MODELLING OPTIMAL WATER RESOURCES ALLOCATION IN TIGA DAM, KANO STATE

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DECLARATION

I Mohammed Auwal hereby declare, that this work titled "**Modelling Optimal Water Resources Allocation in Tiga Dam, Kano State"**has been solely undertaken by me under the guidance of my supervisors in the Department of Water Resources and Environmental Engineering. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or other institution.

AuwalMOHAMMED(**P16EGWR8020**) ____________ Student ____________ Name
Signature Date

CERTIFICATION

This dissertation report titled "**MODELLINGOPTIMAL WATER RESOURCES ALLOCATION IN TIGA DAM, KANO STATE**" by Auwal MOHAMMED meets the regulation governing the award of degree ofMasters of Science in Water Resources and Environmental Engineering, Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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Engr. Prof. M.A. Ajibike Date ______ ______________
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Dean, School of Postgraduate Studies Signature

DEDICATION

This work is dedicated to the AlmightyAllah, the creator of the earth and universe, for sustaining my lifethroughout my existence and the period of this research work.

ACKNOWLEDGEMENTS

My profound gratitude goes to Almighty Allah who has given me strength and ability to successfully complete this noble dissertation.

My special unforgettable and sincere appreciation goes to my lovely parents in persons ofAlhajiMohammed Kabusi Mustapha andHajiyaRakiya Hassanfor their noble moral upbringing and material support throughout my stay with them. May Allah reward them with Al-JannatulFirdausi. Amin.

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ABSTRACT

This study focused on water allocation for different purposes in Tiga dam, using WEAP model to carry out analysis of the hydrological and meteorological information of the study area, with a view to settling the conflict between water allocation of Kano City and major irrigation project. The research commenced with a preliminary site investigation through reconnaissance survey to analyzeactivities related to water resources in the basin. Meteorological and hydrological data were also collected and used to model the hydrological process of Tiga Dam. The model was validated and calibrated using simulated net-evaporation and observe net-evaporation. Meteorological and hydrological data, population and their growth rate, irrigation area and number of industries from 1987 to 2017(31 years) were used in WEAP model software. The model predicted that in the future time from 2031 to 2050 the dam might not meet up with the total demand. Itonly capable of supplying annual average of 410.5 Mm^3 for agriculture with unmet demand of 123.7 Mm^3 and when per hectare demand increase by 33.9%(agricultural scenario), it will supply 658.8 Mm^3 with unmet demand of 188 Mm^3.It will also supply annual average of 266.3Mm^3 for Kano population with unmet demand of 61.6 $Mm^3$and 301.3 Mm^3 when per capital demand is increase by 14.3% (Kano population scenario) with 75.3 Mm^3 unmet demand. Annual average supply toKano industries were 15.5 $Mm^3$with unmet demand of 5.4 Mm^3 and 20.2 Mm^3 with 7Mm^3 unmet demandwhen industrial allocation is increase by 30.4% (Kano industrial scenario). The Tiga Reservoir will generate 21288.8GJ annual average hydropower with 161.98GJ unmet hydropower demand from 2026. In general, this model predicts that the annual average future water supply from 2018 to 2050 for all purpose is 692.4

Mm^3 with unmet demand of 190.8 Mm^3 from 2031 but 980.3 Mm^3 for all scenarios with unmet demand of 270.5 Mm^3.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water is the most essential element to life on Earth, sometimes a scarce resource, it is fundamental for living and also essential for agriculture in many regions of the world (as a means to achieve sustainability in production systems). Maximizing net returns with the available resources is of the utmost importance, but doing so is a complex problem, owing to other factors that affect this process (e.g. climatic variability, irrigation system configuration, production costs, and subsidy policies). Many regions are facing freshwater management challenges due to increase, concern on how to allocate limited water resources, environmental quality and policies for sustainable water use (Zakari*et al.*, 2011).

The hydrological cycle is a process that describes the storage of water between the biosphere, atmosphere, lithosphere, and the hydrosphere as shown inFigure 1.1. Theseprocess are the principal sources of fresh water to support life necessities and man`s economic activities. Thus, water on this planet can be stored in any one of the following atmosphere,oceans, lakes, river,soil glaciers, snowfields, and ground water.

Water moves from one reservoir to another, through processes such as evaporation, condensation, precipitation, deposition, runoff, infiltration, transpiration, melting, and groundwater flow. However,the oceans supply most of the evaporated water found in the atmosphere. Out of this evaporated water, only 91% of it is return to the oceans basin by way of precipitation. The remaining 9% is transported to areas over landmasses where climatological factors induce the formation of precipitation (Pidwirny, 2006).

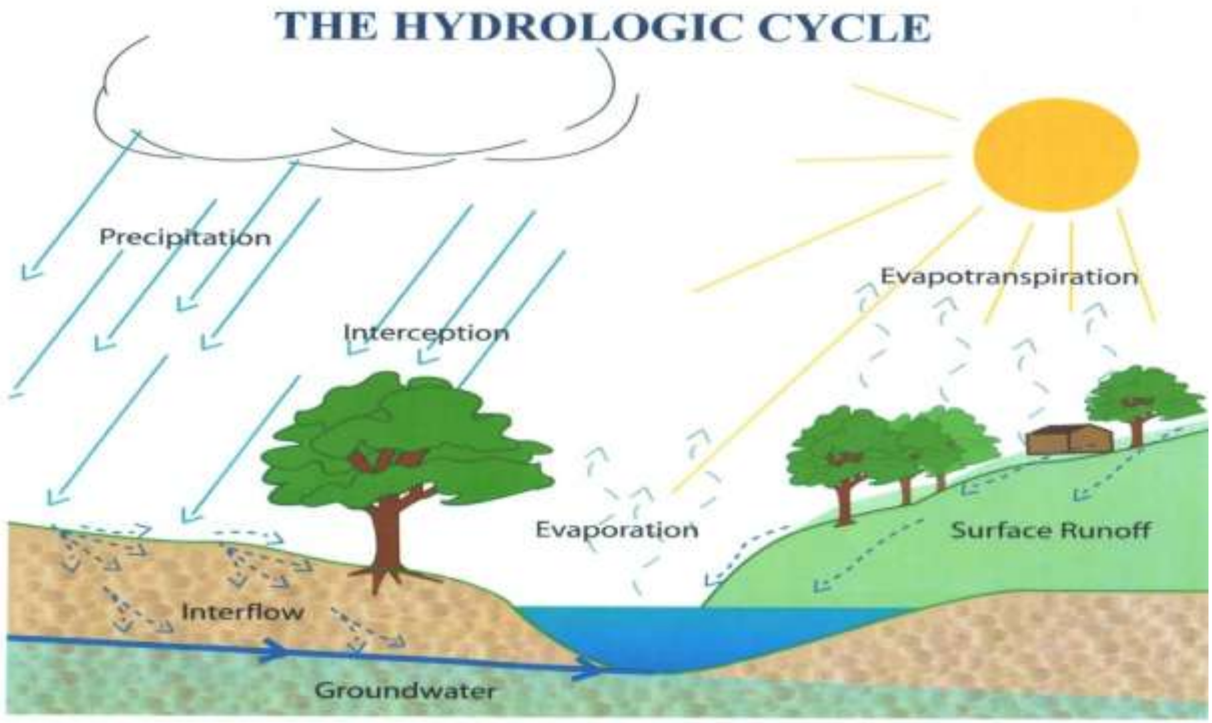

Figure 1.1: Diagrammatical representation of hydrological process(Source: Utah State University, 2015).

Furthermore, due to advancement in technology, the challenges of water allocation can be easily overcome using computer base modelling approach. This includes the modelling of hydrological process.For example Water Evaluation and Planning (WEAP) model was previously used in water allocation and forecasting future demand (Abrishamchi*et al.*,2007,Zakari*et al.,* 2011, Alfarra*et al*, 2012, Daniyal*et al*., 2017, andSuryadi*et al.*, 2018.)

The WEAP model can be applied to both municipal and agricultural systems and can address awide range of issues including sectorial demand analyses, water conservation, water rights and allocation priorities, reservoir operation, ecosystem requirements and project cost-benefit analyses (Roberto and Matthew, 2007).

WEAP model has two primary functions:

(i) Simulation of natural hydrological processes (such as evapotranspiration, runoff and infiltration) to enable assessment of the availability of water within a catchment;

(ii) Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e., consumptive and non-consumptive water demands) to enable evaluation of the impact of human water use.

Other applications of WEAP model includes modelling of hydrological process for determination of water allocation for irrigation purpose inRiver Basins (RB).

1.2 Statement of Problems

There are many problems in Hadejia-Jama-are River Basin (HJRB) such as improper management and adaptation strategies which may lead to serious water crises and probably environmental refugees (Shakirudeen*et al*, 2011). Sometime it results to conflicts between the Kano city dwellers and rural farmers because of water allocation, which might aggravate due to climate change. Therefore it might compound to water security. Furthermore the existing branch and main canals are inefficient because of siltation which result to waterlogged problems. However, during my field work farmers were complained of poor water allocation for farming activities.

The area faces challenges of its natural resources, the loss of its biodiversity and the consequent climate change brought about by increase in temperature and evapotranspiration which

mightcause water stress (World Bank, 2010).

Thus, this study aimed to address the above problems by determining water allocation for different users considering the available water in Tiga dam. Also, the research evaluated how tooptimize the water available in the dam for present and future uses.

1.3 Justification of the Study

This study focused on the analysis of water availability in the Tiga Dam for potential use considering different demands and scenarios of the dam.It would be helpful in determining available water in the dam for present and future water allocation for different purposes which will enhance the following benefits:

1. Forecasts of future and present water allocation for different purposes.

2. Optimizing the allocation of theavailable water in the dam.

3. Provide solutions to long term negative effect of inefficient allocation, if any.

4. WEAP model will evaluate water use and allocation with a greater focus on balancing supply and demand in a swift and transparent way.

1.4Aim and Objectives

The aim of this study is to evaluate the water allocation for different purposes in Tiga Dam of Kano State using Water Evaluation and Planning System (WEAP) model. The specific objectives are:

i- To model the available water in Tiga Dam usingmeteorological, and demographic data.

ii- To evaluate the present surface water availability with respect to agricultural, industries, domestic and hydro-power.

iii- To forecast water demand with respect to usage and purposes.

iv- To evaluate the predictive performance of the model based on available data.

1.4 Scope of Study

This research is limited to modelling the available water in Tiga dam, so as to determine present and future water demand and allocation for agricultural, industries, domestic and hydro-power. Also to compare different scenarios under present and future water demand, and deficit that will be obtainable in the different demands and scenarios.

CHAPTER TWO

LITERATURE REVIEW

2.1Water Resources

Mustafa and Yusuf (2012) viewed water as an essential constituent of life. But is not evenly distributed on the entire universe; it's either in excess in some regions or scarce in others. Man's ability to manage water resources will greatly depend on his understanding of hydrologic processes and the physical system involved.Water is the most essential element to life a scarce resource and fundamental for living. It is also essential for both agriculture in many regions of the world and means to achieve sustainability in production systems (Zakari*et al.*, 2011). "Fresh water is crucial to human society, not just for drinking, but also for farming, washing and many other activities". And also indispensable for all forms of life and is needed in almost all human activities. Water scarcity is a key issue affecting the entire global system, especially the water supply systems in the world (Liu *et al.*, 2017; Hoekstra, 2016).

In developing countries, quite often in the semi-arid regions,developing and managing available surface water resources has been an important issue. These resources is an integral part of the natural environment. To determine effective societal water demands, e.g. for domestic, industrial, agricultural, hydropower generation and to protect human settlement from extreme floods, a system for water storage and distribution has been developed over the centuries to balance the uneven natural distribution of water (Ibn-Abubakar, 2005).

2.1.1 Water Resources of the Earth

The total estimated of water resource in the world is about 1.36 x 10^{18} m^3. The estimated water inventory is shown in Table 2.1. As shown in Table 2.1, about 97.2% is made of salt water mainly in the oceans, and only about 2.8% is available as fresh water. Out of this 2.8% fresh water 2.2% is available as surface water whiles the remaining 0.6% as ground water. Also out of 2.2% of the fresh water, 2.15% is in form of ice sheet and glaciers while 0.05% is in lakes, rivers and other form (Mustafa and Yusuf, 2012).

Table 2.1: Estimated Earth's water inventory.

Location	Volume(10^3 Km^3)	% of total water
Fresh water lakes	125	0.009
Rivers	1.25	0.0009
Soil moisture	65	0.005
Groundwater	8250	0.61
Saline lakes and in land seas	105	0.008
Atmosphere	13	0.001
Polar ice-caps, glaciers and snow	29,200	2.51
Seas and oceans	1,320,000	97.22
Total	1.36 x $10^{18}m^3$	100

(Sources: Mustafa and Yusuf, 2012)

2.1.2 Water resources of Africa

Mustafa and Yusuf, (2012) said that the great African rivers are mainly Congo, Nile, and Zambezi rivers. Congo River which receives water from Lommi, Lulonga, Ruki, and Kasai is about 4700 Km long. It also receives water from Lake Tanganyika via its tributaries. The longest river of Africa is the Nile (6550 Km), the principal branch of the river emerging from Lake Victoria. The Nile basin extends to nine countries, namely Zaire, Rwanda, Burundi, Tanzania, Uganda, Kenya, Sudan, Ethiopia, and Egypt. The largest river of West Africa is the river Niger, 4200 Km long. Its principal tributaries are the river Bani in Mali, Kaduna and Benue River in Nigeria. At maximum flood, the river flows at an average flow rate of 7,000cumecs. In Southern Africa, the most important river is the Zambezi, 2700 Km long which empties to the Indian

Ocean. It has many tributaries, Luena, Lungue, Bongo, Kafue, Luangwa, and Shire (Mustafa and Yusuf, 2012).

Furthermore they said that African has lakes which rank among the largest in the world. The largest and deepest are found in East Africa. In the great meridian fractures of the valley there is from north to south the succession of Likes, Mobutu SeseSeko (formerly Lake Albert), Idi Amin (formerly Lake Edward), Kivu, Tanganyika and Malawi in west and Lake Natron and Eyasi in the east.

Lake Tanganyika is the world's second deepest lake (1435 m) and Lake Malawi is almost 700 m deep. The largest lake in Africa is Lake Victoria-Nyanza 83,000 Km^2. Lake Chad has average area of 14,000 Km^2 but its size varies greatly from season to season depending on the water supply. It suffers high evaporation and its existence is threatened if it were not fed on in the southern bank from Logone and Chard (Mustafa and Yusuf, 2012).

They further stated that the artificial lakes in the African continent which boost the water resources of the continent are Lake Volta in Ghana, Lake Nasser in Egypt, the High Aswan dam and Kainji dam in river Niger of Nigeria. Ground water resources are not well harnessed or developed in African continent and so its estimate is not readily available.

