann-Kendall test with the null hypothesis (H_o) claims that the data has no monotonic tendency (i.e., the data are independent and randomized), whereas the alternative hypothesis (H_1) states that the data does have a monotonic trend.

Statistically, Mann Kendall, S statistic is calculated as follow:

$$S=\sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sign\ (Xj - Xi)$$ Equation 2.1

With x = $Xj - Xi$

$$\text{Sign (x)} = \begin{cases} 1\ if\ x > 0 \\ 0\ if\ x = 0 \\ -1\ if\ x < 0 \end{cases}$$ Equation 2.2

Where Xj and Xi are the annual values in years I and j, j>I respectively and n is the data size

When n ≥ 10, the Mann Kendal statistics is normally distributed with the mean and variance (σ^2) is:

E (S) = 0

The variance of the S- statistics is:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{j=1}^{p} tj(tj-1)(2tj+5)}{18}$$ Equation 2.3

where p is tied group number in the dataset, tj is umber of data points in the jth tied group. The sum of the numerator in equation (3) is used only if there is tied values in the data series.

The standard test statistic Z is computed as:

$$Z = \begin{cases} \frac{S-1}{\sigma}\ for\ S > 0 \\ 0\ for\ S = 0 \\ \frac{S+1}{\sigma}\ for\ S < 0 \end{cases}$$ Equation 2.4

The test statistic Z is used to measure the significance of trend and to test the null hypothesis (Motiee and McBean, 2009).

Kendall's tau is a measure of correlation that measures the strength of the association between the two variables and is produced from the Mann-Kendall test. Kendall's tau is similar to Spearman's rank correlation in that it uses the data's ranks to calculate the correlation. That is, the values for each variable are numbered and ordered sequentially, with 1 denoting the lowest value, 2 the next lowest, and so on. Kendall's tau, like other correlation measures, takes values between -1 and +1, with a positive correlation stating that the rankings of both variables rise in lockstep, and a negative correlation implying that as one variable's rank rises, the rank of the other declines (Karmeshu, 2012).

2.6.2 Sen's Slope Estimator

Sen's slope is used to forecast the magnitude of a trend and to estimate the real slope of an existing trend that is assumed to be linear (Thenmozhi and Kottiswaran, 2016). It is given as:

$f(t) = Qt + B$ Equation 2.5

where Q represents slope, B represents constant and r is time. To estimate the vaue of Q, the slope of all the paired data is calculated first using

$Qt = \frac{Xj - Xk}{j - k}$

Where Xj is data value at time j and Xk is data values at time k.

If the time series contains n values and xj, there will be as many slopes estimates Qi as N = n(n-1)/2. The median of these N values of Qi is used as Sen's estimator of slope. The N values of Qi are ranked in decreasing order of magnitude, and Sen's estimator is calculated as:

$Q = \frac{N+1}{Z}$ if N is odd

Or

$Q = \frac{1}{z}(Q\frac{N}{z} + Q\frac{(N+1)}{z})$ if N is even

To obtain an estimate of B from equation (5), the n values of the difference between Xj and Qtj are calculated, and the median of these values gives the value of B.

2.7 Water Evaluation and Planning (WEAP)

2.7.1 Background of WEAP

WEAP is an efficient, comprehensive modeling software that simulates and models water supply, water demands, and environmental requirements, as well as the effects of policies on water quantity, water quality, and the ecosystem. WEAP uses a combination of linear programming and algorithms to solve the water allocation problem, taking into account supply preferences and demand priorities (Sieber. J and D. Purkey, 2011). It can be used by Water planner to assess a wide range of challenges using scenario-based approaches such as climate change, expected water demand, operational objectives, change in watershed condition and available infrastructure (Yates, 2005)

2.7.2 Description of WEAP

WEAP is a proactive management tool that can simulate water demand, water supply, streamflow and storage (SEI, 2007).

WEAP consist of five program structures namely:

i. Schematic
ii. Data
iii. Results
iv. Scenario Explorer
v. Note

I. **Schematic View**: The schematic view serves as the beginning point for modeling activities in WEAP.

II. **Data View**: The Data View is a hierarchical tree that allows you to enter, retain, and manage data as well as specify assumptions for each scenario and the current account. The six primary categories that make up the hierarchical tree are Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Water Quality, and Other Assumptions.

III. **Results View**: The result view's aim is to display the results of scenario calculations as a charts, table, or map.

IV. **Scenario Explore View**: This view is used to display numerous required charts and/or tables in order to investigate the effects of scenarios on various aspects of the water system, such as ecosystem needs and water availability.

V. **Notes view**: This is used for entering statements for documentation and referencing.

2.7.3 Algorithms of WEAP

Water Demand

In WEAP model, two methods are used to calculate water demand

i. The monthly demand option to input demand values monthly or by importing the monthly data using a “ReadFormFile” function from a CSV file

ii. The Annual Demand with Monthly variation option. In this option, the activity level (e.g population) and the water use rate is used to compute the annual water demand

Water demand is thus calculated as follow:

Total demand = Total activity level x water use rate

In WEAP, annual demand for a demand site is the summation of all the demand site’s bottom level branches (Br).

Therefore,

Annual Demand = $\sum_{Br}(TotalActivityLevel * WaterUseRates)$

According to SEI, 2014, the total activity level for a bottom level branch is the product of activity levels for all the branches from the bottom branch back up to the demand site branch (where Br is the bottom level branch, Br' is the parent and Br" is the grandparent)"

Therefore:

$TotalActivityLevel_{Br} = ActivityLevel_{Br} * ActivityLevel_{Br'} * ActivityLevel_{Br''}$

2.7.4 Application of Water Evaluation and Planning

Climate change and variability have a well-known impact on the development of water resources around the world. It has been identified as a major concern affecting the availability of water resources, posing a threat to water resources. To ensure sustainable water resource availability, management, and development in any setting, a comprehensive and holistic strategy to water management and maintenance is required (Bello 2014). However, in order to achieve sustainable development, water resources management and planning necessitate a multidisciplinary and holistic approach that brings together a diverse range of expertise and interests to develop new efficient forecasting tools to process hydrological and water-related data and forecast the effects of various management strategies under the impacts of climate change uncertainty.

Several studies have been done on applying the WEAP model to drainage basin water management, but only a few have focused on urban water supply and demand.

Saraswat et al. (2017) applied a different kind of water management strategies approaches in Kathmandu valley to meet water security. According to the findings, external factors increase pressure on the existing water supply system, worsening the water shortage situation while climate change, on the other hand, has had little effect during the study period. They concluded that an optimal management plan is viable for achieving 100% water demand coverage in the study region by 2027.

To illustrate the value of integrated watershed management in ensuring long-term water resources in Chifeng city China. Hao et al. (2015) used WEAP and soil and water assessment tool (SWAT) models to investigate the effect of climate change and adaptive management scenarios. They concluded that reducing water demand and increasing supply is the most efficient and safest way to solve the water shortage crisis.

Kou et al. (2018) applied WEAP to analyse water demand and supply in five districts of Xiamen city for 35 years (2015 - 2050) using the WEAP model. The result revealed a significant increase in future water requirement in Xiamen City, and water shortage will occur after 2030 if no new water supplies are introduced. Therefore, they concluded that water-saving measures and the use of new water supply systems must be implemented to prevent water scarcity in Xiamen city in the future.

Alemu and Dioha (2020) used WEAP to model different water management scenarios, such as population increase, living standards and strategies affecting water supply and demand in Addis Ababa, Ethiopia. The result shows that in a 48% increase in unmet water demand between 2015 and 2030, a high standard of living and increased population increased.

Adeaga et al. (2019) examined uncertainty and insecurity in water resources from climate variability and change, population increase and economic development in the Yewa basin, Nigeria using the WEAP model. The result from scenario analysis revealed 45.24% of annual water consumption unmet from the mean annual discharge of 3682.46m3/s of streamflow and 1106.26m mean annual rainfall water potential. Therefore, they concluded that an appropriate management mechanism is needed for water resources management in the study area.

Using the statistical downscaling WEAP model, Ougougdal et al. (2020) investigated the impact of IPCC climate change and socio-economic scenarios on future water demand and availability in the Ourika watershed in Morocco over the next 100 years. In all scenarios, the models show a rise in water demand and unmet water demand, as well as an increase in water resource pressure, leading to water scarcity. Simultaneously, as a result of climate change, water demand is predicted to increase to 64 million cubic meters.

WEAP was used by Mounir et al. (2011) to assess future demands in the Niger River Basin. Using a constant population growth rate in the cities, three scenarios were considered. The water year system was used in the second scenario, with climatic conditions varying. On the other hand, the third scenario considered a change in climatic conditions from normal to abnormal in the event of an extreme event. The findings indicate that unmet demand is only seen in areas with higher population growth and a more dynamic climate. As a result, the study proposed building a hydroelectric dam on the Niger River to help regulate water flow and low water levels in the river and provide sufficient water supplies for towns facing water shortages.

Using the Environmental Water Accounts (SEEAW) and WEAP model, Dimova et al. (2013) assessed existing water supplies and socio-economic resource water needs in Bulgaria's river basin. Water supply and utilisation tables, hydrological coupling, and financial details are all important components of Model SEEAW. According to the findings, steam-generating industries use the most water (63% of available water), followed by agriculture and sanitation (16% and 10%, respectively). Finally, they claimed that WEAP software is a dependable tool that can help the development of water beads while many of the desired parameters in the SEEAW table can be obtained as products reports using the SEEAW process, which requires the setup and performance of a comprehensive water management model.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Overview

This chapter contains various procedures and methods applied to achieve the aim and objectives of this research. It comprises preliminary study of literatures, data collection, data preparation, data analysis and modeling.

The preliminary study involved studies of related research articles while data collection involved fieldwork activities involving collection of spatial, meteorological, socio economic and hydrological data which were used in data analysis and modeling of the study area. The data preparation stage involved screening and processing of collected data for further analysis. The trend of the hydroclimatic data was analyzed using Addinsolf XLSTAT in Microsoft Excel while modeling was done using Water Evaluation and Planning (WEAP) software.

3.1 Data Collection

Both spatial and non-spatial data were used for this research, the spatial data used comprises geographical map of the study area while the non-spatial data are meteorological data (rainfall, temperature, windspeed), socio economic data and hydrological data. The data used were sourced from Water Corporation of Oyo State (WCOS), Ogun Osun River Basin Development Authority, Nigeria Bureau of Statistics (NBS), USGS and articles.

3.1.1 Spatial Data

The spatial data including geographical map of the study area was downloaded from https://www.diva-gis.org/datadown. The geographical map of the study area was delineated using QGIS 3.14 version. The geographical map of the study area is shown in Fig. 3.1.

3.1.2 Non-Spatial Data

The non-spatial data includes meteorological data, hydrological (streamflow) data, socio economic data (population, population growth rate) and groundwater data

3.1.2.1 Meteorological Data

Daily climatic data of Ibadan from 1986 – 2015 was collected from the Nigerian Meteorological Agency (NIMET). The datasets was used for determining the trend analysis and also to calibrate and validate the WEAP model. The average monthly values of the data are shown in Table 3.1 while Fig 3.2 shows the mean monthly rainfall and temperature.

3.1.2.1 Streamflow Data

Monthly streamflow data from 1988 – 2018 was collected from Ogun Osun River Basin Development Authority.

3.1.2.1 Socio-Economic Data

Socio economic data including population was obtained from National Bureau of Statistics report. The population data of 2006 was used for this research.

3.2 Description of the study Area

3.2.1 Location

Ibadan (Fig. 3.1) is the capital of Oyo State and is located in western Nigeria. Ibadan is located about 145 kilometers north of Lagos, at latitude 7^0 25' north and longitude 3^0 5' east. It is located at the forest-grassland line, making it a crossroads for people and products from both the forest and grassland sectors. Ibadan is regarded as tropical Africa's largest indigenous city. When Nigeria had only three regions, it was the capital of the ancient Western Region. In the Ibadan Metropolitan Area, there are eleven local governments: five urban local governments in the city and six semi-urban local governments in the suburbs.

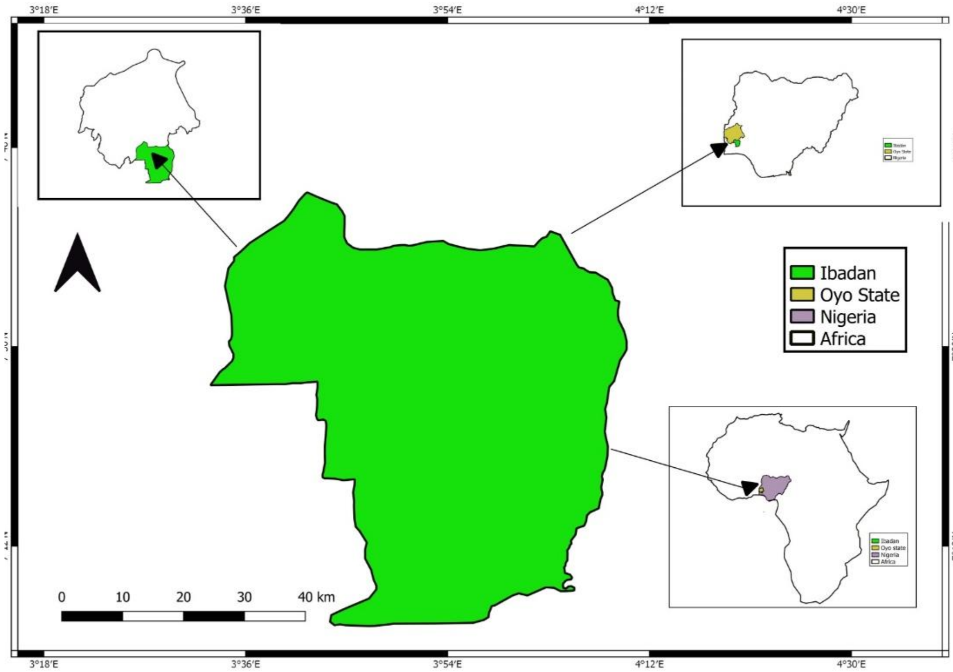

Fig 3.1: Map of the study area

3.2.2 Climate

Ibadan's climate is characteristic of the West African monsoon, with noticeable seasonal fluctuations in wind patterns. The city is impacted by wet maritime South-West monsoon winds flowing inland from the Atlantic Ocean during the rainy season, which runs from March to October. The dry season, when the Sahara Desert's dry dust-laden winds blow, lasts from November to February. The area experiences high relative humidity and two separate rainfall maxima regimes during the rainy season, which runs from March to October. From the middle of January through the commencement of the rainy season in the middle of March, the Harmattan's mean temperatures are at their greatest (averaging 28°C) (IUFMP, 2014).

3.2.3 Geology

The basement complex rocks of Ibadan are mostly Precambrian metamorphic rocks, including granite, quartzite, and migmatite as the dominant rock types. Pegmatite, aplite, and diorite are among the minor rock kinds. Basement Complex is the structure and sequence of geological events in Ibadan. Ibadan is underlain by igneous and metamorphic rocks from the pre-Cambrian period. Granite, quartzite, and migmatite are the major rock types, whereas pegmatite, aplite, and diorite are minor rock types (Ajayi et al., 2012).

3.2.4 Soil

The underlying rocks, particularly granite, gneiss, quartz-schist, bottle gneiss, and schist, formed the soils of the Ibadan region. They are part of the primary soil category known as Ferruginous soils, and were developed under moist semi-deciduous forest cover (Hopkins 1965, D Hoore 1964, Alayande et al., 2012).

3.2.5 Water resources

Ibadan city has eleven dams and a lake located in six local government areas. Six of these dams are managed by the State Government, two are managed by the Federal Government while two are owned by Institutions. The combined capacity of the government owned reservoir is 42.7115 million m^3 (MCM). The Eleyele dam is a 14.63-meter-high earthfill dam with extensively vegetation at upstream and downstream sides that expands incredibly quickly.

Table 3.1: Reservoirs in Ibadan and their location

S/N	Name of Dam/Reservoir	Managed by	Latitude	Longitude	Height of Dam	LGA	Total capacity (MCM)	Water spread area (Ha)	Year of construction
1	Asejire	OYSG	7.36388	4.12723	26.213	Egbeda	32.218	526.316	1972
2	Eleyele	OYSG	7.41667	3.85	14.63	Ido	6.8975	161.943	1942
3	Pade	OYSG	7.62215	4.00374	9.5	Akinyele	0.74	26.12	1992
4	Sanusi	OYSG	7.21059	3.79139	9.5	Oluyole	0.624	23.4	2006
5	Akufo	OYSG	7.48467	3.81451	8.5	Ido	0.11	5	2007
6	Ijaye/Alabata	OYSG	7.618	3.86609	11	Akinyele	2.025	67.5	2010
7	Onidudu	FG	7.6194	3.91649	5	Akinyele	0.097	6.6	2013
8	Eni Oosa	FG	7.618	3.86609	NA	Akinyele	0.12	NA	1981
9	IITA	IITA	7.48508	3.8987	NA	Akinyele	NA	NA	NA
10	UI	UI	7.44203	3.88813	NA	Akinyele	NA	NA	1964
11	Ogunpa Lake	OYSG	NA	NA	NA	IBNE	NA	NA	NA

3.2.6 Socioeconomics and Demography of the study area

Between 1851 and 1921, the population of Ibadan expanded geometrically. It was estimated at 60,000 in 1951 and increased to over 200,000 in 1890, 238,094 in 1921, and 386,359 in 1931 (IUFMP, 2014). According to the NBS after a population census, the population of Ibadan was estimated as 2,559,853 in 2006.

Table 3.2: Population of Ibadan in 2006 (NBS, 2006)

S/N	LGA	2006 Population
1	Akinyele	251,808
2	Egbeda	393,879
3	Ibadan North East	331,444
4	Ibadan North	308,119
5	Ibadan Northwest	154,029
6	Ibadan Southeast	266,457
7	Ibadan Southwest	283,098
8	Ido	104, 087

9	Lagelu	148,133
10	Ona Ara	265,571
11	Oluyole	203,461
	Total Population	2,559,853

3.2.7 Land use

Ibadan is divided into eleven local government areas with a total land area of 3.123 kilometers. The urban region accounts for 15% of the land mass, while the agrarian and peri-urban areas account for the remaining 85%. In the past, Ibadan was mostly known for agriculture, but urbanization and industry have resulted in changes in land use, which have invariably modified the city's watershed characteristics (IUFMP. 2014).

3.2.8 Water Supply in Ibadan

Ibadan's public urban water comes from the Eleyele and Asejire reservoirs. Water Cooperation of Oyo State operates and maintains these two reservoirs, which supply two water works (WCOS). Table 3.3 shows that the total designed supply capacity of the Asejire and Eleyele waterworks per day is 186000m^3 /day and 33000m^3 /day, respectively. Six of the eleven local government areas are partially served by water from the Asejire and Eleyele reservoirs (Fig 3.2), while the rest of the local government relies on exploitation of available groundwater and other available surface water such as streams.

Table 3.3: Existing Ibadan water supply scheme and their production capacities (WCOY)

No.	Water Supply Scheme	Local Govt. Served	Capacity (MLD)
1	Asejire	Ibadan-North Ibadan- North East Ibadan- North West Ibadan- South West Ibadan-South East Egbeda	186,000
2	Eleyele	Ido Ibadan-North West Ibadan-SouthWest	27,000

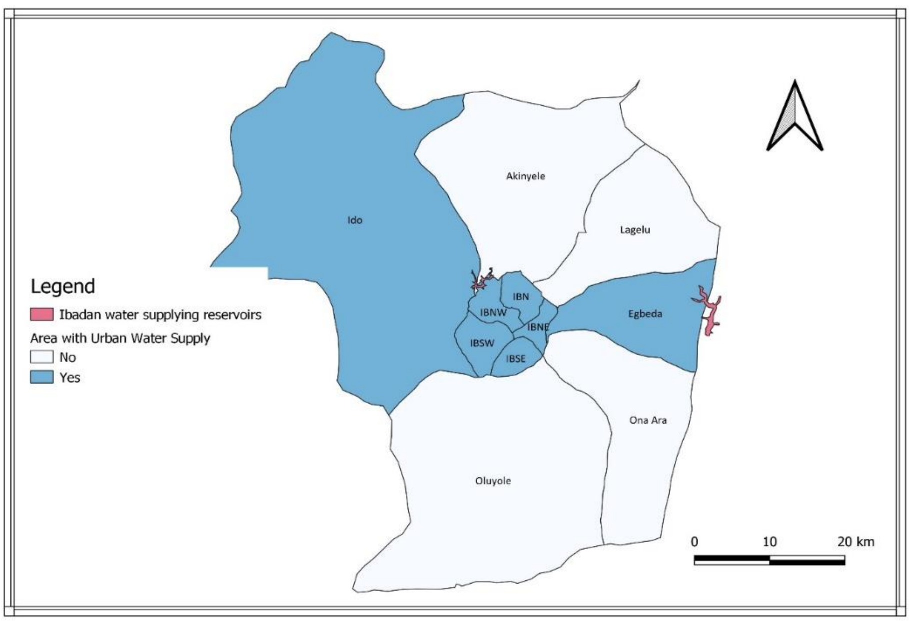

Fig 3.2: Coverage of Ibadan urban water supply

3.3 Methodology for Trend Analysis

Data used: Rainfall, Minimum and maximum Temperature data for 30 years

Method: Monthly rainfall and temperature data were analyzed using Mann- Kendal test to determine the monthly, annual and seasonal trend for a period of 30 years (1986 - 2015) and Sen's slope was used to estimate the magnitude of the trend.