2.1.3 Water Resources of Nigeria

The water resources of Nigeria are enormous and unevenly distributed among the various hydrological areas. The Niger Delta and tropical rainforest areas have the highest precipitation of about 300 mm/year and longer duration of rainfall up to eight months. This is followed by the Savannah zone with 1000 mm to1250 mm/year rainfall, the amount of rainfall decreasing northwards. The Sahel has annual precipitation of less than 750 mm/year and may be as low as 500 mm/ year in the northeastern region occasionally. Rainfall duration can span for 3-4 months in these northern zones and shallow wells normally dry up during the dry seasons due to insufficient recharge. The southwitnesses massive flooding and inundation of coastal aquifers by salinewater especially low lying areas and reclaimed wetlands (Amah, 2015).

2.1.4Hydrological Process

This is the phase of transformation in which water goes through from oceans to atmosphere, then to land back to sea. The various processes that come in to play in various stages of the hydrological process include precipitation, evaporation, and other form of losses in general, there are distinct feature identifiable with the hydrologic system which include precipitation, evaporation and evapotranspiration, surface and sub-surface flows.

Mustafa and Yusuf, (2012) said that moisture evaporates from the ocean and other water surface in to atmosphere. Thereafter, precipitation take place and this is in the form of rain, drizzle, dew, sleet, hail or snow fog, and mist. The precipitation that falls on land run off while part of it infiltrates into the grand, some runoff in to streams, lakes and ocean as shown in figure 2.1

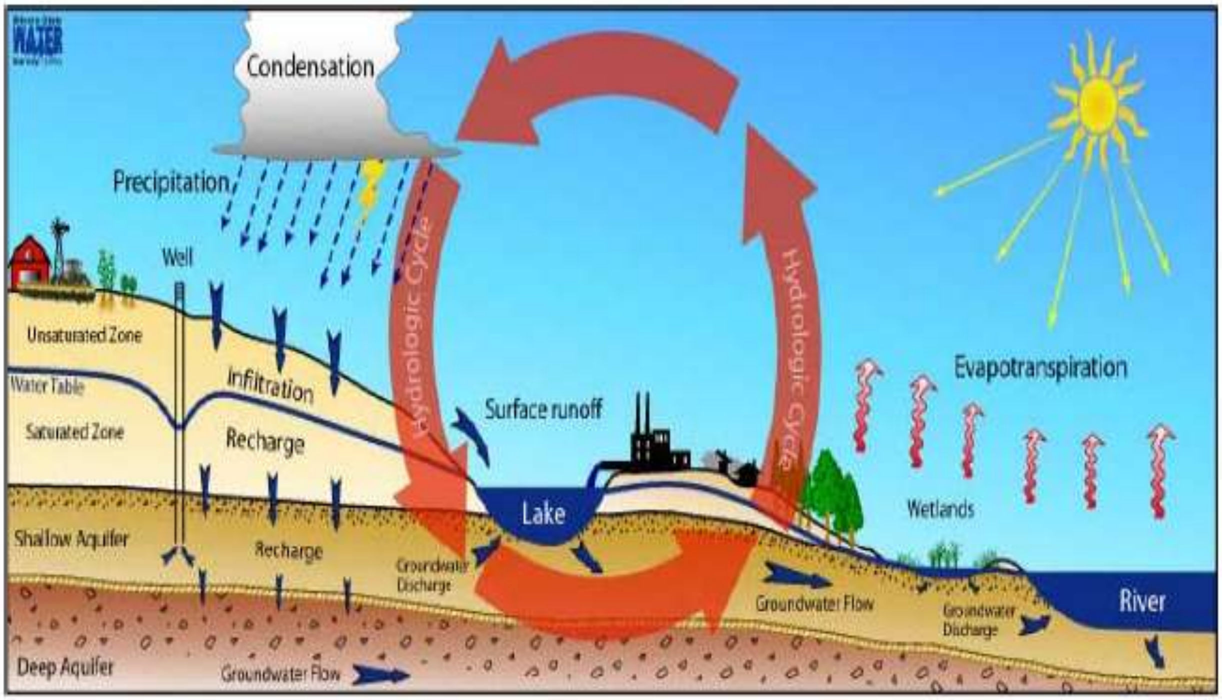

Figure 2.1: Physical and biological framework of hydrological process (Sources: Winstanley, 2007).

2.1.5 Hydro-Meteorological Data

Hydrologic data collection is very vital in valuation of various components of hydrological process. Without adequate hydrological data, design of hydraulics structure is very difficult. Unfortunately, there is paucity of data in many catchments which often make hydrological planning a herculean task. Homogeneity regions are often used to generate data for such area. Some hydro-meteorological station are established in Nigeria to measure stream flow discharge in some major rivers, air temperature, rainfall depth, etc in some airports. The various hydro meteorological data necessary for comprehensive water resources planning and design are: climatic data such as; precipitations record, evaporation etc. (Mustafa and Yusuf, 2012).

2.1.6 Water Allocation

According to Myat and Aye (2014), "Water of a desired availability and quality is often scared to satisfy the demand for different uses, decisions and plans have to be made on how it will be shared between different locations and competing users". At present time water shortage is one of the real challenges facing many countries in the world. Thus, the water allocation plan and water resources development projects are undertaken to address these requirements. And water allocation plans need to balance the water supplies with demands, particularly to manage the natural water availability to avoid frequent or unexpected water shortfalls. This is the practice of water allocation. In simple term, it is the mechanism for determining who can takewater, how much they can take, from which location and for what purposes.

Myat and Aye (2014), further said that as the difference between water resources and demand is ever increasing, the government is facing with the increasingly difficult task of allocating the available water resources among the competing demands. In the face of growing competition, the water allocation has evolved to be a complex process. Simulation and optimization modellingtechniques can help to analyze this complicated process and to develop sustainable water allocation solutions. Over the years, a number of computer-based tools that employ simulation and optimization techniques have been developed. Among them, Water Evaluation and Planning (WEAP) model developed by Stockholm Environment Institute, has been used worldwide in order to perform allocation, scenario analysesand reporting data tool for water resources management.Water allocation using physical model coupling with management layer in whichcooperative role playing game theoretic approaches and has been utilized to investigate how the net benefits can be fairly reallocated to achieve optimal economic reallocation of water resources (Trinh, 2016).

Water resources management in an equitable and sustainable way is intrinsically complex. This is due to the fact that the scale of management implied by hydrological characteristics often comprises layers of social, managerial, and economic institutions. Even at the sub-basin level there may be many users such as local small-scale farmers, large-scale commercial farmers, hydro-electric power companies, industrial users, municipal water users, and those using water resources for leisure or tourism(Ostrom, 1990).

Water allocation and resources management studied has been carried out as a decision support system for many river basins in the world, starting with simple simulation and analysis of various water allocation scenarios and, above all, scenarios of users' behavior in Olifants River Basin of South Africa using WEAP modelling package (Levite*et al.*, 2003).The adoption of water demand management fromscenario simulation procedures offers opportunities for remedying the watershortage for different user groups. Water allocation modelling approach has been proven to be reliable tools for decision makers and users to appropriately plan their water allocation activities. When sufficient experience has been achieved using water allocation for water resourcesallocation between regions and user groups, there was other pressing issue with water allocation model application ashow the model can incorporate water management scheme for ecological assessment (Yates*et al.*, 2005).Also Schluter(2005) said that the water resources model beside addresses the waterdemand from user groups also need to takes into account the water needs of the ecosystem to assist in the evaluation of tradeoffs in water allocation and the determination of ecosystem restoration goals.

2.1.6.1 Water Allocation in Kano State

Despite the fact that Nigeria has two major rivers which crosses its breadth and length and drainage density spread all over the country, but still there is a problem of limited water supply.

However, recently the drought, flood, urban water shortages and continuous water contamination in Nigeria and different parts of the world's draw the attention of stakeholders for the need of efficient and effective planning of water resources in Nigeria (Bello and Tuna, 2014).

Ibn-Abubakar (2005), said that people at the down-stream site had been deprived and conflict between the requirements of Kano city and the major irrigation projects, and those of farmer, fishermen and wildlife in the Hadejia –Nguru wetland. There was also no clear policy primarily based on management of water demands for both downstream and upstream beneficiaries.

Kano state is yet to provide adequate water supply to its population. Because the total water demand of Kano state is 975 million liters per day (Mlpd) and the supply is 270 Mlpd (the difference is 705 mld). Thus the Kano state is only getting 27.7% of its daily requirements. The total water demand of Kano metropolitan presently is about 550 million liters per day but the whole water work is able to supply only 200 million liter per day, about 36%. It is very clear that the demand is far away from the supply (Bello and Tuna, 2014). This shows that the government alone cannot satisfy the demand of the public (Table 2.2)

Table 2.2: Water Demand, Supply and Deficit in Kano States.

Spatial Unit	Demand (Mlpd)	Supply (Mld)	Deficit (Mlpd)	Supply/Demand Ratio
Kano metropolitan	550	200	350	36%
Rest of Kano	425	70	355	16%
Total	975	270	705	28%

(Source: Bello and Tuna, 2014.)

2.2 Demographic Data of Kano State

Acording to the Census of 1991 and 2006 the population growth in Kano indicate a very rapid growth rate more especially in urban areas. In 1991, the population in the Kano State was

5,810,470 while in 2006 it was 9,401,288 including urban and rural population. Table 2.3 shows population distribution by local government areas of Kano state (NPC, 2006).

Table 2.3: Population distribution of Kano state by sex and local governments

Local Governments	Land Size Km^2	Census 2006, Total Population			Inter Census Growth Rate
		Male	Female	Both Sexes	
Ajingi	746.28	86605	86005	172610	3.36
Albasu	415.203	94862	92777	187639	3.36
Bagwai	423.676	83511	78022	161533	3.36
Bebeji	746.777	97351	94565	191916	3.36
Bichi	640.858	139346	138963	278309	3.36
Bunkure	508.183	87185	87282	174467	3.36
Dala	19.926	237943	180816	418759	3.36
Dambatta	767.455	105538	104936	210474	3.36
Dawakin Kudu	401.149	116109	109388	225497	3.36
DawakinTofa	501.377	126390	119807	246197	3.36
Doguwa	1527.783	77849	72796	15064	3.36
Fagge	21.657	111859	88236	200095	3.36
Gabasawa	633.516	107869	103335	211204	3.36
Garko	469.212	82025	79941	161966	3.36
GarumMallam	223.388	71515	47107	118622	3.36
Gaya	640.026	105199	102220	207419	3.36
Gezawa	355.481	143380	138948	282328	3.36
Gwale	19.119	219201	138626	357827	3.36
Gwarzo	410.55	94669	88955	183624	3.36
Local Governments	Land Size Km^2	Census 2006, Total Population			Inter Census Growth Rate
		Male	Female	Both Sexes	
Kabo	355.932	83156	70002	153158	3.36
Kano Municipal	18.176	219636	151607	371243	3.36
Karaye	499.562	71727	72318	144045	3.36
Kibiya	420.494	70942	67676	138618	3.36
Kiru	966.63	140565	126603	267168	3.36
Kumbotso	164.704	166171	128220	294391	3.36
Kunchi	703.802	55221	54949	110170	3.36
Kura	215.526	76921	66173	143094	3.36
Madobi	285.544	71095	66590	137685	3.36
Makoda	462.918	110014	110080	220094	3.36
Munjibir	435.582	108218	111393	21961	3.36

Nasarawa	35.653	323740	272671	596411	3.36
Rano	542.104	75997	72279	148276	3.36
RiminGado	235.389	53245	50126	103371	3.36
Rogo	835.222	113104	114503	227607	3.36
Shanono	728.671	68466	70662	139128	3.36
Sumaila	1300.907	125162	125217	250379	3.36
Takai	622.779	100269	102370	202639	3.36
Tarauni	29.676	122069	99775	221844	3.36
Tofa	210.817	49870	48733	98603	3.36
Tsanyawa	515.281	80638	77092	157730	3.36
Tudunwada	1252.345	113791	114867	228658	3.36
Ungogo	213.831	192372	173365	365737	3.36
Warawa	376.152	66800	65058	131858	3.36
Wudil	377.559	100357	88282	188639	3.36
Kano	21,276.872	4,947,952	4,453,336	9,401,288	21,276.872

(Sources: NPC, 2006).

2.2.1 Industries and Industrial Development in Nigeria

Industrialization in Nigeria began just before political independence, after the World War II, with the setting up of some industries in Lagos, Ibadan, Port Harcourt, Aba, Enugu, Ilorin, Kaduna, Funtua, Jos, and Kano. These cities not only attracted more people but also remained growth centers in reality. Indeed each separately, or in combination with others, acted as a nucleus in the formation of the various industrial axes that firmly set the country within the ambit of industrial capitalism. The Lagos/Ibadan/Ilorin industrial axis, the Aba/Nnewi/Port-Harcourt industrial axis, the Kaduna/Jos industrial axis, and the Kano axis are some ofthe notable ones in the country (Liman, 2015).

2.2.2 Industries in Kano Metropolis

In 1940 there was only one industry in Kano metropolis Table 2.4 shows the historical development of industries in Kano State and the location of industries estates were captured in Figure 2.2

Table 2.4: Establishment of Industries in Kano metropolis

Location of Industries	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	ni	Totals
Bompai	1	2	11	30	30	30	12	0	2	118
Tokarawa	0	0	0	8	17	18	10	0	2	55
Outside estate	0	0	0	4	8	12	6	0	0	30
Challawa	0	0	1	4	12	15	11	0	4	47
Sharada 1	0	0	1	9	5	10	3	0	9	37
Sharada 2	0	0	1	9	7	13	4	1	16	51
Sharada 3	0	0	0	3	11	10	2	0	4	30
Outside estate	0	0	0	4	1	6	2	0	0	13
Totals	1	2	14	71	91	114	50	1	37	381

(Source: Liman, 2015.) Key: ni = not indicated

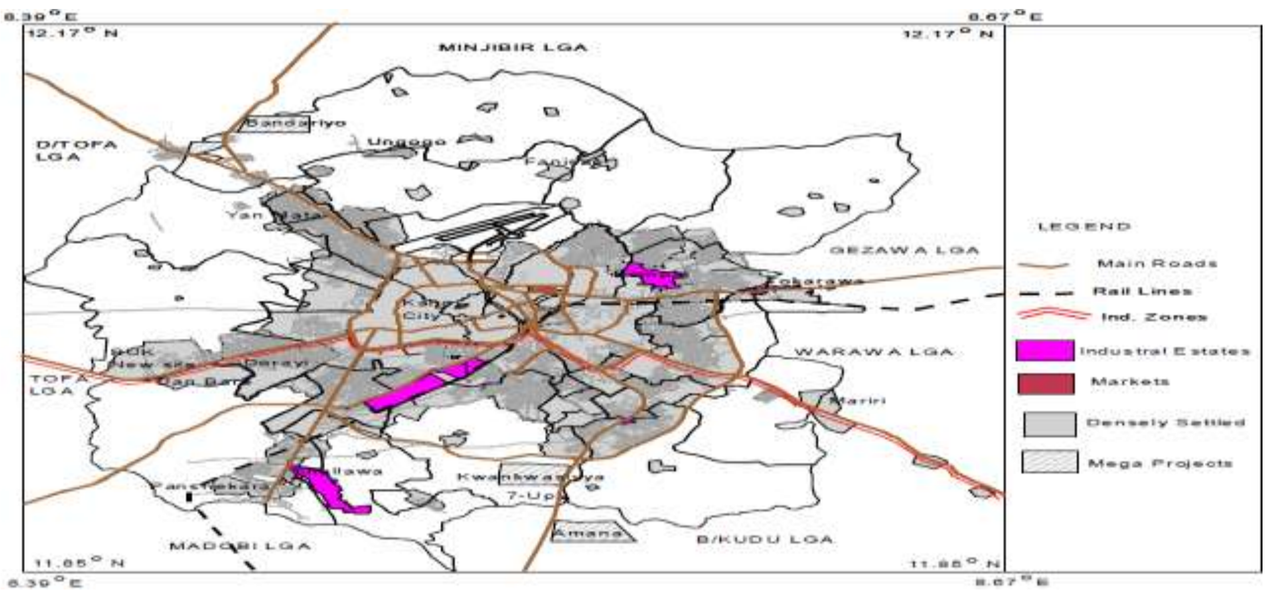

Figure 2.2 Industrial Estates in Kano metropolis (source: Liman, 2015)

2.3 Agricultural Practice in Kano state

Irrigation is artificial application of water to sustain plant growth. Abrishamchi*et al.*(2007) understand that today's agriculture accounts for the majority of water withdrawals; hence irrigation is the dominant water use in many arid and semi-arid river basins. As populations continue to rise, irrigated agriculture will provide an increasing share of total food production to meet the growing demand. Moreover, water demands for domestic and industrial uses in developing countries grow even more rapidly than agricultural water demand.