Research Design:

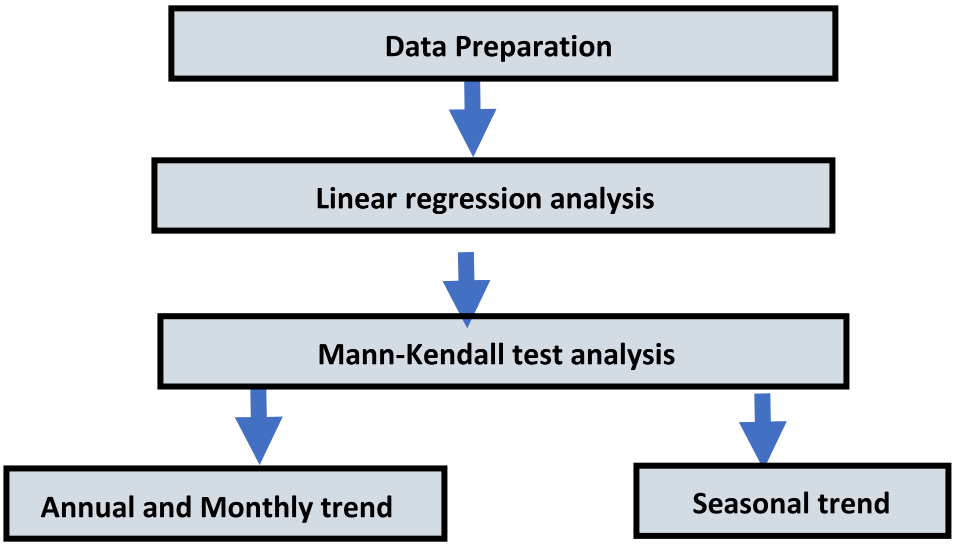

Fig 3.3: Conceptual framework for trend analysis

Procedures Used for Trend Analysis

The trend analysis of rainfall, maximum and minimum temperature was carried out using Addinsoft XLSTAT which was used on the monthly and annual data of rainfall, maximum and minimum temperature. The MK trend test was calculated using equation 3.1 – 3.4 while the Sen's slope estimator was calculated using Equation 3.5.

3.4 Application of WEAP Model

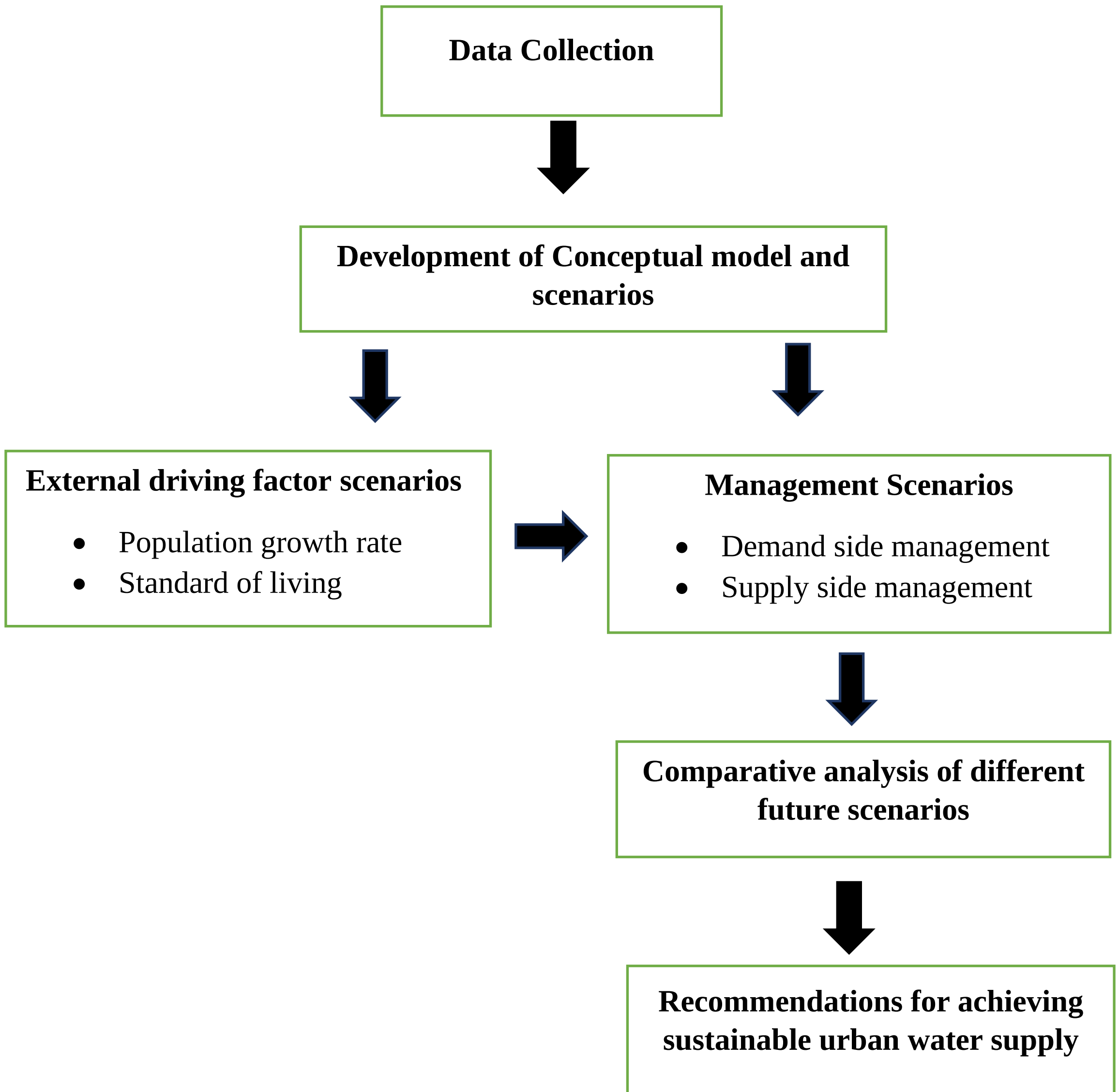

Fig 3.4: Conceptual framework for WEAP model

3.4.1 Procedures used for Data Input in and WEAP Model Setup

Delineated geographical map of the study area was imported into WEAP environment with the reservoirs and rivers. The general parameters setting was fixed to standard units. The demand sites (all the eleven local governments), the rivers (river Ona and Osun) and reservoirs were drawn by dragging the demand site symbol over the map and tracing the imported rivers lengths while the reservoirs were located on the rivers. To meet the demand sites water need, transmission links were created to connect the water supply sources (reservoirs and rivers) to each demand site, Fig 3.5. The schematic view of water demand and supply nodes or sites are shown is Fig 3.5. The main rivers (River Ona and Osun) feeding the two reservoirs (Eleyele and Asejire) are shown in blue colour while the reservoirs are shown in triangular shape symbols. The transmission link which shows the direction of water supply from the source is shown in green colour and the return flow link to discharge unused water from the demand sites are shown red. The WEAP model establishes a transmission link between the various supply nodes and demand sites to connect the various water supply sources to each demand site in order to meet the aggregate demand at each demand site (MESP, 2009). The total amount of water that has to be transported to the demand site is equal to the total amount of water that needs to be extracted from the source, less any potential losses. However, WCOY does not have data on water loss at each demand site.

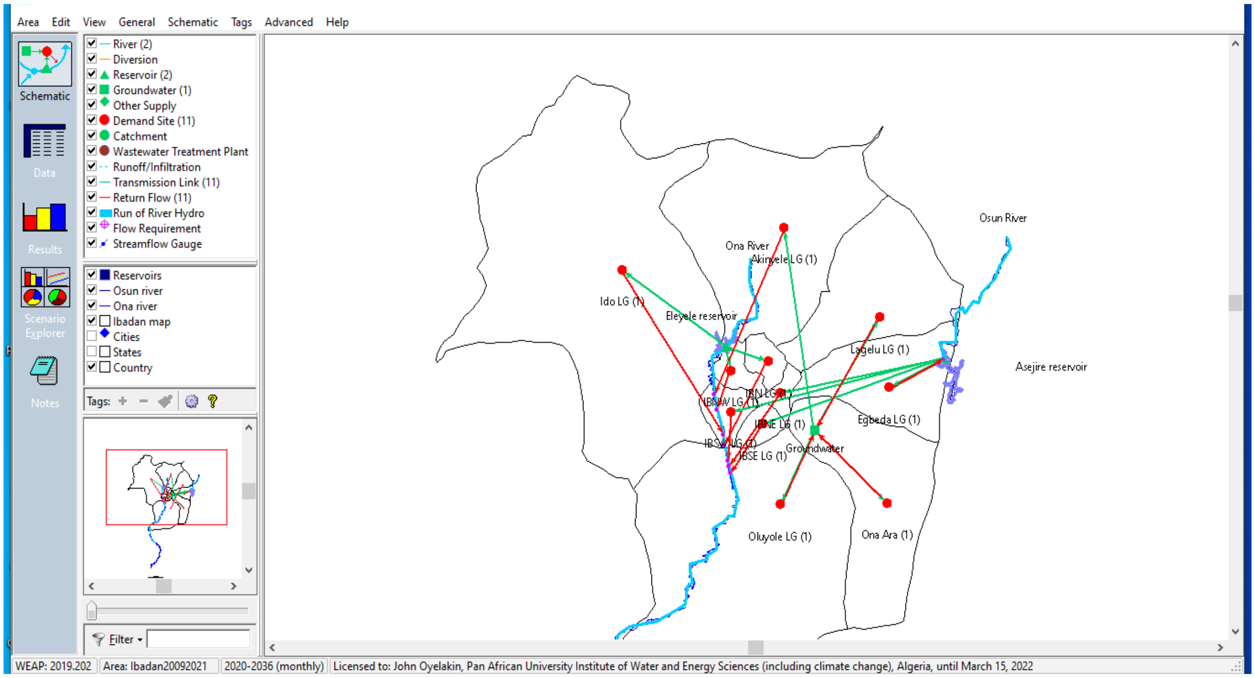

Fig 3.5: Schematic view of the study area in WEAP

According to Leevite et al., 2003, key assumptions refer to variables that are defined by users which can be referenced for the analysis of water demand and supply systems. These assumptions were established as a result of scarce data.

Table 3.4: Key assumptions used in WEAP modeling

Key Assumptions	Current Year (2020)	Reference/Scenario Year Period (2021 – 2036)	Unit
Population	Projected from 2006 population census result	Projected from 2006 population census result	people
Population growth rate	3.35 (NBS, 2006)	2.0 and 5.0 (assumed)	%
Annual water use	24.638	54.75 (assumed)	m^3/year

Water Supply

In this study, the demand sites were supplied with water from the water supply sources (reservoirs) by using the transmission links to meet the total demand of water required at each demand site. The total amount of water supplied equals the amount of water withdrawn minus the potential amount of water losses. According to WCOS, the unaccounted water (water loss) is about 40%.

Table 3.5: Reservoirs capacity used for water supply

Reservoir	Storage capacity (MCM)
Asejire Reservoir	32.218
Eleyele Reservoir	6.8975

For the groundwater source, since there was no data for the study area in literatures and the agency in charge, the groundwater storage of the aquifer was assumed to be 80 million m^3

Hydrologic Simulation

The goal of modeling water systems is to learn more about how a watershed responds to various hydrologic circumstances (Azadani, 2012). When modeling a water system, it's crucial to know how it works under various hydrologic conditions. Natural hydrological changes (monthly and annual) can have a big impact on your scenarios' outcomes. WEAP forecasts surface water hydrology for the research period using four different methods: the "Water Year Method, Expressions, Catchments Runoff and Infiltration, and the Read From File Method." For each month of the research period, these methods can be used to forecast the inflow to each system's surface and groundwater inflow locations (SEI, 2015).

In this study, the water year method was used to simulate hydrologic inflows. The Standard Precipitation Index (SPI) was used to calculate the water year. Using long-term historical meteorological data, SPI devised the hydrological water year approach (i.e. rainfall). In this study, SPI with a 12-month time period (SPI 12) was used. The Standardized Precipitation Index (SPI) is the most widely used indicator in the world for detecting and describing meteorological droughts. The SPI indicator, developed by McKee et al. (1993) and described in detail by Edwards and McKee (1997), quantifies precipitation anomalies at a given location by comparing observed total precipitation amounts for a specified accumulation period to the long-term historical rainfall record for that period. For that place and time period, the historical data is fitted to a probability distribution (the "gamma" distribution), which is then transformed into a normal distribution with a mean SPI value of zero (EDO, 2020).

Water Year Method

The Water Year Method allows for the easy examination of the consequences of future changes in hydrological patterns using simplified historical data. The Water Year Method predicts future inflows by altering inflow data from the Current Accounts according to the Water Year Sequence and Definitions in the Hydrology section (SEI, 2015). The hydrological conditions over a one-year period are described by a water year type. WEAP divides the water year into five categories: Normal, Extremely Wet, Wet, Dry, and Extremely Dry.

Water Year Definition and Sequence

The amount of water flowing into the system was defined in relation to a normal water year to identify each non-normal water year type (Very Dry, Dry, Wet, Very Wet), as shown in Table 3.6.

Table 3.6: Water year definitions

Water Year	Definition value
Very Dry	0.50
Dry	0.75
Normal	1.00
Wet	1.25
Very Wet	1.50

3.4.2 Calibration and validation of data in WEAP

WEAP model simulates streamflow, reservoir storage and water need based on crop, climate and soil data as well as management practices. Calibration and validation are integral processes in modelling. Calibration is the technique of adjusting the input parameters of a model to appropriately simulate outputs while validation is the process of checking the ability of the model to accurately represent the real world. During validation, the simulated outputs were compared with observed outputs for consistencies. After the calibration, the output files were used for the simulations in the model for future prediction. In the modelling procedures, the following key assumptions were made

3.4.3 Scenario Analysis Development for Future Water Demand and Supply

According to Alemu and Dioha (2020), for water evaluation and planning system analysis to perform optimally, water modeling and scenario analysis must be carried out. Scenarios are various assumptions that helps to explain the state of future water demand in a particular location. Future water demand of a place is driven by various factors such population growth, urbanization, standard of living, family income etc. This study employed scenario analysis to examine the water supply and demand in Ibadan in order to contribute to the city's water sustainability goal (SDG 6). These scenario analyses made use of 'IF' condition such as:

What will happen in the study area if population growth, socio-economic pattern and reservoirs capacity are altered?

What will be the result of water conservation practices, overexploitation of groundwater and introduction of waste water recycling programme?

To achieve the objectives of this study, three scenarios were developed namely:

i. Reference scenarios

ii. External factors driven scenarios
iii. Water Management scenarios

Scenario 1: Reference or Baseline Scenario

This is the fundamental step in developing future water demand and supply scenarios, It is also referred to as the "business-as-usual" scenario. In this scenario, all the key assumptions and other variables remain constant with respect to the base year, while socioeconomic and demographic variables grow at the official projected rate (Alemu and Dioha, 2020). Additionally, this scenario serves as a reference point for comparing the outcomes of other scenarios.

Scenario 2: External driven factor scenario

To determine the effect of external driven factors (mainly population growth and living standard) on water demand, various assumptions cases were developed.

Case 1: High population growth (HPG): In this case, the population growth rate was increased to 5%.

Case 2: Low population growth (LPG): In this case, the population growth rate was assumed to be 2%.

Case 3: High living standard (HLS): In this case, the water use rate was increased from 68LPCD to 150LCPD.

It is generally believed that high living standard would lead to increase in water consumption. Therefore, a case of high living standard was considered for the study area for future projection. With regards to high living standard, it was assumed that the per capital is equal to the WHO standard of 150LPCD

Case 4: High population growth and High standard of living (HPG + HLS). This is the worst scenarios where high volume of water would be required. Therefore, the population growth rate was assumed to 5% and the per capital water demand was assumed to be 150LPCD.

Scenario 3: Management Scenario

Case 5: Demand side management Scenario: This scenario assumed a decrease of 20% of water usage from the population by practicing water conservation method.

Case 6: Supply side management scenario: This scenario incorporates two existing reservoirs that are not currently being used to the water supply model. The storage capacities of the two reservoirs are shown in Table 3.7.

Table 3.7: Reservoirs capacity incorporated under supply side management scenario

Reservoir	Storage capacity (MCM)
Alabata Reservoir	32.218
Pade Reservoir	6.8975

CHAPTER FOUR

RESULT AND DISCUSSION

This chapter report and discuss the finding of this research.

4.1 Trend Analysis in Hydroclimatic Data

The trend analysis rainfall, maximum temperature and minimum temperature was done with 30 years rainfall and climatic data from Ibadan (1986 - 2015). Mann Kendall and Sen's Slope estimator was used to determine the trend analysis and the results are shown in Tables 4.1 – 4.3 and Figs. 4.1 – 4.9.

Table 4.1 shows details of the trend analysis of monthly, seasonal and annual rainfall in the study area.

4.1.1 Trend in Monthly, seasonal and annual Rainfall in Ibadan

Table 4.1: Summary of non-parametric Trend of monthly, seasonal and annual rainfall

	Mann Kendall Statistic (S)	Kendal's Tau	Variance (S)	P-value	Alpha	Sen's Slope	Test Interpretation
January	-245.00	-0.574	3141.667	<0.0001	0.05	-10.589	Reject H_0
February	-65.00	-0.149	3141.667	0.254	0.05	-0.95	Accept H_0
March	184.00	0.430	3113.333	0.001	0.05	2.239	Reject H_0
April	181.00	0.430	3076.333	0.001	0.05	4.96	Reject H_0
May	189.00	0.438	3133.000	0.001	0.05	5.982	Reject H_0
June	172.00	0.396	3140.667	0.002	0.05	6.566	Reject H_0
July	209.00	0.480	3141.667	0.000	0.05	4.812	Reject H_0
August	-57.00	-0.131	3141.667	0.318	0.05	-2.033	Accept H_0
September	117.00	0.269	3141.667	0.038	0.05	3.614	Reject H_0
October	-93.00	-0.214	3141.667	0.101	0.05	-2.539	Accept H_0

November	-169.00	-0.389	3141.667	0.003	0.05	-4.703	Reject H_0
December	-208.00	-0.505	3016.667	0.000	0.05	-6.939	Reject H_0
Wet Season	201.00	0.462	3141.667	0.000	0.05	24.783	Reject H_0
Dry Season	-202.00	-0.498	2842.000	0.000	0.05	-21.665	Reject H_0

After performing the trend analysis using Mann-Kendall and Sen's slope test on the rainfall data for 30 years (1986 - 2015) for monthly, seasonal and annual scales, the result is shown in Table 4.1. The null hypothesis (H_0) was rejected if the p value is less than the significant level (alpha) at 0.05. Rejecting H_o implies the presence of a trend in the time series whereas accepting H_o implies that there is no trend in the time series. When H_o is rejected, the result is considered to be statistically significant at 95% confidence level.

For January, the MK statistics, S, Kendall's tau and p-value for rainfall from 1986 to 2015 were -245, -0.574 and <0.0001 respectively (Table 4.1) at 0.05 (5%) significant level. The negative value of S and Kendall's tau show decreasing trend in the time series of rainfall. Since the p-value is less than the alpha value (0.05), the H_o was rejected meaning there is a trend in the time series for the month of January.

The MK statistics, S, Kendall's tau, and p-value for are -65, -0.149, and 0.254 respectively (Table 4.1) at the 0.05 (5%) significant level. The H_o was accepted since the p-value was greater than the alpha value (0.05), indicating that the time series for February has no monotonic trend.

For March, the MK statistics, S, Kendall's tau and p-value are 184, 0.43 and 0.001 respectively (Table 4.1) at 0.05 (5%) significant level. The positive value of S and Kendall's tau show an increasing trend in the time series of rainfall. Since the p-value is less than the alpha value (0.05), the H_o was rejected and H_a there is a trend in the time series for the month of March.

In April, the MK statistics, S, Kendall's tau, and p-value are 181, 0.430, and 0.001 respectively (Table 4.1) at the 0.05 (5%) significant level. The positive values of S and Kendall's tau indicate an upward trend in the rainfall time series. The H_o was rejected since the p-value is less than the alpha value (0.05), indicating that the time series for April has a monotonic trend.

For May, June, July and September, the S values were 189, 172, 209 and 117 while Kendall's tau were 0.438, 0.396, 0.480 at p-values 0.001, 0.0020.038 respectively. This implies that there was an upward or increasing trends for the month since the p-values were less than the α values at 0.05 significant level.

Summarily, the monthly result revealed that there was a significant trend in 9 out of 12 months at 95% confidence level was observed in the month of January, March, April, May, June, July, September, November and December while there was no trend in February, August and October. The Kendal Tau reveal a strong decreasing trend in January and December while there was positive trend in March, April, May, June and July. A strong negative magnitude of trend was shown by Sen's slope in January, November and December while a positive magnitude of 2.239, 4.96, 5.982, 4.812 and 3,614 mm/year were observed in March, April, May, June, July and September respectively.

The season in Ibadan was classified into wet and dry seasons. Wet season starts in April and ends in October while dry season begins in November till March of the following year. There was significant trend during the two seasons. Wet season has an increasing trend with magnitude of 24.783mm/year while there is negative trend in dry season with magnitude of 21.665mm/year. The annual result revealed no trend in the annual rainfall time series between 1985 and 2015. Further analyzing with regression lines corroborate the result by showing increasing trend in wet season with high slope of 25.938 (Fig. 4.1) which is almost equivalent to Sen's slope value of 24.783 and decreasing trend in dry season with slope of 23.303 (Fig. 4.2) which is almost equivalent to Sen's slope of -21.665.