Population growth and the intensification of irrigation on agricultural lands have increased water need over the past decade. As a result, water abstraction for irrigation, livestock, and domestic use have severely stressed the water resources,particularly during dry seasons causing conflicts between upstream and downstream water users. Therefore there is a need to understand the spatial andtemporal water availability and to formulate a tool for planning and decision making in prioritizing of water allocation in some basins. However, given the complexity of the system and the interactions between water supply and demand, a large-scale water supply management tool would be useful for decision makers when formulating water management strategies couple with future changes in water demands (Chow, 1964).

2.3.1 Kano River Project Phase I

Kano River phase I is one of the largest irrigation project, not only in Nigeria, but in West Africa. It is unique in its design, in that, the entire water distribution network operates on gravity. The irrigation water is conveyed from Tiga Dam to the project site through an 18 km long main canal, which split into West and East Branches. They are further broken into lateral canals, distributaries canals, field channels and finally to the farm for the crops to be irrigated (HJRBA (HadejiaJama'are River Basin Development Authority), 2018).

Also HJRBA (2018) said that each of the above mentioned structure is designed to carry a designed discharge sufficient to irrigate the areas. The Night Storage Reservoirs which are constructed in different location throughout the project area is another unique feature of the project. These reservoirs are built to receive and store the flow from branch and lateral canal during the night. This is necessary because since the entire project has to carry out irrigation at the same time during the day, hence large quantity of water has to be stored in different locations of the project at night when no irrigation is taking place. Also designed and built in the irrigation system is an elaborate drainage network system to drain off excess irrigation and rainwater from project area.

HJRBA (2018) further said that the project locates in Bebeji,Tudun-Wada, Kura and Rano Local Government Area of Kano State with project headquarters at Kura Local Government. It lies about 35km south-west of Kano city, on both side of Kano-Zaria trunk road. The elevation of the project lies 440m above the mean sea level, with minimum storage level of Tiga Dam at 506,50m, which provides a perfect setting for gravity irrigation. The main feature of the irrigation project is shows in Table 2.5

Table 2.5: Main feature of the phase I irrigation project

Total irrigation area (Ha)	22000
fully developed irrigation are (Ha)	15000
length of main canal (km)	18
Length of branch canals (km)	56
Length of secondary canals (km)	320
length of main drain (km)	320
length of collector drains (km)	496
Length of field canals (km)	1120
Length of field drains (km)	1120
Length of service road (km)	816
no. of night storage reservoir	8
no. of field structure	16000

Source: HJRBA (2018)

2.3.2 Kano River Project Phase I on Agricultural Development

HJRBA (2018) said that with progress made over the years, the Authorities have been assisting the farmers in farming during dry season (crop supplementary irrigation). Despite the fact that the main function of the Government is the development of surface and underground water resources, which is fully executed, the Government also assists in the area of crop production, crop protection, and general crop husbandry by giving technical advice to the farmer all over the project area. In addition the Government has launched a program to ensure adequate utilization of the scare resources for the soul aimed to ensure complicit resolution. Hence the Government divide the farmers into groups. Table 2.6 summarized the impact of this initiative and it significant in agricultural value chain.

Table 2.6: Crop production and farmer gross revenue.

Wet season 2001					
Crop type	Crop area Ha	Av yield MT/Ha	Product (MT)	Price/MT (₦)	Value (₦)
Rice	14000	4	56000	35000	1960000000
Maize	200	3	600	35000	21000000
Sorghum	500	1.2	600	35000	21000000
Millet	250	1	250	40000	10000000
Cowpea	50	0.8	40	48000	1920000
Sub-total	15000		57490		2013920000
Dry season 2000/2001					
Wheat	4400	2.4	10560	40000	422400000
maize	3450	2.5	8625	35000	301650000
Tomato	2700	15	40500	16000	684000000
Onion	1950	27	52650	13000	684450000
Cowpea	300	0.7	210	48000	10080000
Other	200	10	2000	10000	20000000
Fallow	2000	0	0	0	
Sub-total	15000		114545	0	2086580000
G/total		0	172035	0	4100500000

(Source: HJRBA, 2018)

The project has over the years improved the living standard of the farming communities within and outside the project area in the following major areas:

- Provide all year round employment for over 35000 farmers and their families.

- Farmers produce over 150000MT of food and cash crops valued 2.7 billion naira annually. In the year 2001/2002 farmers realized higher revenues due to the good prices offered in the market for their produce as could be seen in table 2.6.

- Provide over 1.2 million man days of employment to farm laborers from within and outside project area annually.

- Contributes significantly toward enhancing national food security.

- Generates about 100000MT of crop residues, which is used as fodder in the livestock

2.4 Hydrology and Hydraulic Structure

2.4.1 Dam

Dam is a structure build across a river with the aimed of storing water. WB (World Bank) and LCBC (Lake Chad Basin Commission) (2002) Viewed that the damming of rivers has traditionally been one of the most important ways to ensure enough water resources for irrigation, hydropower generation and domestic use. About 60 per cent of the world's largest 227 rivers have been strongly or moderately fragmented by dams, diversions or canals, with effects on freshwater ecosystems.

In Nigeria, the major dams are concentrated in the drought-prone and semi-arid Northern part of the country in a bid to ensure adequate supply of water in the prolonged dry season, and also to check flood occasioned by torrential rainfall in the zone. Such dams include KainjiDam (River Niger), Tiga Dam (Rivers Kano and Duku), Jebba Dam (River Niger), Kafin-Zaki Dam (River

Jama'are), DadinKowa Dam (River Gongola) and Shiroro Dam (River Kaduna). All of which can be classified as large dams based on the International Committee on Large Dams (ICOLD) criteria for classifying dams as shown in Figure 2.3 (McCartney *et al*., 2001).

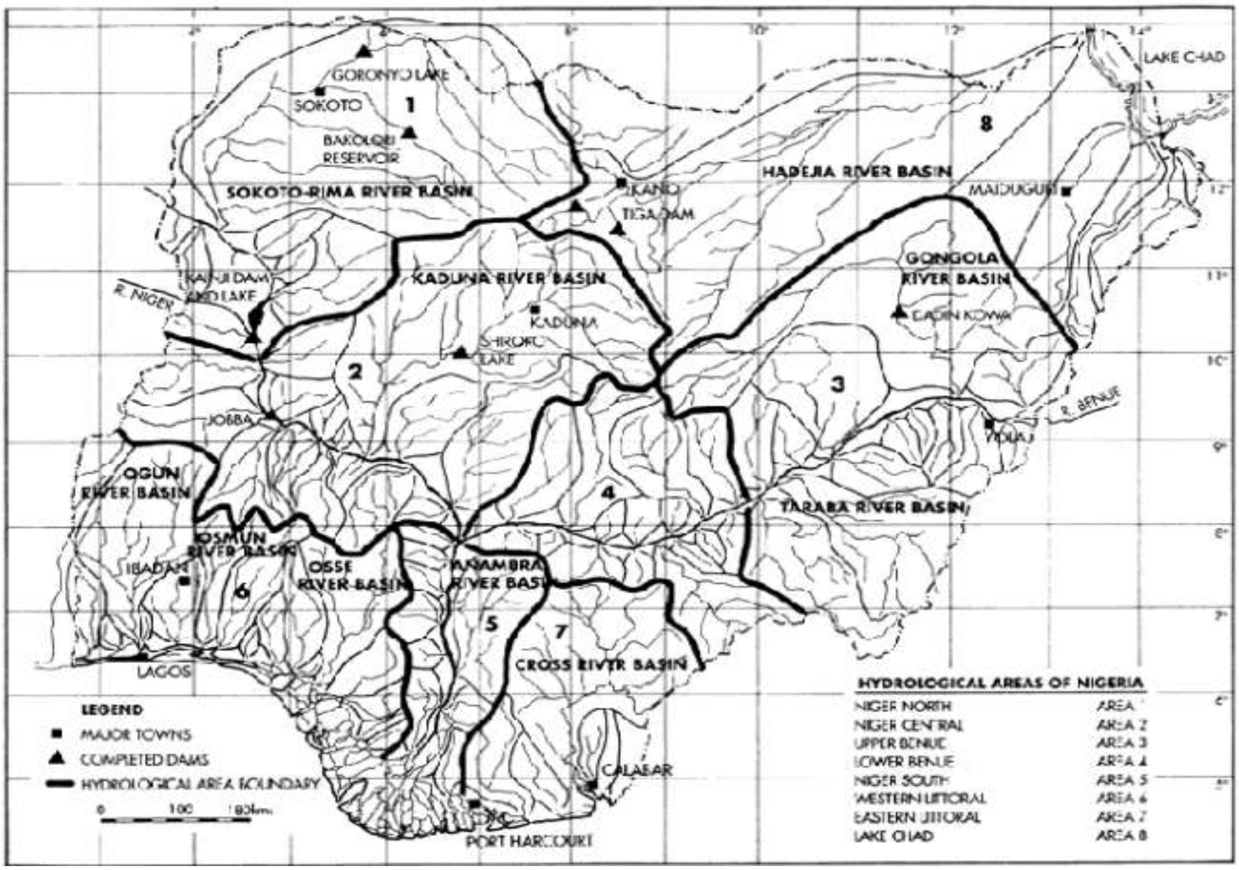

Figure2.3:Hydrological map of Nigeria showing the largedams and their position in their respective rivers basins (Source: Ita, 1994).

WB and LCBC (2002) Tiga Dam, was constructed on the Kano River and was commissioned in 1974 while Challawa Gorge Dam, on the Challawa River, in 1992. These two rivers meet at southernpart of Kano City to form the Hadeija which in turn is the principal source of supply for both the wetlands and for the northern part of Lake Chad.The dam was based on a design of NEDECO (Netherlands Development Company) but was constructed between 1970 and1974 without professional engineering input. HJRBDA took over responsibility for operating and maintaining the dam in 1976.The Tiga Damis a zoned earth-fill embankment whose main characteristics are as presented in table 2.7. Simon (1997) Discover that at present, it is estimated that 500 000 tons of sediment per annum enter the Tiga Reservoir.

Table 2.7: The main characteristics of Tiga Dam

Embankment height river bed level		48m
Embankment length		6000m
Crest elevation		530.96masl
Upstream slope		1:3
Downstream slope		1:2.5
Crest width		7.6m
Outlets	Main	3.65m diameter
	secondary	2no 0.9m diameter
Main spillway	527.3m crest level	122m
	527.6m crest level	527.6m
Emergency spillway	25.1mcrest level	200m
	526 m crest level	714m

Source: WB and LCBC (2002)

The Tiga Dam is located on River Kano, 70Km south of Kano City. It's one of largest dams in the country and was designed and builds between 1970 and 1974. This dam is the cornerstone of water resources development in Kano River valley in Kano State and Hadejia River valley in Jigawa State. The dam sustains irrigation agriculture for thousands of hectares in Kano river irrigation project phase I and Hadejia valley irrigation project currently being developed (HJRBA, 2018). The features of the dam are summarized in Table 2.8.

Table 2.8: Features of Tiga Dam

Types of the dam	Zoned Earth fill
Crest length	6000m
Structural Height	48m
Hydraulic height	42.68m
Maximum Base Width	274.30m
Total Storage Capacity	1,974Mm^3
Active Storage Capacity	1845 Mm^3
Surface Area of Reservoir	18900Ha
Total volume of fill Material	9.18 Mm^3
Spillway Type	Free overflow Concrete Ogee (457m)
Emergency	2000
Diameter of the main outlet	3.65m
Water Releases to Water board	22m^3/s

Source: HJRBA (2018)

2.4.2 Hydrology

This is the harnessing and management of water beneath and upon the earth in form of solid, liquid, or gases. Nami (2002) said that the hydrological regimes of rivers of inter-tropical Africa are directly influenced by rainfall, he further said that despite the relative abundance of water at times in the Lake Chad Basin area (north-eastern Nigeria), the flow of rivers has been constantly diminishing. Partly due to decreasing rainfall in the hydro-logically active upstream basins but also as a consequence of increased flow alterations and abstraction for human consumption (World Bank, 2002).

HadejiaJama'are River Basin is one of the headwaters of Lake Chad but the river flow is interrupt along its course by many dams such as Tiga Dam, Kafin-Zaki Dam, Challawa (Akindele, 2012). Shettima (2009) found that the river flow at Gashua in Yobe State, downstream of Tiga Dam fell by about 100 million cubic meters per year on completion of the dam. Table 2.8 shown reservoir characteristics of Tiga Dam and Figure 2.3 is main canal of the dam:

Table: 2.9 Reservoir characteristics of Tiga Dam

Full storage level (m)	527.3
Area at full storage level (km^2)	-
Volume at full storage level (Mcm)	1968
Dead storage (Mcm)	123
Direct catchment area (km^2)	6553
Mean annual inflow (Mcm)	1300
Annual yield (Mcm)	-
Design flood (m3/s)	3257 (10,000 year)

Source: WB and LCBC (2002)


Figure 2.4: Main canal of Tiga Dam (source: field work)

2.4.3 Hydrologic Characteristic

Kano has highest number of dams in Nigeria which result to 26 dams. Tiga Dam is the biggest dam in terms of volume in the whole West Africa.

The hydrologic characteristic of Kano dams was summarized in Table 2.8.