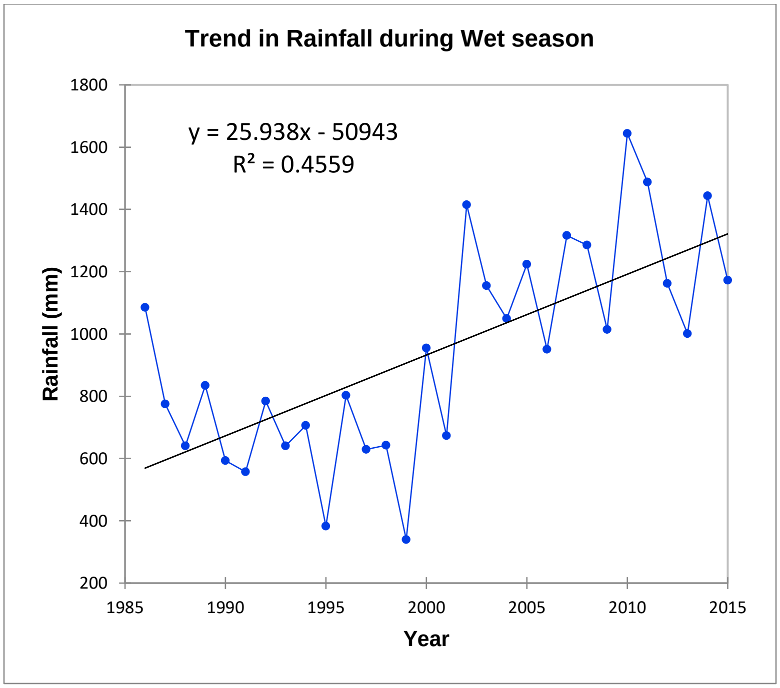

Fig 4.1: Graph of rainfall trend in wet season from 1986 -2015

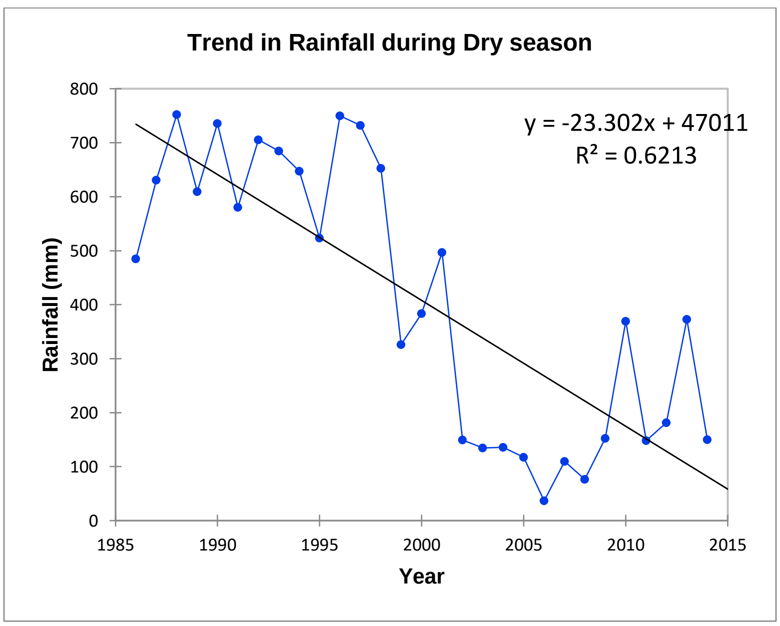

Fig 4.2: Graph of rainfall trend in dry season from 1986 -2015

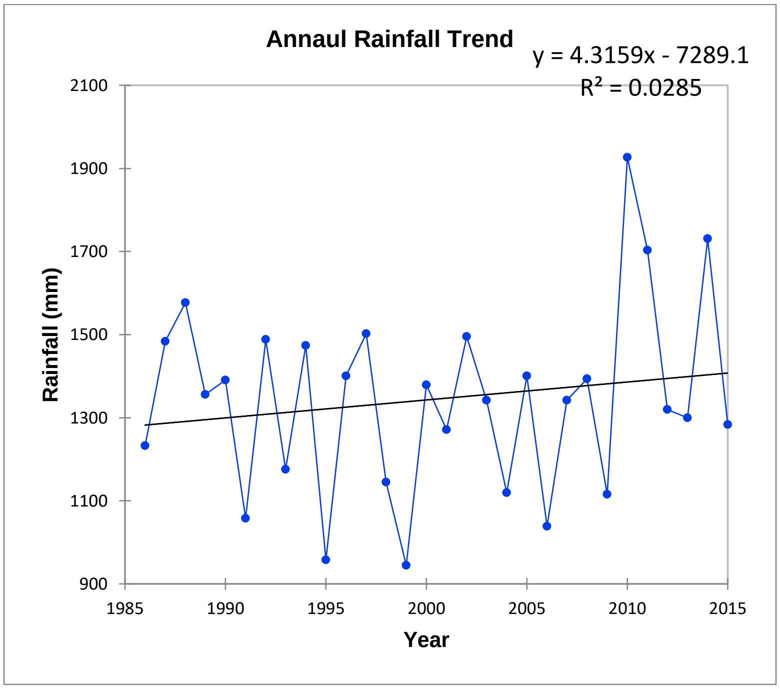

Fig 4.3: Graph of annual rainfall trend in dry season from 1986 -2015

Table 4.2: Trend in monthly, seasonal and annual maximum Temperature in Ibadan

	Man Kendall Statistic (S)	Kendal's Tau	Variance (S)	P-value	Alpha	Sen's Slope	Test Interpretation
January	-175.00	-0.402	3141.667	0.002	0.05	-0.124	Reject H_0
February	-209.00	-0.480	3141.667	0.000	0.05	-0.188	Reject H_0
March	-221.00	-0.508	3141.667	<0.0001	0.05	-0.170	Reject H_0
April	-231.00	-0.531	3141.667	<0.0001	0.05	-0.138	Reject H_0
May	-217.00	-0.499	3141.667	0.000	0.05	-0.112	Reject H_0
June	-177.00	-0.407	3141.667	0.002	0.05	-0.076	Reject H_0
July	-109.00	-0.251	3141.667	0.054	0.05	-0.024	Accept H_0
August	-17.00	-0.039	3141.667	0.775	0.05	-0.004	Accept H_0
September	-137.00	-0.315	3141.667	0.015	0.05	-0.046	Reject H_0
October	-151.00	-0.347	3141.667	0.007	0.05	-0.057	Reject H_0
November	-207.00	-0.476	3141.667	0.000	0.05	-0.130	Reject H_0
December	-173.00	-0.398	3141.667	0.002	0.05	-0.099	Reject H_0
Wet Season	-193.00	-0.444	3141.667	0.001	0.05	-0.062	Reject H_0
Dry Season	-188.00	-0.463	2842.000	0.000	0.05	-0.145	Reject H_0
Annual	-187.00	-0.430	3141.667	0.001	0.05	-0.086	Reject H_0

For maximum temperature analysis result, the highest maximum temperature was recorded in March 1998. The MK test revealed that all the months were statistically significant at 95% confidence level except August therefore all the H_o were rejected except in August because the p values were less than the α at 0.05. Further interpretation reveals negative or decreasing trend in all the eleven months while the Sen's slope shows a negatively weak magnitude in all the month (Table 4.2). Decreasing significant trend were observed in the wet season, dry season and annual scale with decreasing magnitude of 0.062, 0.145, 0.086°C/year (Table 4.2). The result of the MK test is confirmed by regression lines in Figs 4.4, 4.5 and 4.6 which all shown decreasing trend for the wet, dry seasons and annual scale.

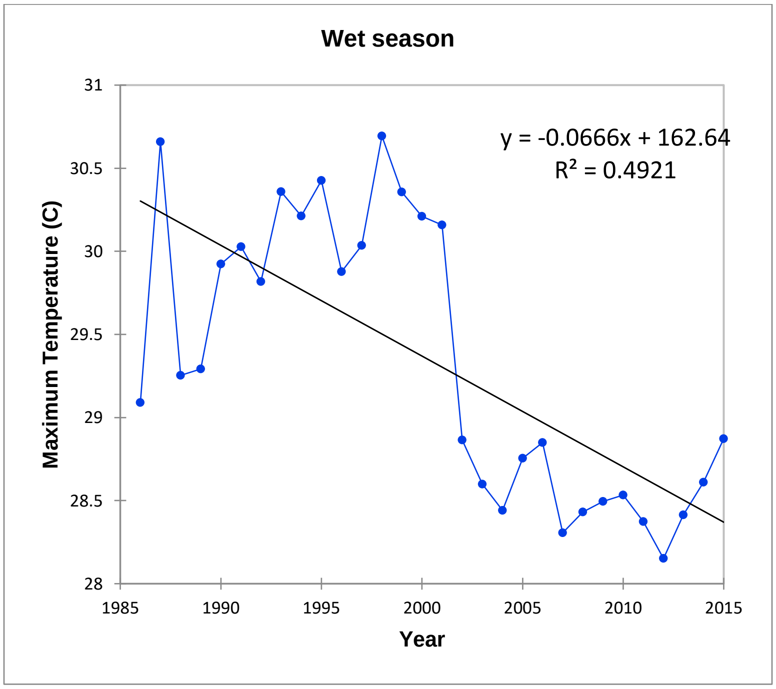

Fig 4.4: Graph of maximum temperature trend in wet season from 1986 -2015

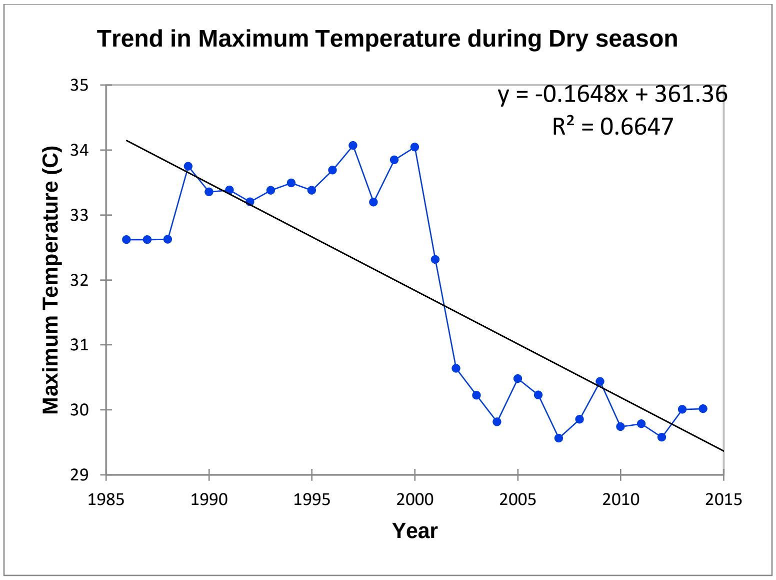

Fig 4.5: Graph of maximum temperature trend in dry season from 1986 -2015

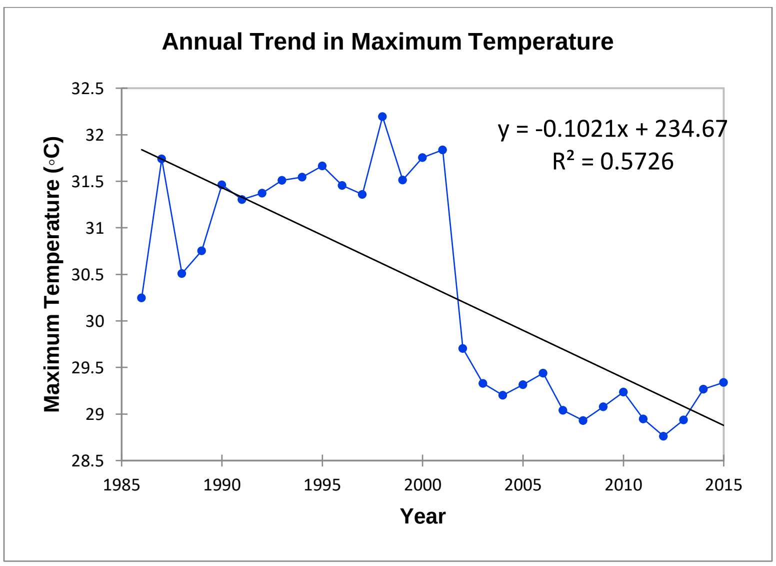

Fig 4.6: Graph of annual maximum temperature trend from 1986 -2015

Table 4.3: Trend in monthly, seasonal and annual minimum Temperature in Ibadan

	Man Kendall Statistic (S)	Kendall's Tau	Variance (S)	P-value	Alpha	Sen's Slope	Test Interpretation
January	-31.00	-0.071	3141.667	0.592	0.05	-0.018	Accept H_0
February	35.00	0.080	3141.667	0.544	0.05	0.021	Accept H_0
March	99.00	0.228	3141.667	0.080	0.05	0.019	Accept H_0
April	91.00	0.209	3141.667	0.108	0.05	0.026	Accept H_0
May	153.00	0.352	3141.667	0.007	0.05	0.043	Reject H_0
June	140.00	0.322	3141.667	0.013	0.05	0.027	Reject H_0
July	53.00	0.122	3141.667	0.354	0.05	0.011	Accept H_0
August	-18.00	-0.041	3140.667	0.762	0.05	-0.003	Accept H_0
September	85.00	0.195	3141.667	0.134	0.05	0.025	Reject H_0
October	161.00	0.370	3141.667	0.004	0.05	0.023	Reject H_0
November	-57.00	-0.131	3141.667	0.318	0.05	-0.011	Accept H_0
December	-45.00	-0.103	3141.667	0.432	0.05	-0.025	Accept H_0
Wet Season	131.00	0.301	3141.667	0.02	0.05	0.022	Reject H_0
Dry Season	14.00	0.034	2842.000	0.807	0.05	0.003	Accept H_0
Annual	61.000	0.140	3141.667	0.284	0.05	0.01	Accept H_0

Highest monthly minimum temperature was recorded in April while the highest annual minimum temperature was in 1998. For January, February, March April, July, August, October, November and December the S values were -30, 35, 99, 91, 53, -18, 161, -57 and -45 while Kendall's tau was -0.071, 0.08, 0.228, 0.209, 0.122, -0.041, 0.37, -0.131 and -0.103 at p-values 0.592, 0.544, 0.080, 0.354, 0.762, 0.134, 0.318 and 0.432 respectively. This implies that there was no significant trend for these month since the p-values were greater than the α values at 0.05 significant level. The MK test further revealed monthly significant trend in May, June, September and October at α = 0.05. The magnitude of the trend as revealed by the sen's slope is weak for all the months.

Seasonal trend was observed only in wet season while there was no trend in annual and dry season. This result also agrees with the regression line fitting as shown in Figs 4.7, 4.8 and 4.9

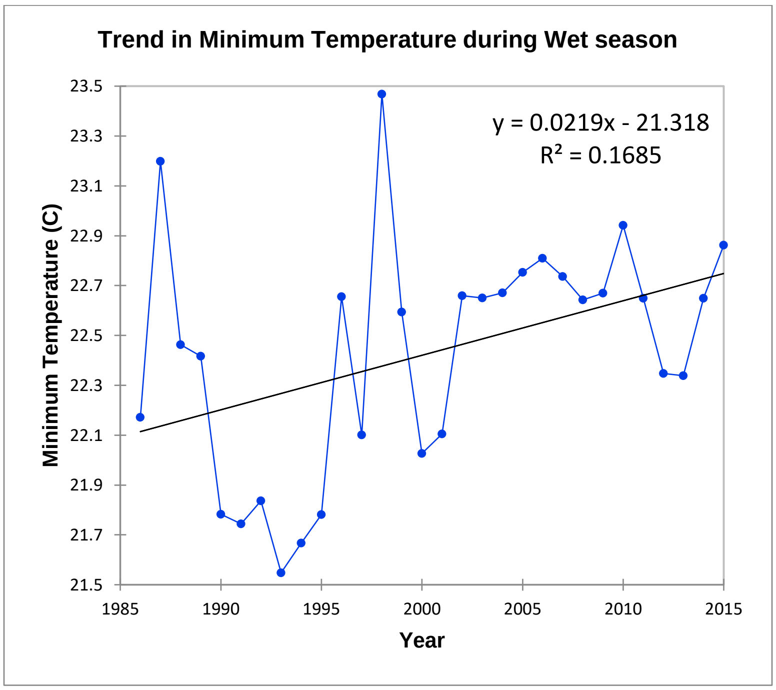

Fig 4.7: Graph of minimum temperature trend in wet season from 1986 -2015

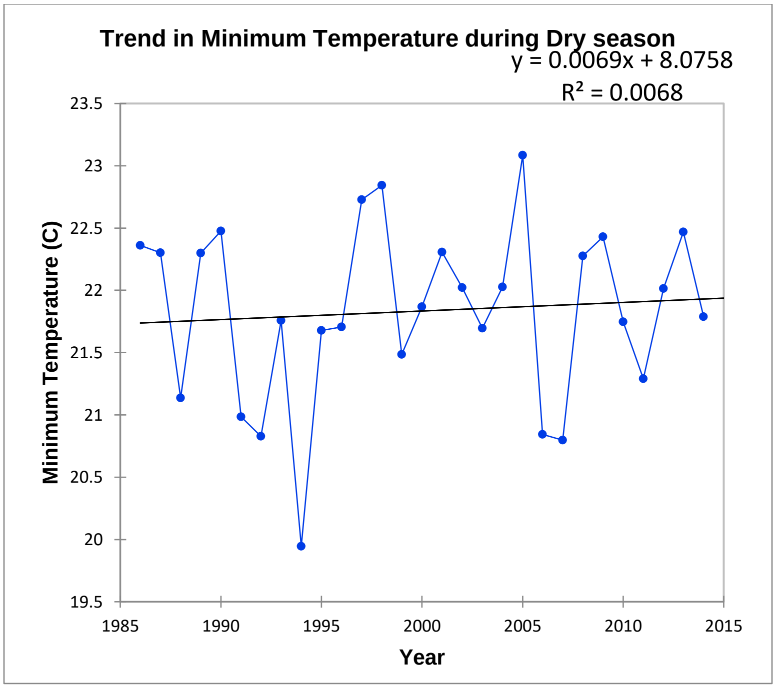

Fig 4.8: Graph of minimum temperature trend in dry season from 1986 -2015

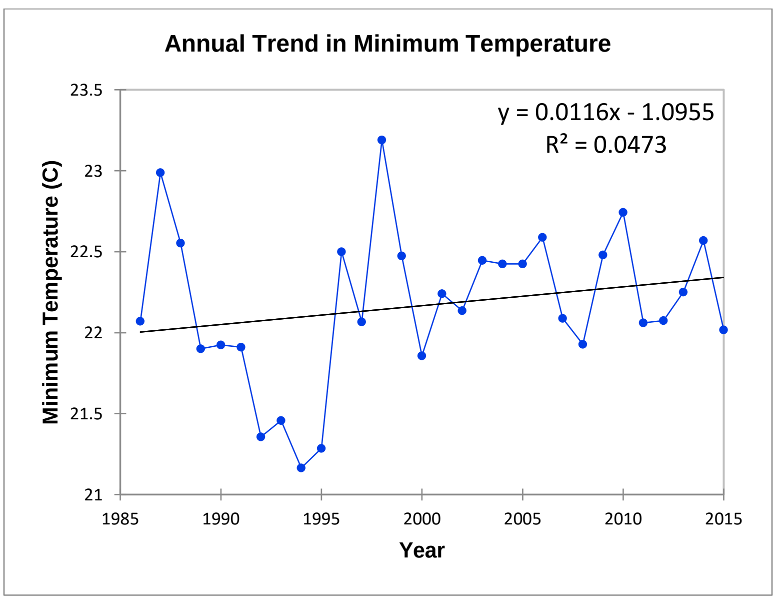

Fig 4.9: Graph of annual minimum temperature trend from 1986 -2015

4.2 Water Demand and Supply Analysis Using WEAP Model

4.2.1 Calibration and Validation of WEAP Model

Prior to analyzing the scenarios, the WEAP model was calibrated. This was vital to ensure that the model closely reflect the present situation in the study area. The model was calibrated using streamflow data from 1994 to 2000, and validated using streamflow data from 2002 to 2007. Overall, the model performed well during both the calibration and validation phases. The R^2 values for calibration was 0.914,. The graph in Fig 4.1 illustrates the model calibration process. The graph and statistical analysis indicate that the model adequately reproduces the observed data.

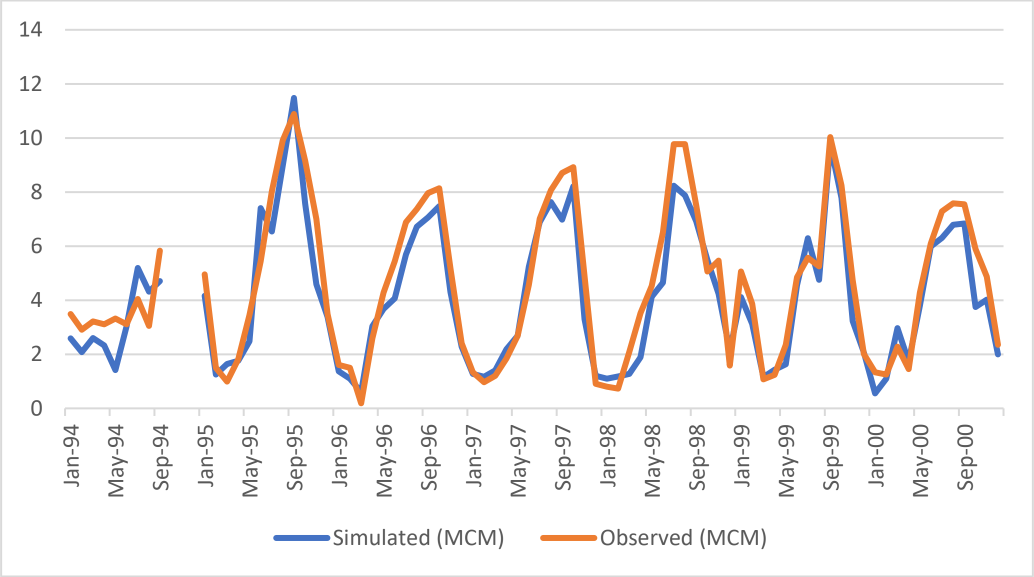

Fig 4.10: Graph of calibration result of monthly observed and simulated streamflows

4.2.2 Comparison of water demand and water supply

Water demand from the WEAP model generated using projected population of 2006 and water use rate of 68 LCPD (Istifanus,2017) was compared with the water supplied for water consumption from WCOY as shown in Fig 4.12. The assumption made is that all the water supplied reached the final consumers at the demand site.

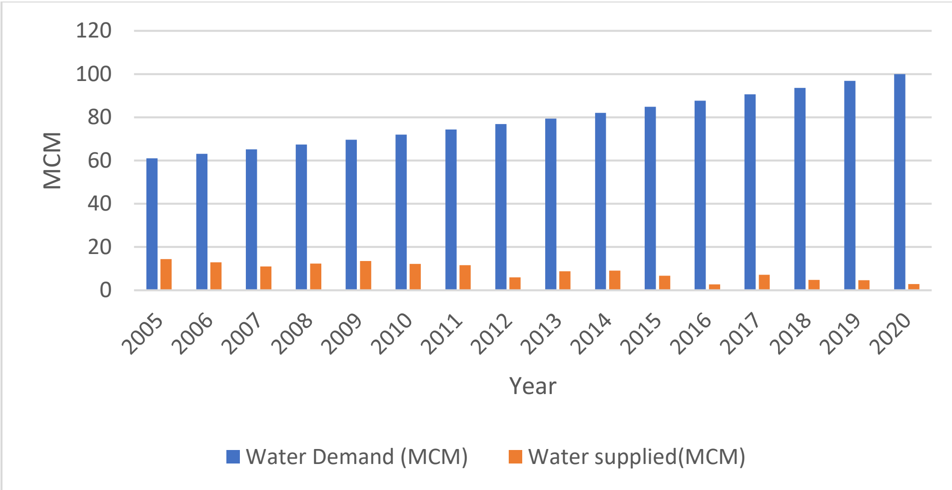

Fig 4.12: Comparison between water demand and water supplied from 2005 to 2020

Fig 4.12 shows a wide difference between the study area water demand and the amount being supplied by urban water supply service (WCOY). As a result of this, most of the citizens in the study area depend on other sources of water to meet their water requirements.