Table 2.10: Hydrologic characteristic of some Kano state dams

Water Resources	Average annual rainfall (mm)	Catchm-Ent Area (km²)	Average annual runoff (Mm³)	Active Storage capacity (Mm³)	Dead Storage Capacity (Mm³)	Total Available water 1n Reservoir (Mm³)		Average Storage Reservoir In Oct (Mm³)	Regional Drinking Water 2000 (Mm³)	Irrigation requirement Mm³		Area foe Irrigation Ha		Irrigation Area by individual farmer	
						May 1978	Oct. 1983			At present	After exact project	At present	After exact project	Irrigation requirement Mm³	Area Ha
Birnin kudu	966	40	0.9	0.94	6.946	8.25	1.19	8.8896	2.59	-	-	-	-		
Bagauda	1000	207	3830	20.91	1.298	11.58	19.9	28.66	1.89	-	-	-	-		
Karaye	940	80	1415	15.99	8.619	10.39	13.18	18.966	9.00	0.085	0.340	9	20		
Kafingana	-	-	-	0.88	-	8.22	-	8.6996	-	0.135	0.135	8	8		
Tiga	1016	6641	1059.00	1845.00	128.668	14.82	1219.88	1631.66	-	391.000	1700.000	23000	100000		
Tomas	838	585	28.3	56.60	6.619	11.09	14.28	28.204	2.70	3.604	4.165	260	350		
Jakara	836	559	43.00	54.37	16.320	9.53	31.74	69.896	-	0.238	14.100	20	600	0.700	100
Gari	831	1155	140.00	203.00	11.668	49.14	11.96	92.66	1.39	1.870	34.970	110	2293	4.200	600
KafinChiri	864	225	35.57	24.60	6.528	9.73	11.37	16.788	6.00	-	13.400	-	574		
Warwade	660	106	7.69	9.70	1.606	8.49	1.42	3.302	2.70	-	-	-	-		
Tudun Wada	1016	85	14.00	-	-	-	-	-	0.90	-	-	-			
Watari	813	653	89.50	92.74	11.808	-	51.55	68.005	13.00	-	22.000	-			
Guzuguzu	813	106	18.17	21.53	3.698	-	3.08	8.71	-	-	-	-			
Magada	813	119	20.91	17.22	2.400		12.95			-	2.380	-			
Pada	813	62	10.96	10.50	11.500	-	4.60					-			
Marashi	813	43	7.75	5.79	0.980	-	-								
Challawa Gorge	841	3859	589.00	904.00	65.00	-	-								
Ibrahim Adamu	813	-	7.38	7.38	0.815	-	1.2								
Ruwankanya	1016	-	-	-	-	-	-								
	813	43	-	-	-	0.70	0.6								

Source: MANS Kano state (1984)

2.5 Review of Previous Studies

Base on the review of previous studies,it shows that there is no any research carried out in the study area (Tiga Dam) to determined future and present water allocation for different purpose with modelling tool especially WEAP model.

Many researches were conducted around the world to find out water allocation for different purposes and water resources management system (Suryadi*et al.*, 2018, Daniyal*et al.*, 2017, Berredjem and Hani, 2017, Trinh, 2016, Akindeleand Indabawa, 2015, Myat and Aye,2014, Alfarra*at el.*, 2012, Shakirudeen*et al.*, 2011, Zakari*et al.*, 2011, Abrishamchi*et al.*,2007 and Ibn-Abubakar, 2005,). These studies are summarized in Table 2.10.

Table 2.11 Summaryof previous studies

Author(s)	Title	Findings	Remark
Suryadi*et al.*, 2018	Study on water resources allocation for kertajati, jatitujuh, and ligung sub-districts to support the development of west java international airport (BIJB) and kertajati aero-city area.	The total demand of three districts from 2015 to projected years 2040 was determined. At 2040 total water demand would reach 1,450.60 L/s.	Water demand for irrigation was not determined and there are farming activities within the catchment.
Daniyal*et al.*, 2017	Modelling water demand and supply for future water resources management	The total water demand at 2015 for agricultural, domestic, and industrial sector was 40.37MAF but as a result of the population growth it would be increase to 56.5MAF at 2050. When management method were introduced in to the model sprinkler reduced 20% of agricultural water consumption, drip reduced 35% of agricultural water consumption, and lining of canal reduced 50% of seepage water loses.	Population growth control was not used to manage domestic water demand.
Berredjem and Hani, 2017	Modelling current and future supply and water demand in the northern region of the Seybouse Valley (Algeria).	The water demand in the sub-basin of lower Seybouse increased from 82.64 hm^3 at 2010 to 178.04 hm^3 at 2050. 53% for household, 30% for	Management method was not used in mode and also water deficit was not determined.

		irrigation and 17% for industries.	
Trinh, 2016	Application of Agent-Based Model on water allocation to improve water usage efficiency and reduce conflict.	The conflicts were resolved as a result of determining irrigation water allocation and deficit to each sub-district.	The research was on irrigation purpose only.
Akindele, and Indabawa, 2015	A review of the effects of dams on the hydrology, water quality and invertebrate fauna of some Nigerian freshwaters	It was reviewed that river flow downstream of Tiga Dam fell by about $100m^3$ per year and there were decrease of some chemicals parameters towards the dam site, particularly total alkalinity, total conductivity, total hardness etc. while pH and dissolved oxygen showed an increase.	This is just a review paper.
Myat and Aye, 2014	Proposal of water allocation plans for Mandalay area in Myanmar	It had found that 3 cities out of 8 were faced with unmet demand of 1410.58 MG/month for domestic and industrials at 2015 while no unmet demand for irrigation and hydropower. Management methods were used to take care with unmet demand in future.	Is very difficult to achieve the management method.
Alfarra at el, 2012	Modelling water supply and demand for Effective water management allocation in the Jordan Valley	It was predicted that there would be unmet water demand in future time but when control measures were used the unmet water demand was reduced by 18.3 %.	Variations of population growth and irrigation area increase intermittently were not considered.
Shakirudeen et al., 2011	Hydro-climatic variability of the Hadejia-Jama'are river Systems in north-central Nigeria.	The low level of temporal variability of PE over the basin shows that temperature has increased marginally over the years.	In this research no any hydrological model used for water allocate.
Zakari, 2011	Application of Water Evaluation and Planning (WEAP): A Model to Asses Future Water Demands in the Niger River (In Niger Republic).	In 2030, there would be a deficit of 33.7 MCM of water set as follows: 9.8 MCM for the irrigation, 22.1 MCM for Niamey city and 1.8 MCM for Tillabéry town, due to higher population growth and climate variable.	There is no any water conservation method if the phenomena of rapid population increase and climate change will not able to retain
Abrishamchi*el al.*,2007	Water resources management scenario analysis in the Karkheh River Basin, Iran, using the WEAP model	It had been found that the reservoir would not serve the demand in 2020 ground water and ongoing dam constructions were used to take care with the	Management method did not take care with the enterer water deficit.

		water deficit.	
Ibn-Abubakar, 2005	Assessment of reservoir storage in a semi-arid Environment using Gould probability matrix.	In this research Tiga Dam reservoir was divided in to five zones and 9x9 matrixes was developed in which probabilistic approaches shown that substantial amount of water had been trapped without efficient utilization.	No any water allocations carry out in this research.

2.6 Hydrological Models

Abrishamchi*et al*. (2007),said that water resources system simulation models are needed to assess the impact of management measures in scenario frameworks. There are many computer base models that can be applied in the basin scale, such as RIBASIM, WEAP, MODSIM, etc. WEAP was selected among them for reasons below:

1- Its integrative approach in considering hydrological inputs for water allocation and management systems.

2- Its extensive usage allover the world (Universal).

2.6.1 WEAP Model

The (Water Evaluation and Planning) (WEAP model) is a microcomputer tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for policy analysis. A growing number of water professionals are finding WEAP to be a useful addition to their toolbox of models, databases, spreadsheets and other software. The Stockholm Environment Institute provided primary support for the development of WEAP. The Hydrologic Engineering Center of the US Army Corps of Engineers funded significant enhancements. A number of agencies, including the World Bank, USAID and the Global Infrastructure Fund of Japan have provided project support. WEAP has been applied in water assessments in over one hundred countries (WEAP tutorial, 2016). The Water Evaluation and Planning System (WEAP) aims to incorporate water supply projects in the context of demand side issues, issues of water quality and ecosystem preservation into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side of the equation water use patterns, equipment efficiencies, re-use, prices, hydropower energy demand, and allocation on an equal footing with the supply side--stream flow, groundwater, reservoirs and water transfers. WEAP is a laboratory for examining alternative water development and management strategies(Sieber et. al., 2015).

WEAP applications generally involve five main views (WEAP tutorial, 2016). These are presented below:

(1) Schematic:

This view contains GIS-based tools for easy configuration of your system. Objects (e.g., demand nodes, reservoirs) can be created and positioned within the system by dragging and dropping items from a menu. ArcView or other standard GIS vector or raster files can be added as background layers. You can quickly access data and results for any node by clicking on the object of interest as shown in Figure 2.5.

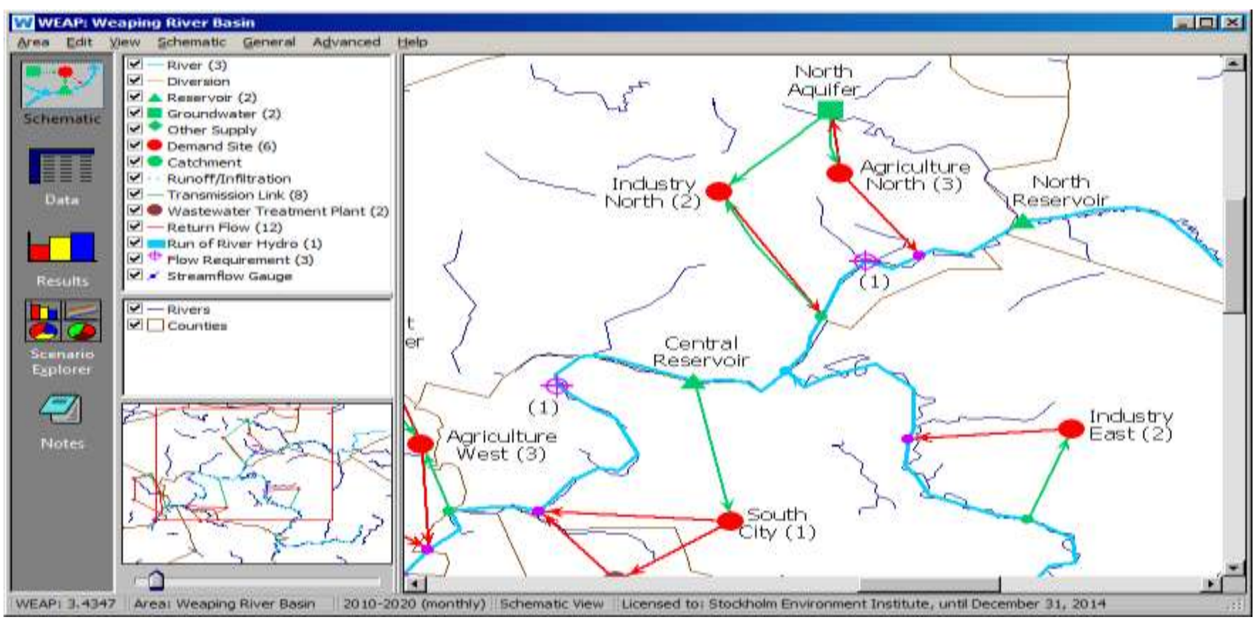

Figure 2.5: A screen shot of Study Area (Weaping River Basin)

(2) Data:

The Data view allows you to create variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel, Figure 6.6.

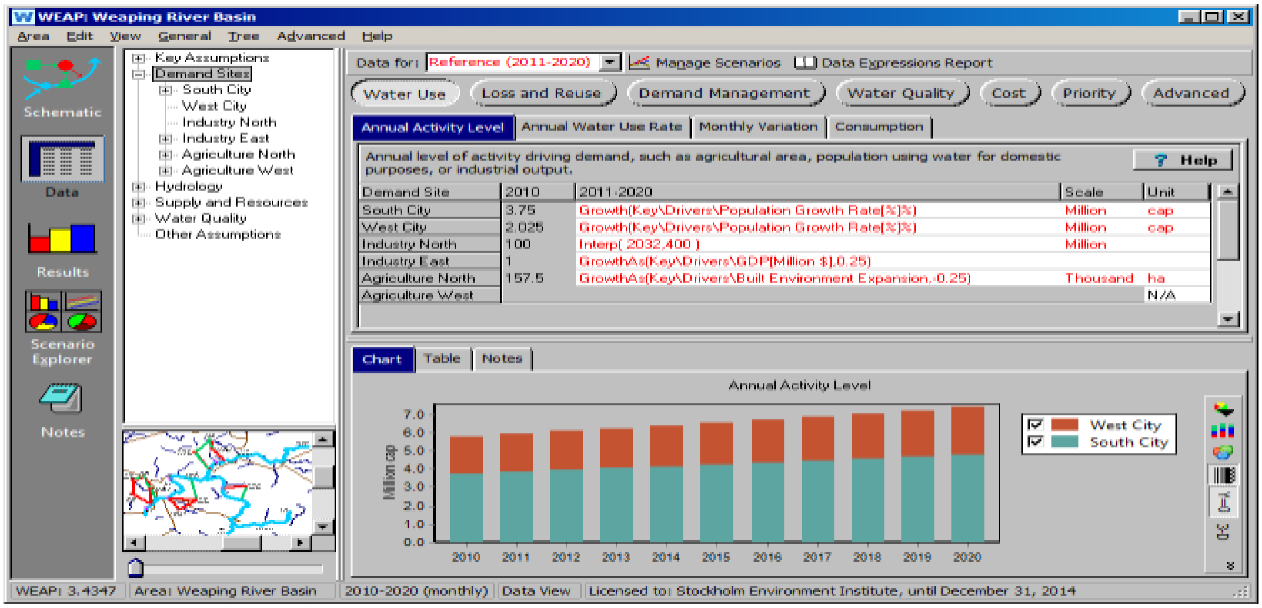

Figure 2.6: Inter face of the data view

(3)Results:

The Results view allows detailed and flexible display of all model outputs, in charts and tables, and on the Schematic, Figure 2.7.