As it currently stands, WCOY has total number of 7566 active customers (less than 1% of its population) while 49471 are dormant. 92% of the active customers were metered while 7.1% were unmetered.

4.2.3 Future Water Demand Projection

Scenario 1: Reference Scenario

To facilitate scenario simulation and data analysis, the current account and reference scenarios were assigned first. The current accounts depict the water system in its current state (year 2020), while the reference depicts a business-as-usual scenario from 2021 to 2040. The Reference scenario envisions a state in which water supply and demand infrastructures remain unchanged from the current year. The Reference scenario's simulation results are depicted in Fig 4.13. It shows there will be an increase in unmet water demand from 30MCM in 2021 to 57MCM in 2040 resulting into 90% increase.

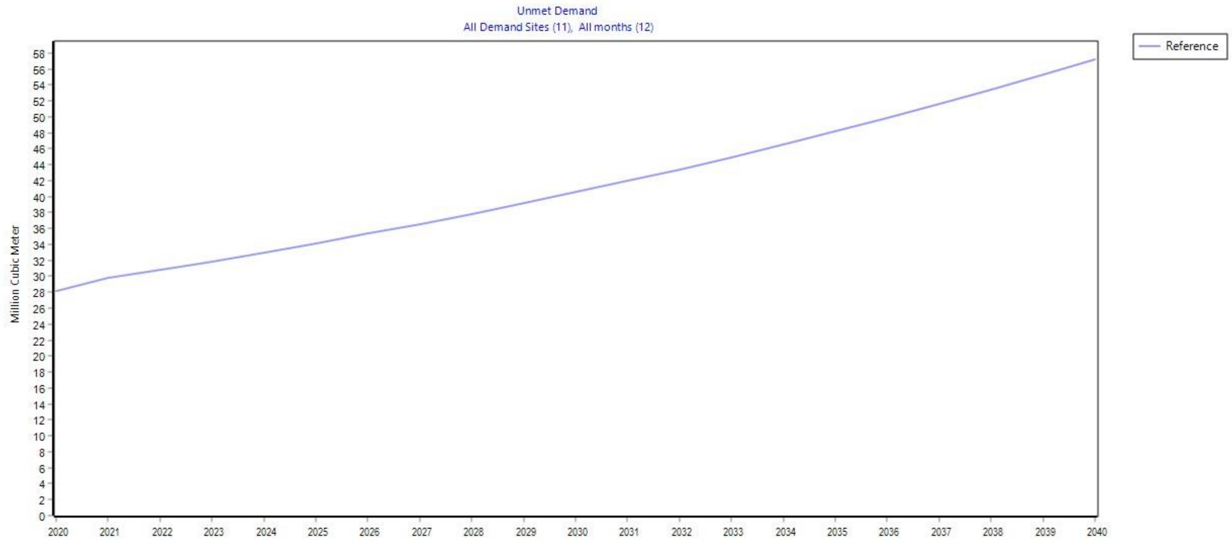

Fig 4.13: Unmet water demand at reference scenario

Scenario 2: External Driven Factor Scenario

Implication of High population on future water demand

The effect of high population growth rate of 5% on water demand shows an increase of 56 million m^3 of water from 2021 to 2040 (Fig 4.14). When compare with reference scenario, an increase of 63% was observed. This high-water demand amount increases the pressure on storage volume of Eleyele and Asejire reservoirs.

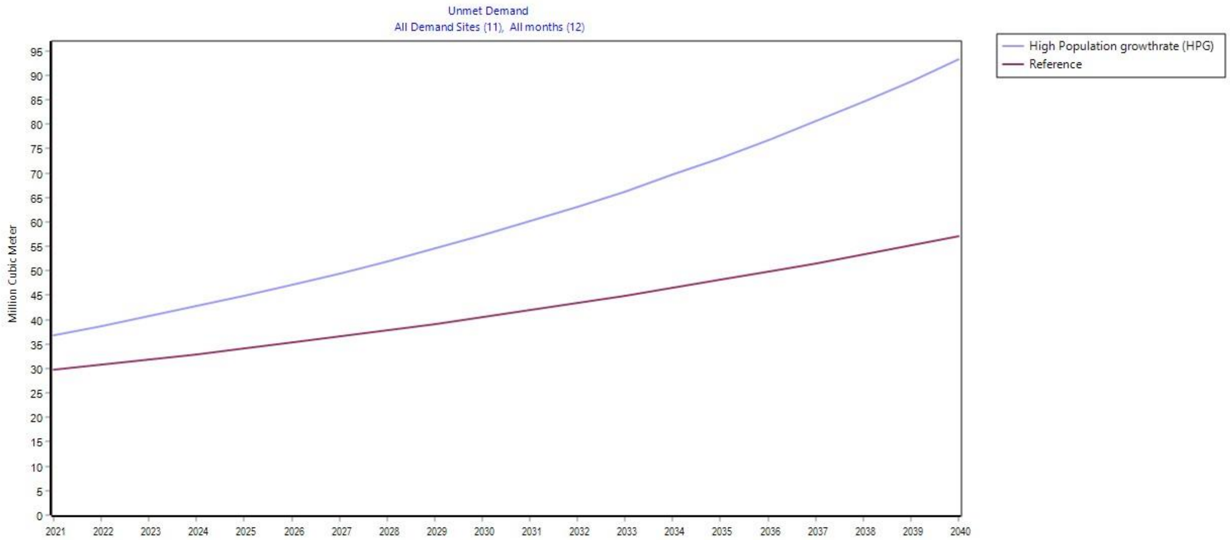

Fig 4:14: Unmet water demand under high population growth grate

Implication of High Living Standard on future water demand

The WEAP model shows that there is an increase in estimated water demand under high standard of living. As shown in Fig 4.15, the amount of unsatisfied water demand by 2040 under this scenario increases by 61million from 66MCM in 2021 to 127MCM in 2036. When compare with reference scenario, an increase of 123% is observed. This implies that increase in population and standard of living in Ibadan would result into water crisis in the future if the status quo remains the same.

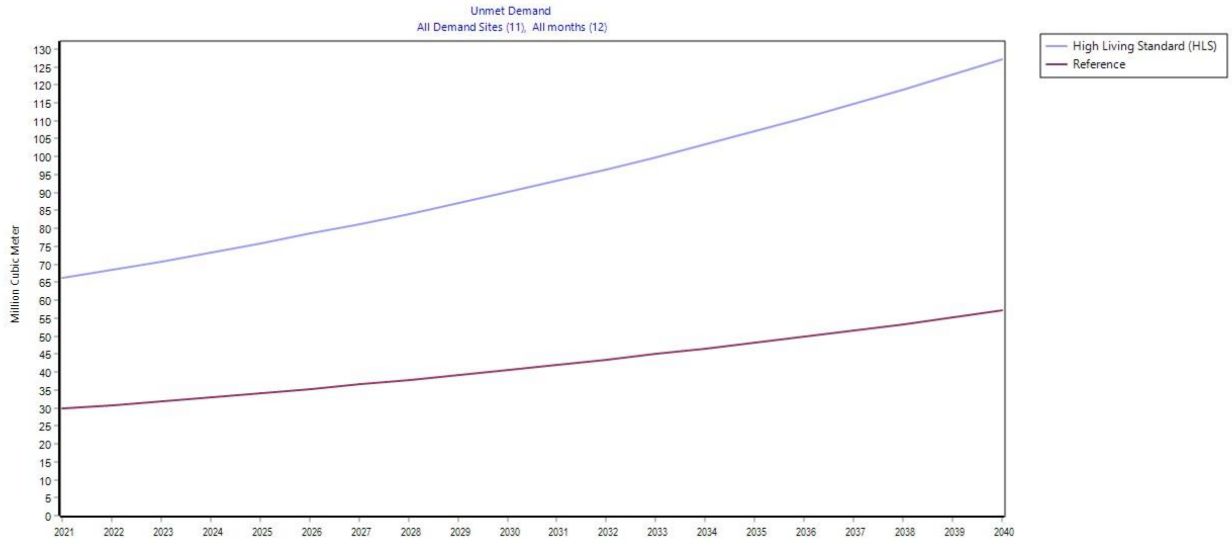

Fig 4.15: Unmet water demand under high living standard

Implication of HLS and HPG

As increase in standard of living increases water demand so also increase in population growth. From Fig 4.16, the unmet water demand in Ibadan under this scenario increased from 82MCM in 2021 to 207MCM in 2040 which shows an increase of 152.4%. When compare with the reference scenario, it shows an increase of 263% that is from 57MCM to 207MCM. This can be regarded as the worse scenario that can be predicted.

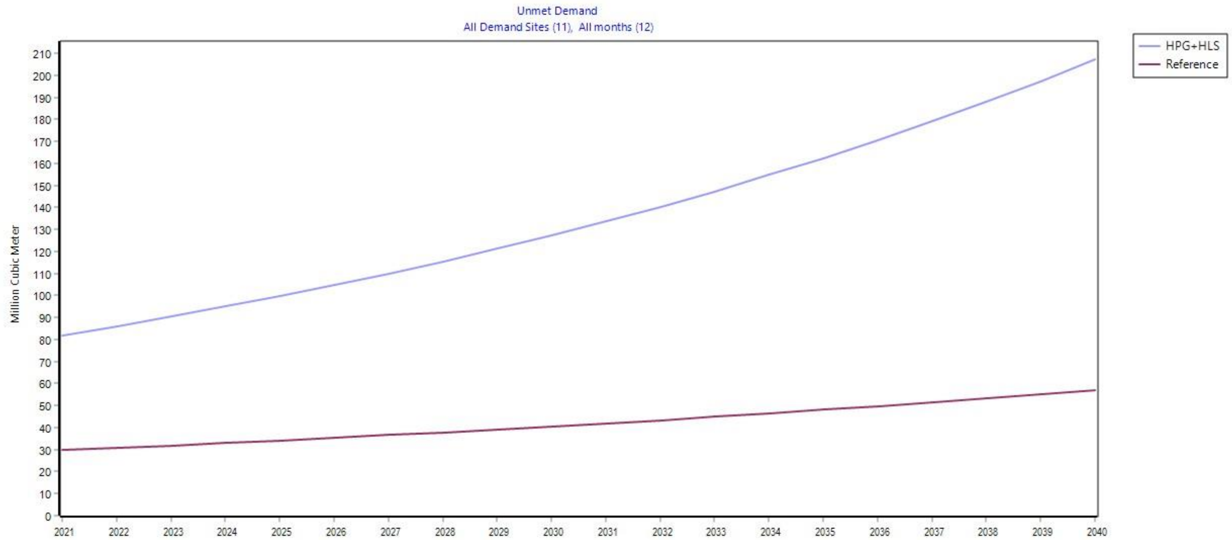

Fig 4.16: Unmet water demand under high living standard and high population growth rate

Implication of Low population growth

With low population growth rate of 2%, the unmet water demand would increase from 24MCM in 2021 to 35MCM in 2040 (Fig 4.17) showing an increase of 45%. When compare with the reference scenario, in 2040 the unmet water demand would decrease from 57MCM to 35MCM showing a decrease of 38.6%.

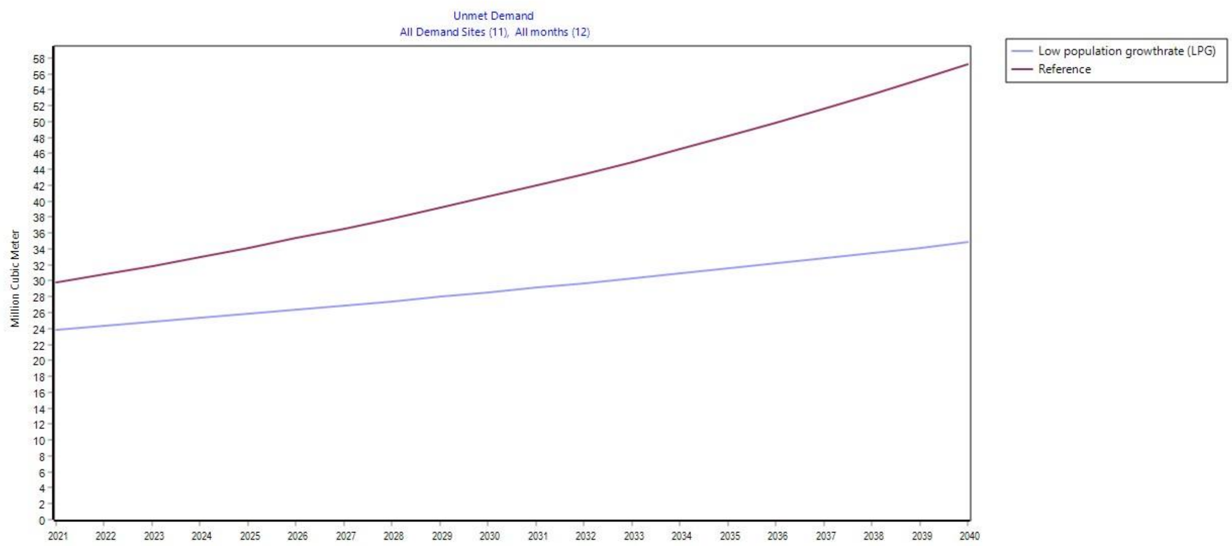

Fig 4.17: Unmet water demand under low population growth rate

Scenario 3: Management Scenario

Demand Side Management Scenario

Fig 4.18 shows the result when water conservation is practiced which leads to reduction of 20% in water consumed, the unmet water demand decreases from 30MCM to 24MCM in 2021 and 57MCM to 46MCM in 2040 resulting in a decrease of 19.4% when compared with the reference scenario.

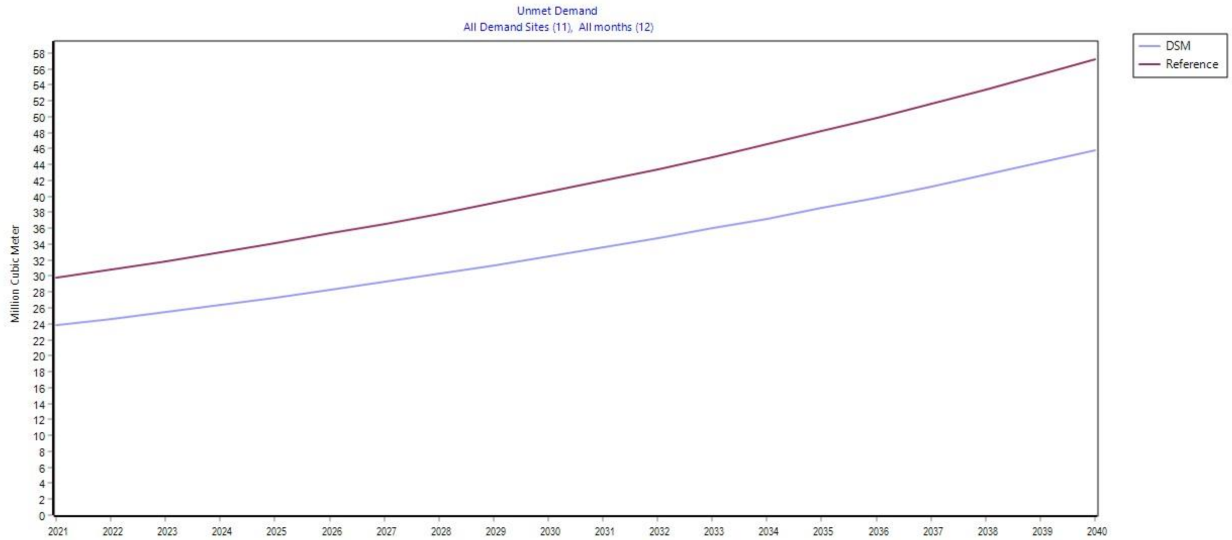

Fig 4.18: Unmet water demand under demand side management approach

Supply Side Management Scenario

Fig 4.19 shows the result when two existing reservoirs is incorporated into water supply, this reduces the unmet water supply in 2021 from when compared with the reference scenario.

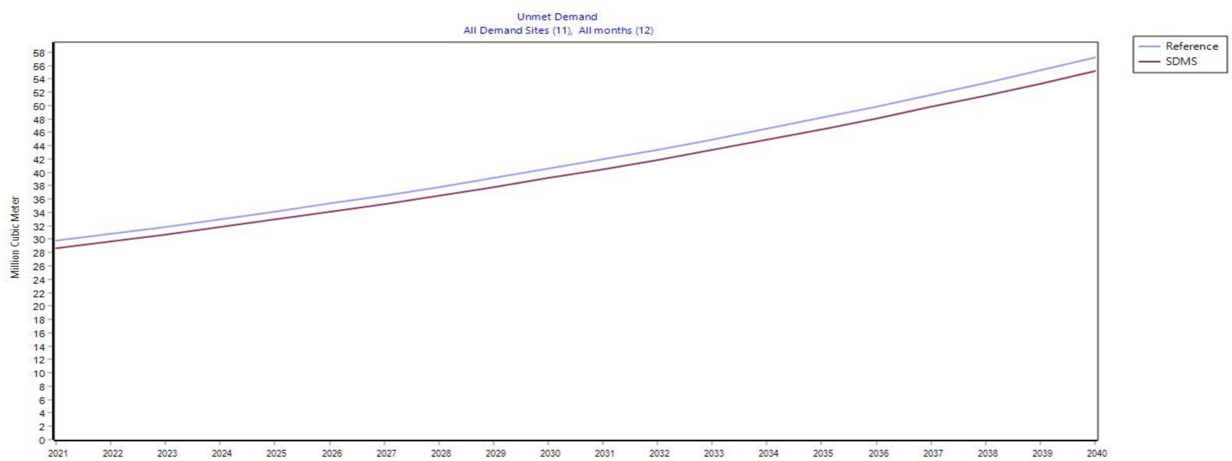

Fig 4.19: Unmet water demand under supply side management approach

Comparison of all the scenarios

Fig 4.20 shows all the scenario created, it is seen that high living standard with high population growth rate impacts more on water demand while the least impacted on water demand is low population growth.

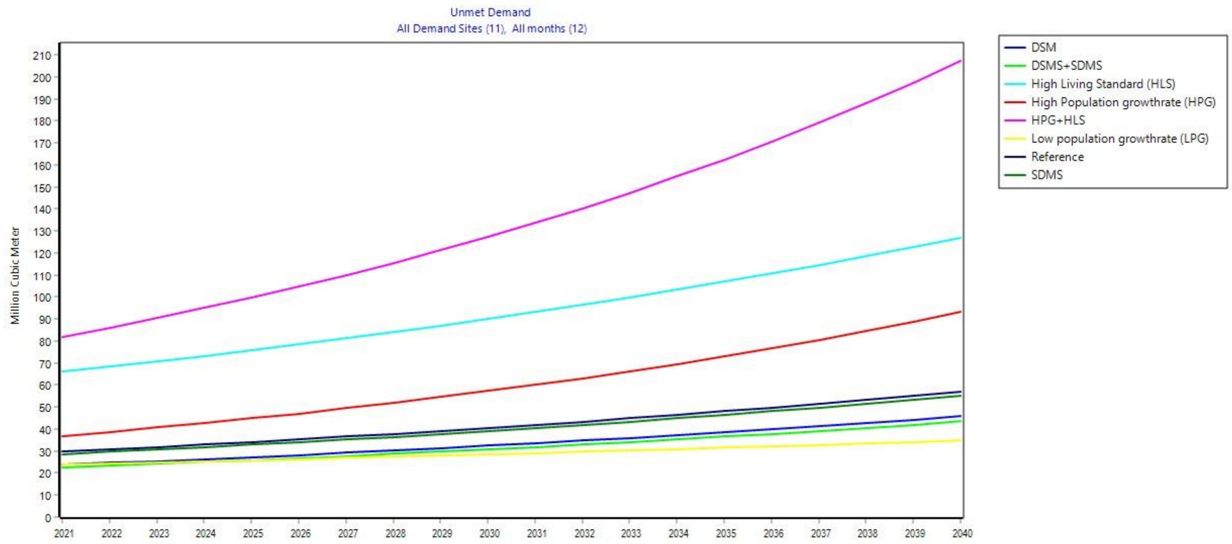

Fig 4.20: Unmet water demand under all scenarios

4.3 Recommendation for Achieving Sustainable Urban Water Supply

i. Appropriate and suitable water management techniques should be encouraged to reduce water scarcity.

ii. Investments in water supply schemes and infrastructures is imperative

iii. Government should make and implement sustainable water policies

iv. Provision of strong institutions for management of available surface and groundwater resources.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research used the WEAP model to evaluate water demand and supply in Ibadan. The WEAP model estimated the water demand in 2020 to 100 million m^3 using consumptive water use rate of 68LPCD. This shows a wide difference between water demand and water supplied by the agency responsible for urban water supply thereby making the inhabitants to source water from other sources to meet their water needs which is putting increasing pressure on the available groundwater due to indiscriminate exploitation. Under reference scenario, increase of 27MCM was projected in 2040. Impact of high population growth rate increases the unsatisfied water demand to 36MCM between the study period. The effect of high standard of living revealed that there will be 122% increase in the unmet water demand when the inhabitants increase their water consumption rate from 68LPCD to 150LPCD. The findings indicate that unmet water demand will continue to grow in the coming years as a result of population growth, increase in standard of living and limited available water resources. As a result, securing additional water supplies becomes critical in order to meet the increased demand for water. When the two management approaches were incorporated into the model where water conservation practices and integration of two existing reservoirs were utilized, the result showed reduction of 19.4% and 7.5% decrease in unmet water demand when compared with the reference scenario. To achieve sustainable urban water management, indiscriminate exploitation of groundwater should be discouraged and rainwater harvesting should be encouraged.

5.2 Recommendations

I recommend that future work should be done in the study area to incorporate rainwater harvesting as supply side measures and waste water treatment plants to ensure water reuse when the water and sanitation plan of Ibadan is unveiled. Also, Further research on the impacts of climate change on water supply and demand should be studied while additional studies can incorporate water quality into the model by including data on the water quality of supply sources in order to analyze the system's water quality.

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