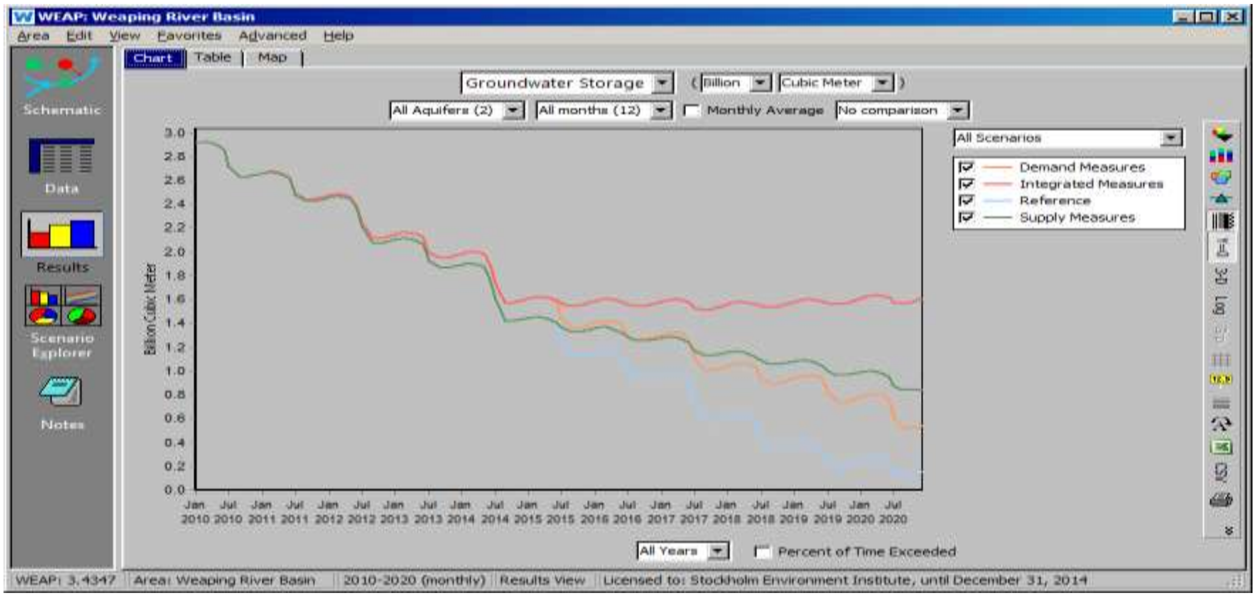

Figure2.7: Graphical representation of the result

(4) Scenario Explorer:

You can highlight key data and results in your system for quick viewing, Figure 2.8.

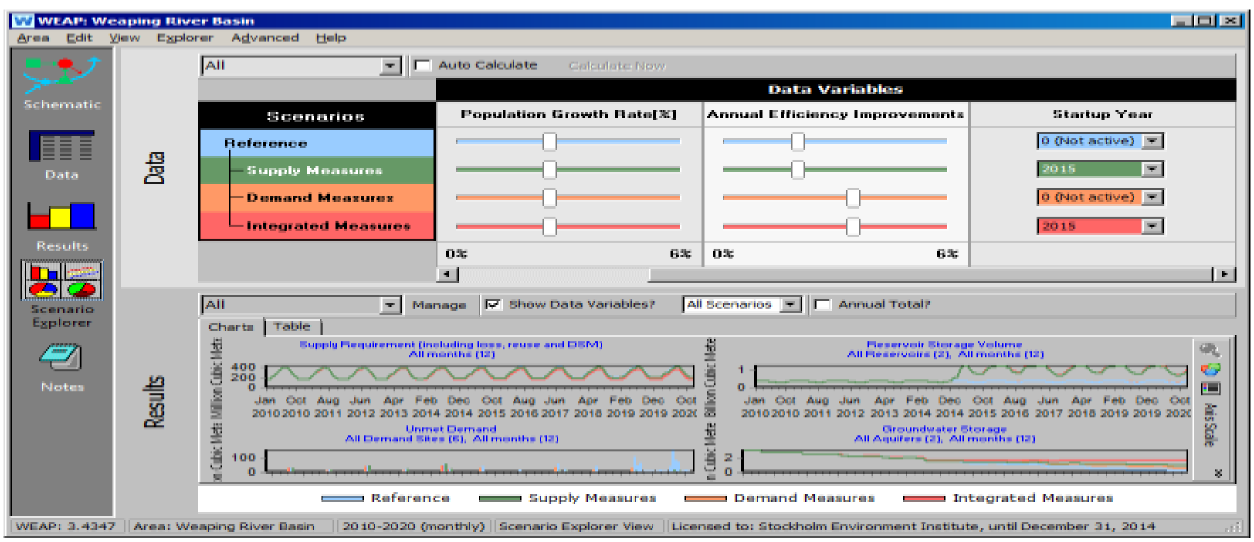

Figure 2.8: Result of the scenarios

(5)Notes:

The Notes view provides a place to document your data and assumptions as shownin Figure 2.9

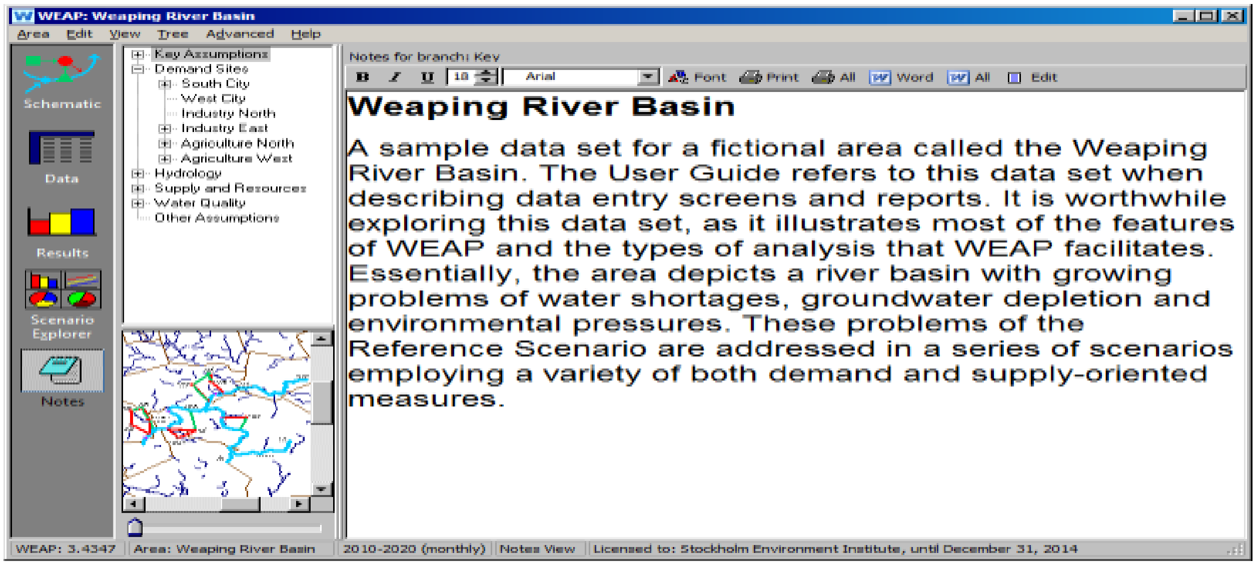

Figure: 2.9: Note path environment

2.6.2 Catchment Simulation Methods

Sieber et al., (2015) said there is a choice among five methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include

(1) The rainfall runoff method (simplified coefficient method): It determines evapotranspiration for irrigated and rain-fed crops using crop coefficients, the same as in the Irrigation Demands Only method. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via runoff/infiltration links.

(2) Irrigation demands method versions (simplified coefficient method): This is the simplest method among others. It uses crop coefficients to calculate the potential evapotranspiration in the catchment, then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet. It does not simulate runoff or infiltration processes, or track changes in soil moisture.

(3) The rainfall runoff method (soil moisture method): This method is more complex, representing the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Base flow routing to the river and soil moisture changes are simulated in the lower soil layer. It requires more extensive soil and climate parameterization to simulate these processes.

Note that the deeper percolation within the catchment can also be transmitted directly to a groundwater node by creating a Runoff/Infiltration Link from the catchment to the groundwater node. The method essentially becomes a 1-layer soil moisture scheme if this is link is made.

(4) The MABIA method: Is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity. It was derived from the MABIA suite of software tools, developed at the Institute National Agronomies de Tunisie by Dr. Ali Sahli and Mohammed Jabloun.

The MABIA Method uses the 'dual' Kc method, as described in FAO Irrigation and Drainage Paper No. 56 (Spanish version of FAO 56), whereby the Kc value is divided into a 'basal' crop coefficient, Kcb, and a separate component, Ke, representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. In this way, MABIA is an improvement over CROPWAT, which use a single Kc method, and hence, does not separate evaporation and transpiration.

(5) The plant growth model or PGM: The Plant Growth Model simulates plant growth, water use, and yield using a daily time step. It was developed to provide a method for studying the impacts of altered atmospheric CO2 concentration, temperature stress, season length variability, and water stress on plant water use and crop yields. It requires specification of parameters that control the rate of plant development and water use. The growth routines in the model are based on the approach taken in the SWAT and EPIC models allowing use of their databases for parameterization of the model. Soil moisture hydraulics are simulated using a 13-layer model that represents the top 3.5 meters of the soil profile. Outputs from the model include surface runoff, deep percolation, plant ET, water and temperature stress, biomass production and yield.

Santikayasa et al., (2007) said thatPopulation growth and the intensification of irrigation on agricultural lands have increased water demand over the past decade. As a result, water abstraction for irrigation; livestock and domestic use have severely stressed the water resources, particularly during dry seasons causing conflicts between upstream and downstream water users. There is therefore a need to understand the spatial and temporal water availability and to formulate a tool for planning and decision making in prioritization of water allocation in the area or basin.

2.6.3 Soil Moisture Method

This is one dimensional, 2-compartment (or "bucket") soil moisture accounting scheme which is based on empirical functions that describe evapotranspiration, surface runoff, sub-surface runoff, and deep percolation for a watershed unit as shows in Figure 2.10. This method allows for the characterization of land use and/or soil type impacts to these processes. The deep percolation within the watershed unit can be transmitted to a surface water body as base-flow or directly to groundwater storage if the appropriate link is made between the watershed unit node and a groundwater node.

2.6.3.1Land Use: The following parameters were used in the Soil Moisture methodto give the approximate representation of the stream flow within the basin.

Area: Land area for land cover class within branch or basin catchment.

Kc: The crop coefficient, relative to the reference crop, for a land class type.

Root Zone Water Capacity: The effective water holding capacity of the top layer of soil, represented in mm.

2.6.3.2Deep Water Capacity: Effective water holding capacity of lower, deep soil layer (bottom "bucket"), represented in mm. This is given as a single value for the catchment and does not vary by land class type. This is ignored if the demand site has a return flow link to a groundwater node.

2.6.3.3Deep Conductivity: Conductivity rate (length/time) of the deep layer (bottom "bucket") at full saturation (when relative storage $z_2 = 1.0$), which controls transmission of base-flow. This is given as a single value for the catchment and does not vary by land class type. Base-flow will increase as this parameter increases. This is ignored if the demand site has a return flow link to a groundwater node.

2.6.3.4Runoff Resistance Factor: Used to control surface runoff response. It is related to factors such as leaf area index and land slope. Runoff will tend to decrease with higher values (range 0.1 to 10). This parameter can vary among the land class types.

2.6.3.5Root Zone Conductivity: Root zone (top "bucket") conductivity rate at full saturation (when relative storage $z_1 = 1.0$), which will be partitioned, according to Preferred Flow

Direction, between interflow and flow to the lower soil layer. This rate can vary among the land class types.

2.6.3.6Preferred Flow Direction: Preferred Flow Direction: 1.0 = 100% horizontal, 0 = 100% vertical flow is used to partition the flow out of the root zone layer (top "bucket") between interflow and flow to the lower soil layer (bottom “bucket") or groundwater. This value can vary among the land class types.

Initial Z_1: Initial value of Z_1 at the beginning of a simulation. Z_1 is the relative storage given as a percentage of the total effective storage of the root zone water capacity.

Initial Z_2: Initial value of Z_2 at the beginning of a simulation. Z_2 is the relative storage given as a percentage of the total effective storage of the lower soil bucket (deep water capacity). This parameter is ignored if the demand site has a runoff/infiltration link to a groundwater node. This rate cannot vary among the land class types.

A watershed unit can be divided into N fractional areas representing different land uses/soil types, and a water balance is computed for each fractional area, j of N. Climate is assumed uniform over each sub-catchment, and the water balance is given in equation 2.1

$$Rd_j \frac{dz_{1,j}}{dt} = P_e(\mathbf{t}) - \mathbf{PET}(\mathbf{t})\mathbf{k}_{\mathbf{c},\mathbf{j}}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t) z_{1,j}^{RRF_j} - f_j k_{s,j} z_{1,j}^2 - \left(1 - f_j\right) k_{z,j} z_{1,j}^2 \quad (2.1)$$

Where: $z_{1,j}$ = [1,0] is the relative storage given as a fraction of the total effective storage of the root zone, Rd_j (mm) for land cover fraction, j, the effective precipitation, P_e, excluding the snowmelt since snow is not experienced in the study area.

The effective precipitation, P_e, is then computed using Effective rainfall formula of USDA Soil Conservation Service as shown in equation 2.2 and 2.3

$$P_e = P_m * (125 - 0.2 * P_m)/125 \text{ .... For } P_m \leq 250 \text{ mm} \quad (2.2)$$

$$P_e = 125 + 0.1 * P_m \text{ .... For } P_m > 250 \text{ mm} \quad (2.3)$$

In Equation 2.1, PET is the Penman-Monteith reference crop potential evapotranspiration, where $k_{c,j}$is the crop/plant coefficient for each fractional land cover. The third term represents surface runoff, where $RRF_j$is the Runoff Resistance Factor of the land cover. Higher values of RRF_j lead to less surface runoff. The fourth and fifth terms are the interflow and deep percolation terms, respectively, where the parameter $k_{s,j}$is an estimate of the root zone saturated conductivity (mm/time) and $f_j$is a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically. Thus total surface and interflow runoff, RT, from each sub-catchment at time t are shown in equation 2.4

$$\boldsymbol{RT(t) = \sum_{j=1}^{N} A_j \left(P_e(t) z_{1,j}^{RRF_j} + f_j k_{z,} z_{1,j}^2\right)} \tag{2.4}$$

For applications where no return flow link is created from a catchment to a groundwater node, base-flow emanating from the second bucket will be computed using equation 2.5

$$\boldsymbol{S_{max}\frac{dz_2}{dt} = \left[\sum_{j=1}^{N} (1 - f_j) k_{s,j} z_{1,j}^2\right] - k_{s,2} z_2^2} \tag{2.5}$$

Where the inflow to this storage, S_{max} is the deep percolation from the upper storage given in Equation2.1, and K_{s2} is the saturated conductivity of the lower storage (mm/time), which is given as a single value for the catchment and therefore does not include a subscript, *j*. Equations 2.1 and 2.5 are solved using a predictor-corrector algorithm.

When an alluvial aquifer is introduced into the model and a runoff/infiltration link is established between the watershed unit and the groundwater node, the second storage term in Equation. 2.5 is ignored, and recharge R (volume/time) to the aquifer is

$$\boldsymbol{R = \sum_{j=1}^{N} A_j (1 - f_j) k_{z,j} z_{1,j}^2} \tag{2.6}$$

Where A is the watershed unit's contributing area. The stylized aquifer characterizes the height of the water table relative to the stream, where individual river segments can either gain or lose water to the aquifer.

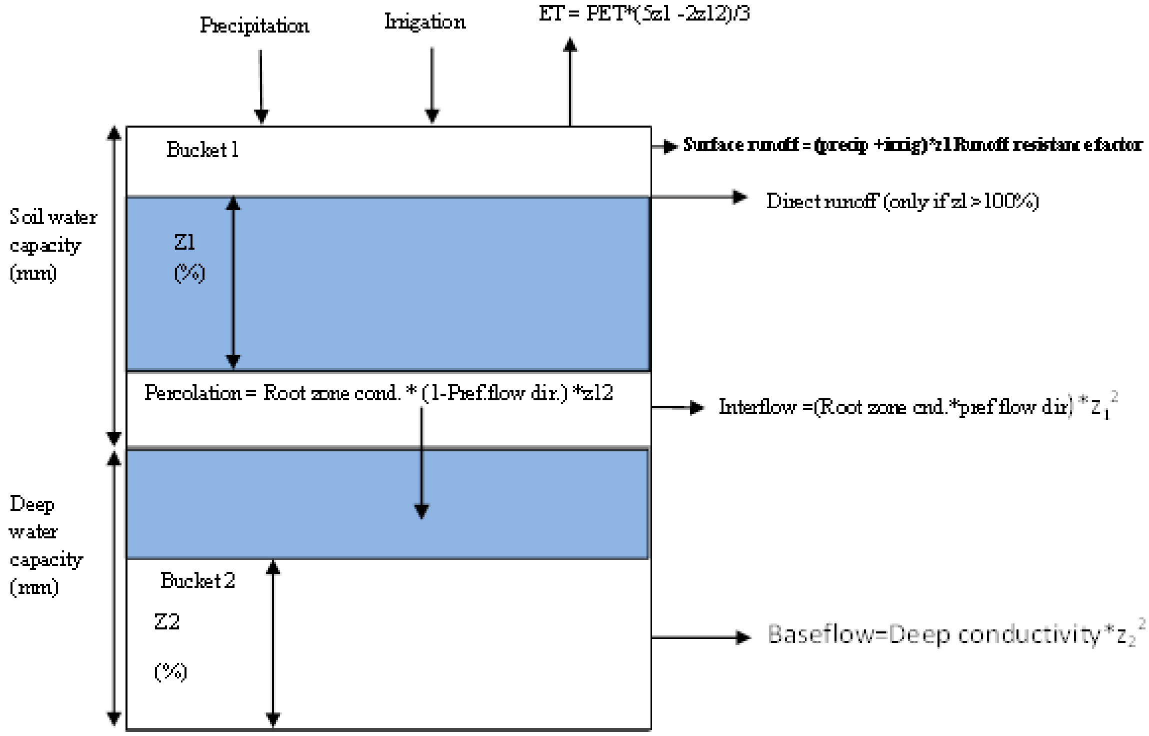

Figure 2.10**:** Conceptual diagram and equations incorporated in the Soil Moisture model

2.6.4 Water Year Method

Sieber et al., (2015)The Water Year Method allows you to use historical data in a simplified form and to easily explore the effects of future changes in hydrological patterns. The Water Year Method projects future inflows by varying the inflow data from the current accounts according to the Water Year Sequence and definitions specified in the Hydrology section. If you want to test a hypothetical event or set of events, or wish to approximate historic patterns, then you should probably select the Water Year Method. For example, you could use the Water Year Method to test the system under historic or hypothetical drought conditions. Hydrologic fluctuations are entered as variations from a Normal Water Year (the Current Accounts year is not necessarily a

Normal water year). The Water Year Method requires data for defining standard types of water years (Water Year Definition), as well as defining the sequence of those years for a given set of scenarios (Water Year Sequence).

A water year typecharacterizes the hydrological conditions over the period of one year. The five types that WEAP uses--Normal, Very Wet, Wet, Dry, and Very Dry--divide the years into five broad categories based on relative amounts of surface water inflows. To define each non-Normal water year type (Very Dry, Dry, Wet, Very Wet), specify how much more or less water flows into the system in that year relative to a Normal water year.

CHAPTER THREE

MATERIAL AND METHODS

3.1Description of the study area

Tiga Dam was built during the administration of GovernorAuduBako in an attempt to improve food security through irrigation projects. The dam is situated in Kano state Nigeria at Latitude 11° 26' 8.39" N and Longitude: 8° 24' 5.39" E, covers an area of 178 square kilometers (69 sq mi) with maximum capacity of nearly 2 billion cubic meters. Water from the dam supplies Kano River Irrigation Project as well as Kano City. The circle section indicate the study area in Figure 3.1.

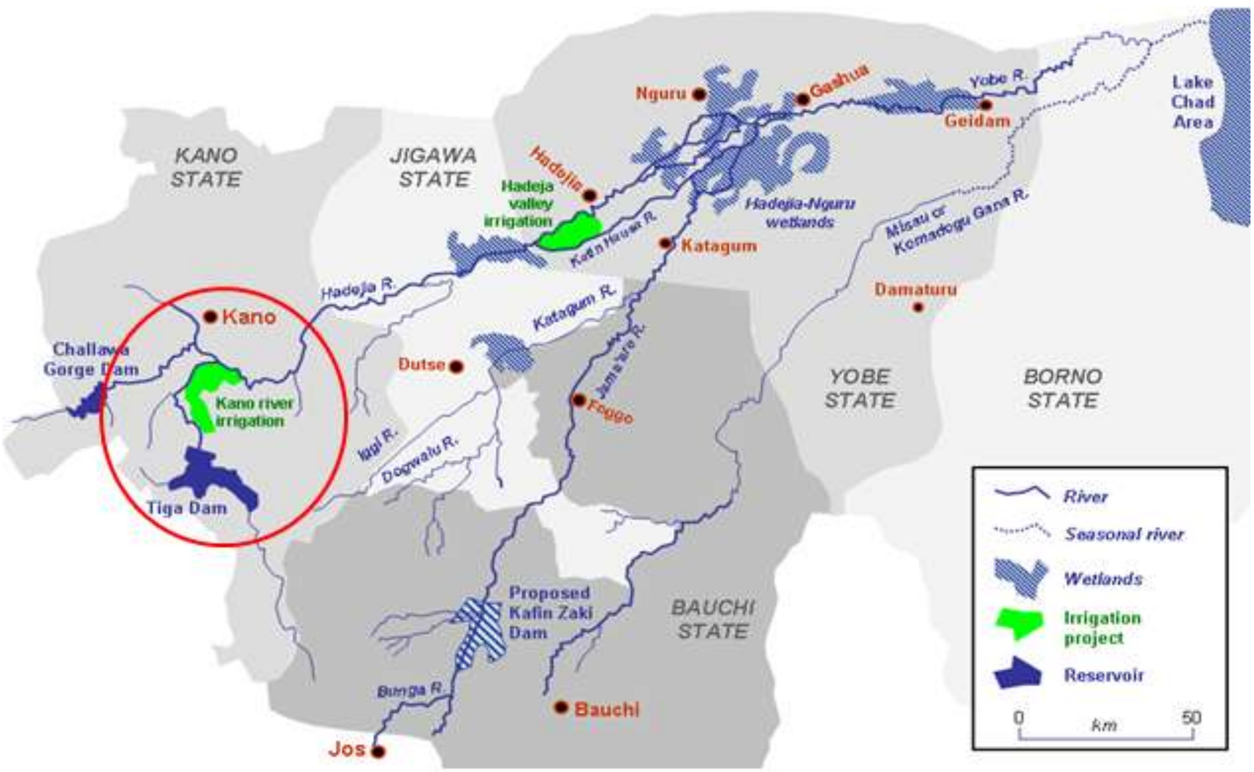

Figure 3.1: Catchment area of the Yobe River Tiga Dam to the west, south of Kano. Source: (Edward,2004).

Also, Kano State is located in the north-west region ofNigeria. It has a total land area of 20,131 km^2 (7,773 sq. mi), which represents 3.13% of the entire total area of the country. Kano State is bounded on the west by Katsina State, on the south-west by Kaduna State, on the east by JigawaState and southeast by Bauchi State. It is a part of the Sudano-sahelianregion of the country and comprises of 44 local government areas, it has three geo-political zones, namely Kano Central, Kano South and Kano North (Bello and Tuna, 2014).

Kano has a total population of 9,383,682 and population density of 470 per/sq. km (Nicol, 2000). Kano metropolitan has population of 2,163,225 (NPC, 2006). 75% of the people living in Kano are living in rural areas (Kano State of Nigeria, 2005). Currently the rate of population growth observed to be 2.9% per annum in Kano State. Moreover, high dependency ratio has been observed in Kano State and about 47% of the total populations in the study area are under 15 years of age (NPC, 2006).

Geology of Kano is mostly basement complex couple with weathered rock. Water table in Kano is usually found at a depth lower than 20 m. The hydraulic conductivity of the aquifer ranges from 0.039 to 0.778 m/d and permeability falls between 3.756 to 36.600 m^2/d.

Naturally, Kano state possesses three different kinds of vegetation cover. In the southern part of Kano it is called northern guinea savannah due to its richness and biodiversity. At about 200 km from the second type of vegetation cover emerges and is known as Sudan savannah. This kind of cover is characterized with scatted trees and more or grasses and shrubs. The third type of vegetation cover in Kano is found at theextreme northern part and is term Sahel vegetation cover (Bello and Tuna, 2014).

3.1.1Climate and Hydrology of Study Area

According to Bello and Tuna (2014), Kano state has a typical wet and dry climatic type. Seasonal migration of Inter Tropical Convergence Zone (ITCZ) which also known as Inter Tropical Discontinuity (ITD) gives rises to two distinct seasons namely wet and dry. Mean annual rainfall ranges from over 1,000 mm in the extreme south to a little less than 800 mm in the extreme north. The rains last for three to five months. Mean temperature ranges from 26°C to 33°C. Then, a cool and dry season lasts from October to mid-May of the year. In this period the mean monthly temperature is between 21^0C to 23^0C. In addition to that, Shakirudeen*et al*, (2011) said that the mean annual rainfall ranges from about 1100 mm in the upstream basement complex area, to about 400 mm in the middle part of the basin and less than 300 mm near Lake Chad.

Table 3.1 show hydrological and meteorologicalcharacteristic of Kano River basin

Table 3.1: Meteorological andHydrological Characteristic of Kano River Basin.

Basin	Area Gauged (km2)	Mean Rainfall (mm)	Water Inflow (Billion m^3)	Discharge (Billion m^3)	Estimated Evapotranspiration (Billion m^3)	Retained water (Billion m^3)
Kano	7,097	1000	7.10	1.21 (17%)	4.68 (66%)	1.21(17%)

(**Source:** Olofin, 1987)

Kano River rises from the foot slopes of Jos plateau in the south and flows generally to the north and northwest to about 30 km from its confluence with river Challawa where it swings north east. It flows up to Kano central alongTamburawa and River Challawa to the western part of Kano. It is observed that water is abundantly available during the wet season at both surface and subsurface.

Kano River which rises from a fairly humid zone has a mean discharge of 39 cubic meters per second (m^3/s). Challawa River which rises from a drier area has a mean discharge of 22m^3/s. The streams in Kano are characterized by flashy flows, storm discharges and seasonality. Surface water is not available during dry season except in few deep ponds, even on the basement complex structure, while groundwater level falls rapidly through seepage, extraction by man and high evapotranspiration.

Besides, Kano has the highest concentration of dams in Nigeria with more than 26 reservoirs constructed across the main rivers. These dams were constructed as a result of the drought that happened at the early 1970s and 1980s. The dams in the state include Challawa Gorge dam, Tiga dam, Thomas, Watari dam, and Kussalla dam (Mbagwu, 1994). Tiga and Challawa dams are among the largest dams in Africa. Tiga dam was constructed in Kano State in the year 1974. It is 6 km long and constructed along river Kano with carrying capacity of 1,974,000,000 m3 from its catchment area of 6553 km2. The dam was constructed mainly to provide water for Kano river irrigation project, Kano city water supply and so on (Bello and Tuna, 2014).

3.2 Materials

The materials used in this research work were: demographic, agricultural, industrial, meteorological, and water demand data with other essential equipment such as measuring tape, stop watch etc. These are discussed separately under the following sub-headings.

3.2.1 Demographic Data

Table 3.2 represents census 2006 demographic data for some selected local government in Kano State. It was obtainedfrom the study area in my field work in 2017 to know local government Tiga Dam supply water for.

Table 3.2: Population distribution used for domestic activities and their local governments.

Local governments	Population	Inter-census growth rate
BEBEJI	191916	3.36
DALA	418759	3.36
FAGE	200095	3.36
GAYA	207419	3.36
GEZAWA	282328	3.36
GWALE	357827	3.36
KUMBUTSO	294391	3.36
WARURE	131858	3.36
WUDIL	188639	3.36
GABASAWA	211204	3.36
NASSARAWA	596411	3.36
RANO	148276	3.36
TOTAL	3229123	3.36

(Sources: NPC, 2010 from Table 2.3 and field work).

3.2.2 Agricultural Data

Agricultural data include the total irrigated land which is 15000 Ha and extimated water application per hectare which is 6000m^3/ha (HJRBDA, 1986 and Sangari, 2006). Due to Kano River Project Phase I, farmers utilized an average volume of water amount to 4481.76 m^3/ha (Source: field work).

3.2.3 Industrials Data

Tiga Dam supplies about 334 industries with water for industrial used (Liman, 2015 and field work) in which 23m^3 water is allocated per industry. However, 30 m^3 per industry is needed to satisfy industrial demand (Source: field work).

3.2.4 per Capital Water Demand

The per capital demand is 105L/day that is estimated to be an average of 3L for drinking per day, 30L for flushing toilet, 5L for spiritual activities, 36 L for bathing and 31L for cleaning, cooking and washing clothes (Source:, field work). But according to the World Health Organization (WHO) for developing countries, the minimum standard amount of water demand per capita is 120 liter per day (WHO, 1999).

3.2.5 Meteorological Data

31 years meteorological data were obtained from IAR meteorological station and Tiga Dam meteorological station, Meteorological data such as rainfall depth, evaporation, maximum and minimum temperatures, and hydrological information (namely, initial storage, observed volume,

tail-water elevation, reservoir curve, maximum turbine flow, and storage capacity) were obtained.

3.2.6 Equipment

The following equipment were used in this research; 100 m measuring tape, cut trout flume, pump, known volume container, record sheet, stop watch and laptop computer.

3.3Methodology

3.3.1 Data Collection

The research commenced with a preliminary site investigation through reconnaissance survey to analysesagricultural activities taking place in the study area, other activities related to water resources in the basin and site visits to collect meteorological and hydrological information.

These information and data stated above assisted in modelling of the optimal water resources potential of Tiga Dam as follows:

3.3.2 Survey of Water Demand

A structured questionnaire was developed in other to estimate the pattern of domestic and industrial water utilization by end users, the sample of the questionnaire was presented in appendix A. The sample size calculator was used to determine sample size needed, Figure 3.2 represent sample size calculator. 650 questionnaires were administered, but 600 were retrieved for analysis. Some of the questionnaires were filled using face-to-face interviews of householdswhile others were filled by the households. Statistical analysis of the questionnaires results were shown in section 4.1.

Figure 3.2: Sample size calculator (Source: Manno, 2013)

3.3.3 Demand Site Modelling

The water resources of the study area were analyzed based on the existing river system considering upstream and downstream sections, the Kano city demand, the agricultural, and industrial were determined asshow in Figure 3.3. Relevant information were inputted in each and every demand side as shown in Figure 3.3. The short copies of the demand sides were shown in Figure 3.4 to 3.6. The scenarios results were obtainedwhen correlated different scenarios with reference account of different demands

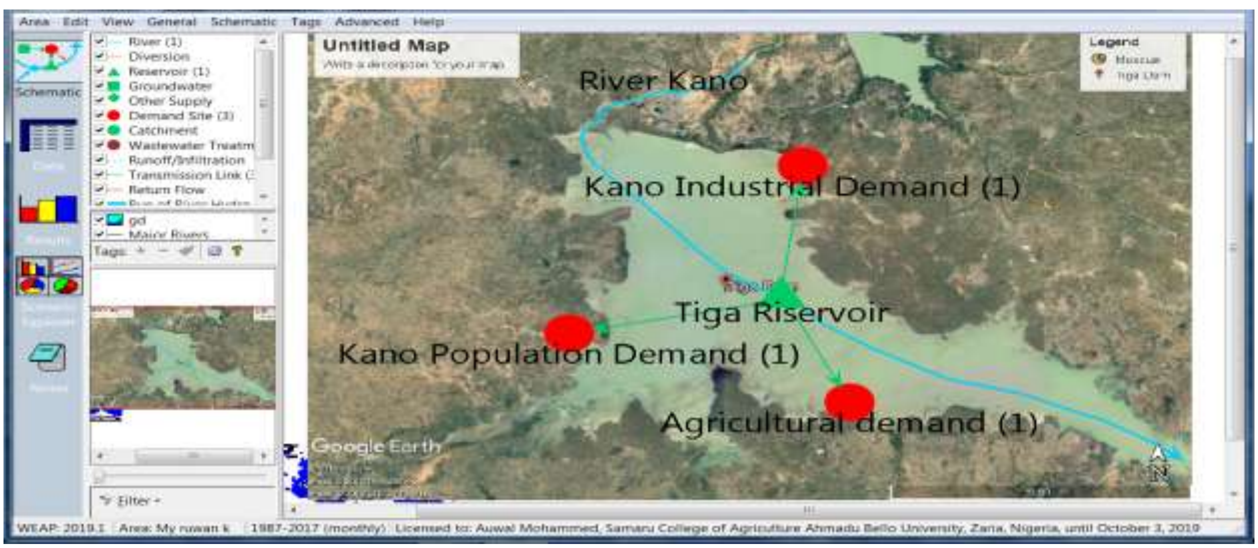

Figure 3.3:The Schematic diagram of the demand side of Tiga Dam

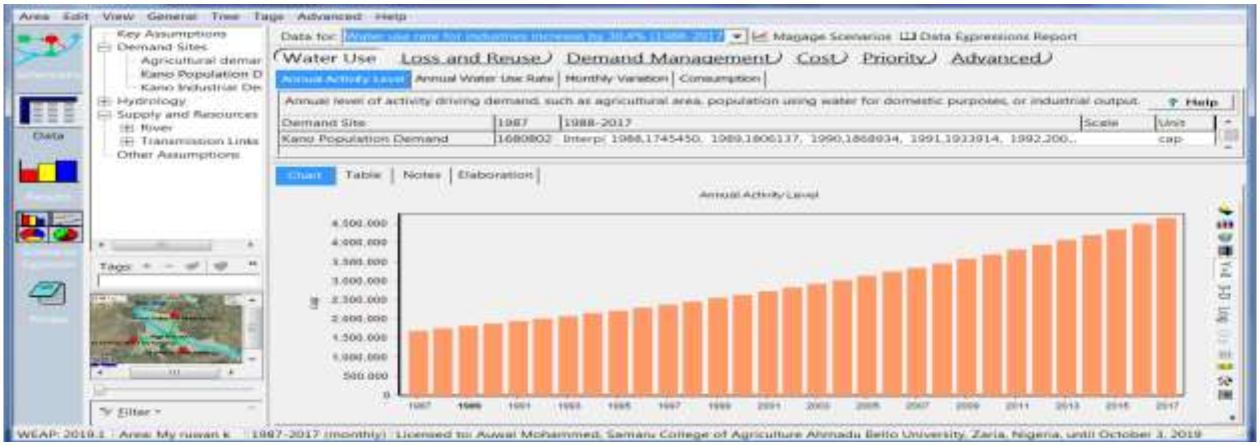

Figure 3.4:A screen copy of modelling of Kano city demand

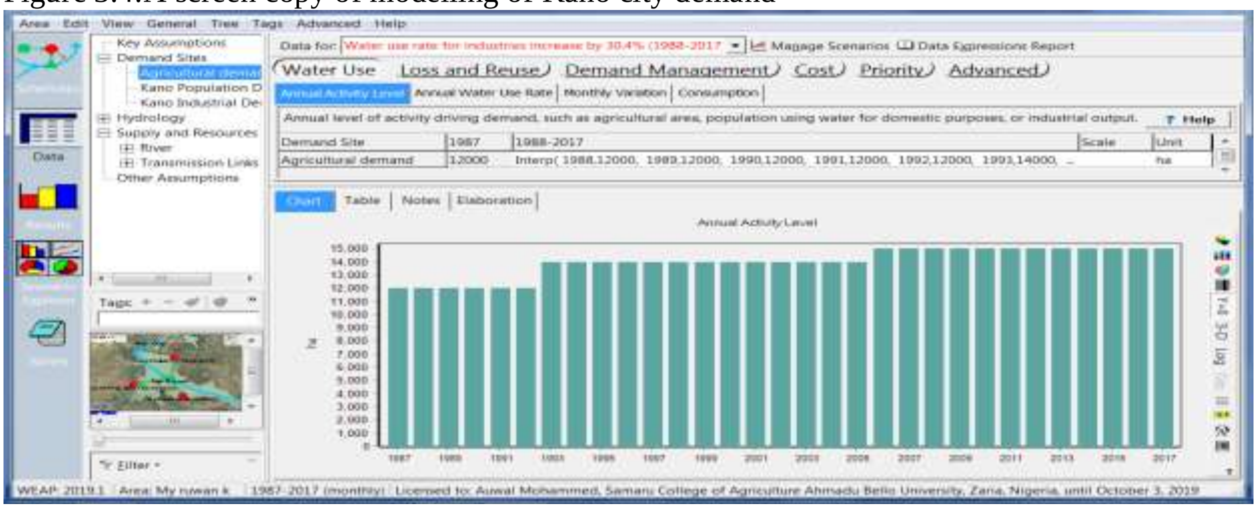

Figure 3.5:The Schematic representation of modelling of agricultural demand

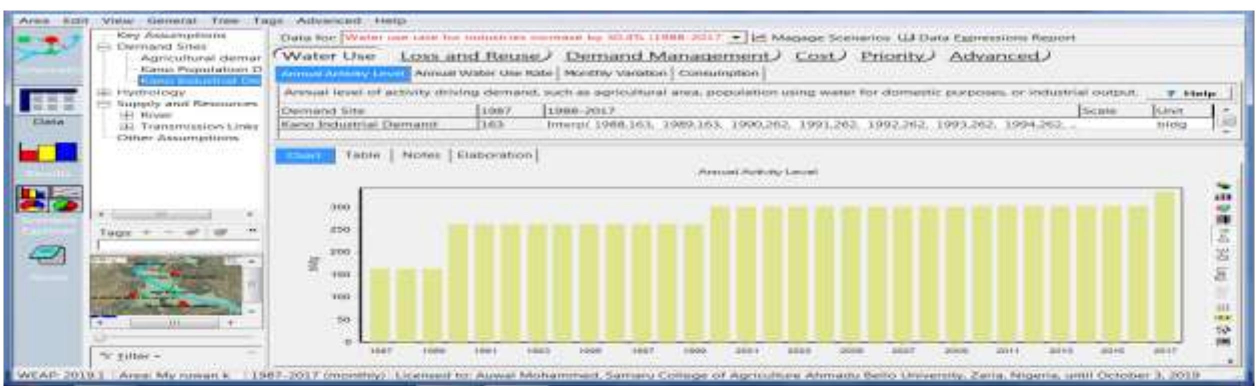

Figure 3.6:The Schematic representation of modelling of industrial demand

3.3.4Water Year Method

For careful examination of the water resources potential of Tiga Dam, all the information of the watershed and demand points for modelling optimal water resources allocation process are represented in the figures 3.3-3.6. Rainfall data were used to computewater year type as shown in Table 3.3, Figure 3.7 and Figure 3.8.

Table 3.3: Analysis of water year type for reference account

Years	Rain fall(mm)	Water year value	Year type	Net evaporation (mm)	Observe volume (Mm^3)
1987	461.6	0.567307062	Very dry		
1988	967.9	1.189550489	Wet	3130	1800
1989	588.7	0.723513145	Very dry	3737	1500
1990	594.4	0.730518453	Very dry	3543	1260
1991	904.8	1.112000498	Normal	3092	1600
1992	944.9	1.161283456	Wet	2922	1590
1993	802	0.985659151	Normal	2995	1240
1994	819.2	1.006797976	Normal	3377	1700
1995	573.3	0.704586523	Very dry	4320	1100
1996	700.8	0.861284206	Dry	4809	1250
1997	661.8	0.81335315	Very dry	4801	1200
1998	1153.7	1.417898956	Very wet	4299	1850
1999	716.6	0.880702428	Dry	4670	1300
2000	922.6	1.133876724	Normal	4686	1600
2001	981.3	1.206019108	Wet	4208	1500
2002	502.7	0.617819021	Very dry	5386	1100
2003	882.63	1.084753537	Normal	4069	1400
2004	760.8	0.935024292	Dry	1890	1350
2005	926.7	1.13891563	Normal	1621	1500
2006	922.4	1.133630924	Normal	1542	1450
2007	611.3	0.751288577	Very dry	3236	1200
2008	729.9	0.897048147	Dry	1928	1260
2009	747.2	0.918309872	Dry	1716	1300
2010	970.8	1.193114593	Wet	1785	1600
2011	771.5	0.948174607	Normal	4001	1250
2012	936.2	1.150591144	Wet	2269	1400
2013	1007.6	1.238341846	Wet	2266	1500

2014	849.28	1.043766339	Normal	3031	1260
2015	825.3	1.014294884	Normal	2786	1200
2016	1003.4	1.23318004	Wet	2595	1650
2017	982.42	1.20739559	Wet	2273	1350
Average	813.6687				

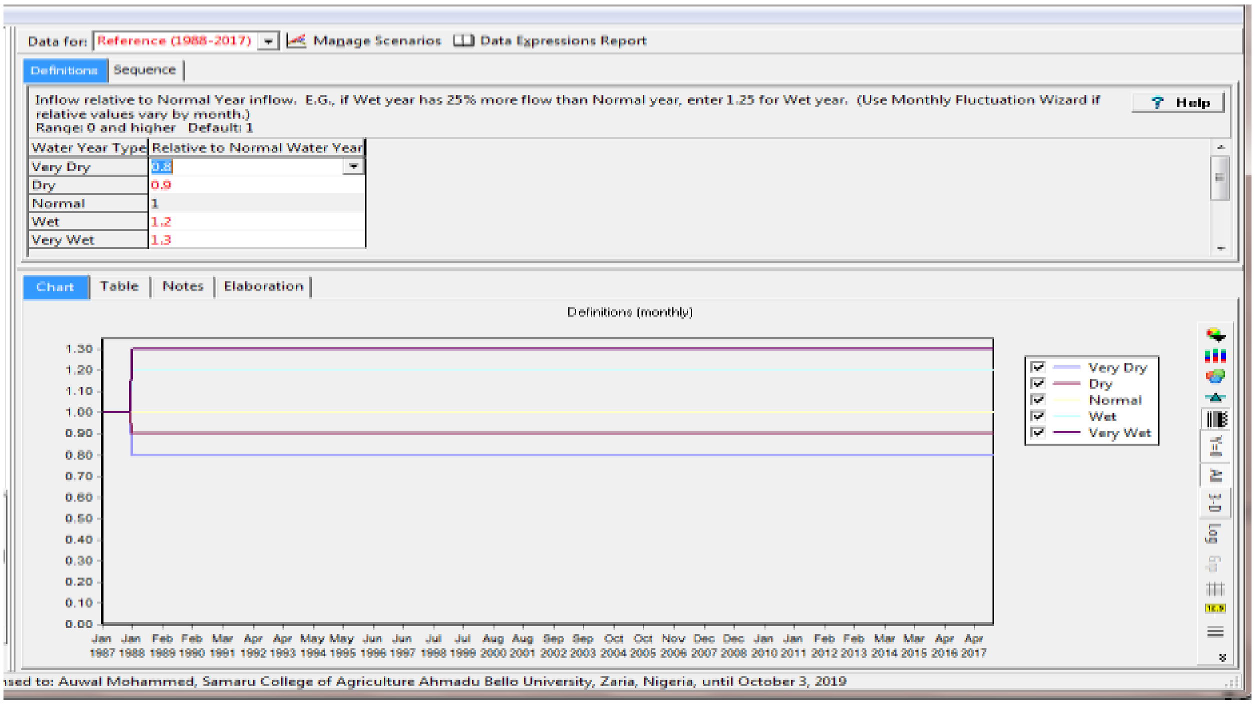

Figure 3.7: Description of water year type for reference account

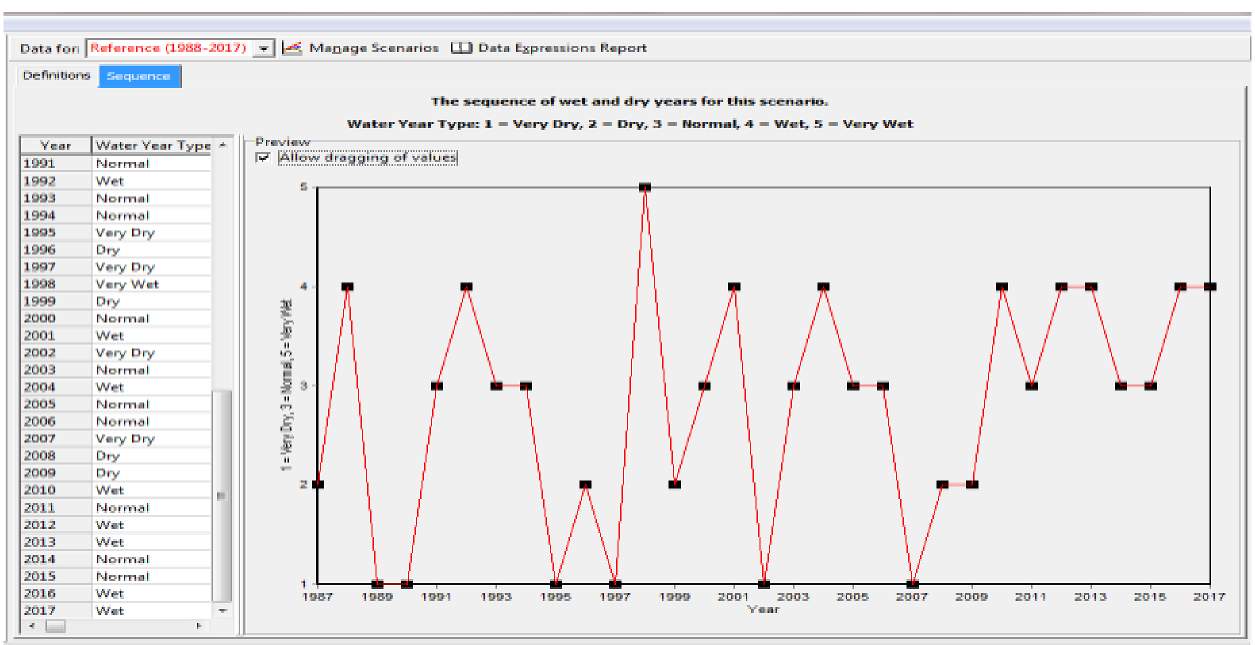

Figure 3.8: Water year sequence for reference account.

Water year method is a sub-division under Rainfall Runoff Method (Simplified Coefficient Method) which has the following simulation algorithm as shown in Equation 3.1 to 3.5

$PrecipAvailableForET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * PrecipEffective_{LC}$……..3.1

$ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5}$……………………..….3.2

$PrecipShortfall_{LC,I} = \text{Max}\ (0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I})$…..3.3

$SupplyRequirement_{LC,I} = (1 / IrrFrac_{LC,I}) * PrecipShortfall_{LC,I}$……………..…3.4

$SupplyRequirement_{HU} = \sum_{LC,I} SupplyRequirement_{LC,I}$…………………………..3.5

Where subscripts LC= land cover, HU = hydro-unit, and I = irrigated

3.3.5 Model Calibration and Validation

Assessment of model performance is very important because itprovide a quantitative estimate of the model's ability to mimic the modelled case study. It provide a means for improvements of the model calibration through adjustment of model parameters, andto compare current modelling efforts with previous relevant studies.The calibration was done by manual check of the model simulated versus observed net evaporation value shown in Table 4.11 to ascertain the accuracy of the output.

The model was validated by comparing observed versus simulated net evaporation value of the catchment. This is to ensure model performance. Coefficient of determination (R^2), and Nash-Sutcliffe efficiency (NCE) were used in evaluating the model validation performance. However, the R^2 and NCE models used are shown as follows;

i- Correlation Coefficient(R^2):

The range of R^2 lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction. A value of zero means no correlationat all whereas a value of 1 means that the dispersionof the prediction is equal to that of the observation. The R^2 value is computed using equation 3.6.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})(Q_{sim,i} - \bar{Q}_{sim})}{\sqrt{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})^2}\sqrt{\sum_{i=1}^{n}(Q_{sim,i} - \bar{Q}_{sim})^2}}\right]^2 \qquad (3.6)$$

Where, $Q_{obs,I}$= observed value, Q_{obs}= mean of the observed value,$Q_{sim,I}$= simulated value, Q_{sim}= meanof observed value, n = number of observations.

ii- Nash-Sutcliffe coefficient of efficiency (*CE*).

The Nash-Sutcliffe coefficient of efficiency indicates how well the plot of observed versussimulated value fits the 1:1 line and is commonly used in hydrologic model evaluations. If themeasured variable is estimated most accurately by the model, then CE = 1; If the CE is negative,the quality of the model results is smaller than the average value of the measured variables (Nash and Sutcliffe 1970).

$$CE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs,i})^2} * 100\% \qquad (3.7)$$

Samuel*et al*. (2019) further classify Nash-Sutcliffe coefficient of efficiency accuracy in Table 3.4 and the model equation is shown in equation 3.7.

Where: CE is the Nash-Sutcliffe coefficient of efficiency; $Q_{obs,i}$ is the observed discharge at the time step i, $Q_{obs,i}$is the mean of the observed discharge; $Q_{sim,i}$ = the simulation discharge at the time step I, and n is the number of observations.

Table 3.4: Nash Sutcliffe efficiency rating

Nash Sutcliffe Efficiency	Rating
0.75 < NS ≤1.0	Very good
0.65 < NS ≤ 0.75	Good
0.50 < NS ≤ 0.65	Satisfactory

Source: Samuel*et al*. (2019)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Initial Analyses of Past and Present Water Demands and Supply

4.1.1 Water demand

Figure 4.1 showsthe schematic diagram of the demand side for different demands (water supply, agricultural and industrial). This Figure was developed from Table 4.1, it was observed from the Table and the Figure that agricultural sector had the highest water demand from 1987 to 2008 than the other two sectors (water supply and industrial).This is because of the increase in irrigation area and the amount of water demand for irrigationincrease comparedto otherstwo. From the Figure, agricultural sector has three stage of water demand as a result of increase of irrigation area 1987 to 1992,1993 to 2002 and 2003 to 2017. Therefore each stage resulted into an increase in demand for water.

Kano population also experienced rapid increase in two periods, from 1987 to 2008 and from 2009 to 2017. The annual variation of water consumption is due to growth rate and consumption per capital, while industrial sector had the least water demand among the three because of low industrial growth. Figures 4.2, 4.4 and 4.6 show the schematics of the demands discussed above.

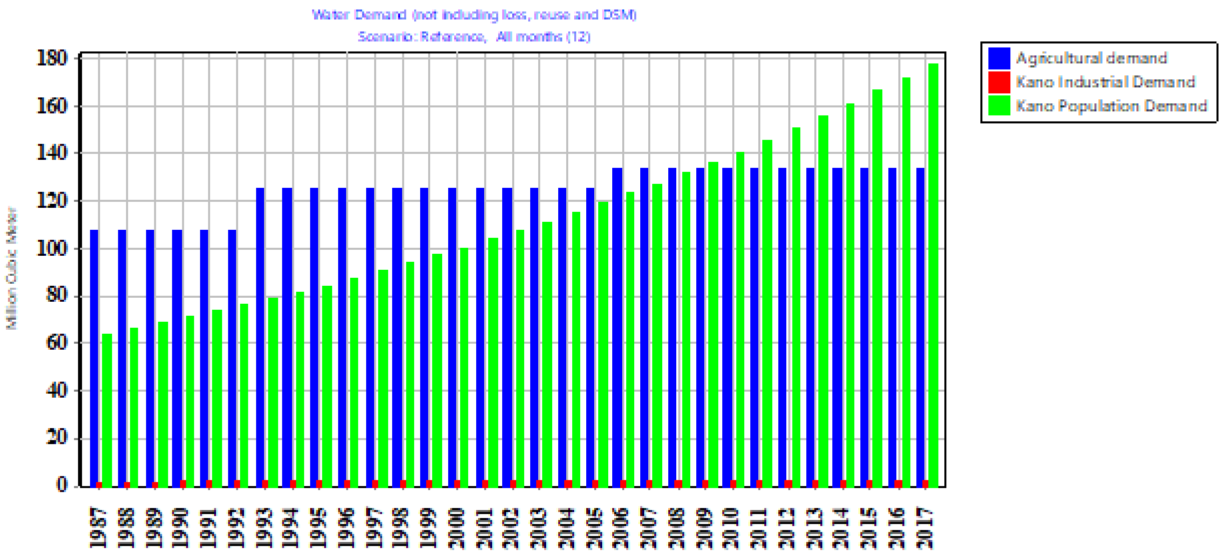

Figure 4.1: Water demand for entire purposes

4.1.1.1 Water Demand for Agricultural Purpose

Figure 4.2 represents the yearly water demand for agricultural practices while Figure 4.3 shows the annual water demand scenario (per hectare application is increase by 33.9% from 1987 to 2017) considering higher water demand from 2006 to 2017.

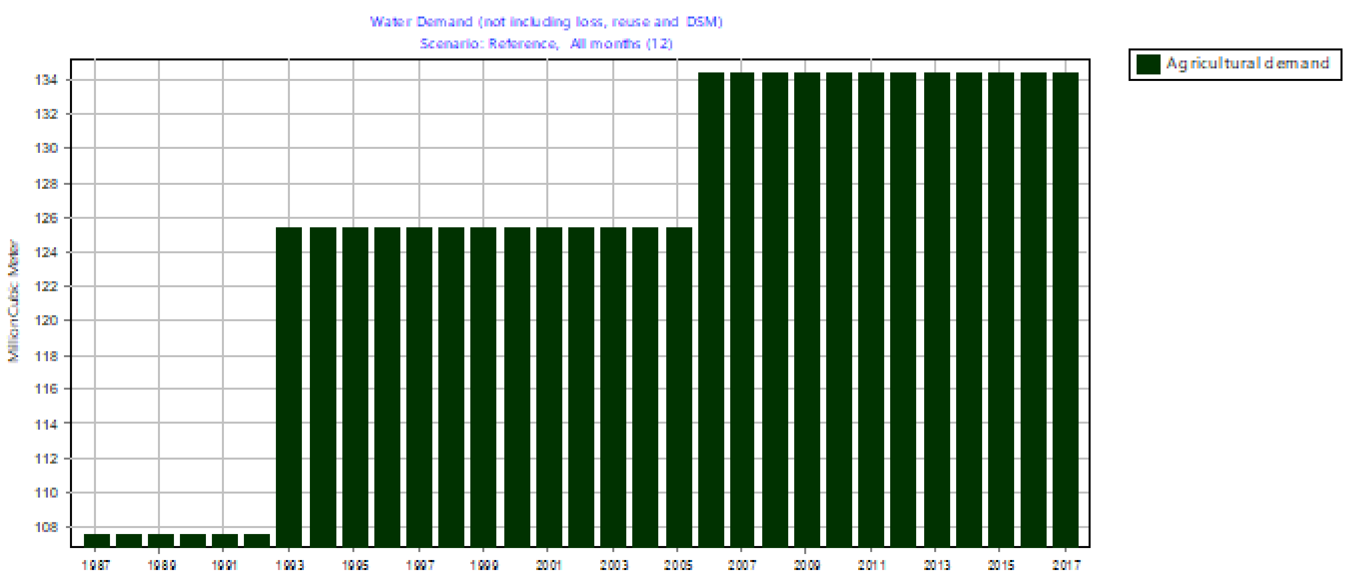

Figure 4.2: Water demand for agricultural purpose

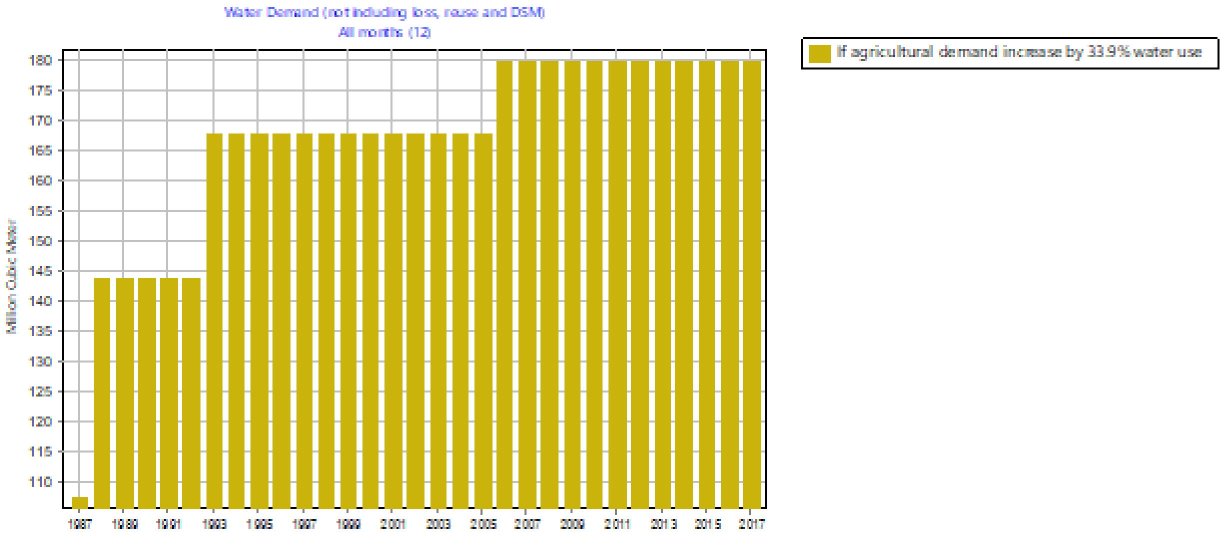

Figure 4.3: Scenario water demand for agricultural purpose

4.1.1.2 Water Demand for Kano population

Figure 4.4 shows past annual water demand and Figure 4.5 is yearly water requirement scenario in which consumption per capital increase by 14.3%, likewise the figures show pattern of annual water demand of Kano population from 1987 to2017.

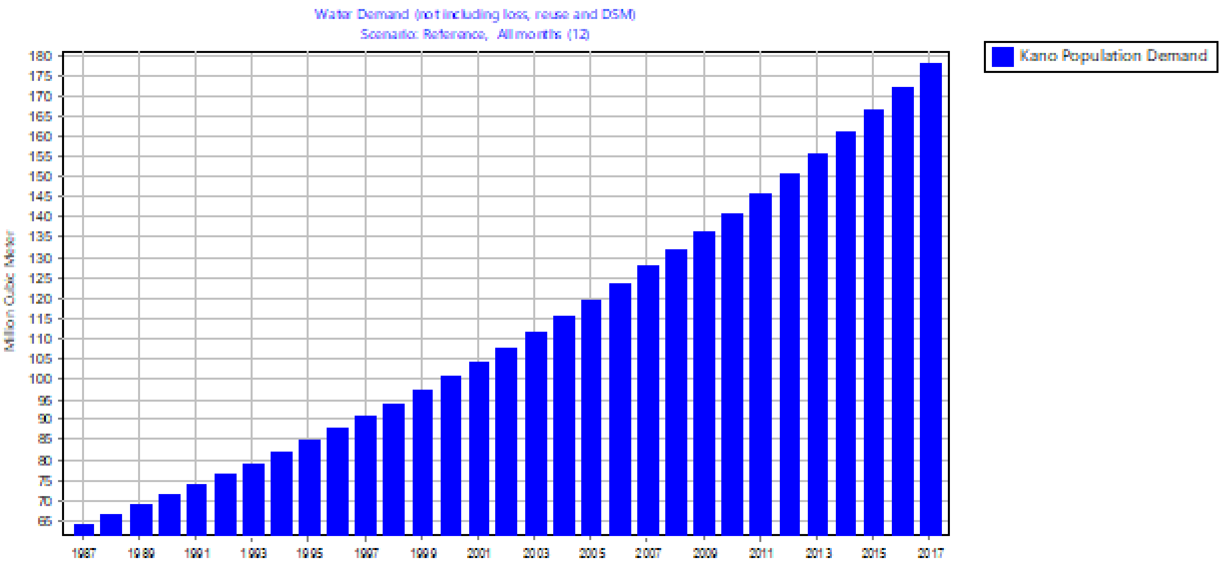

Figure 4.4: Water demand for Kano city population

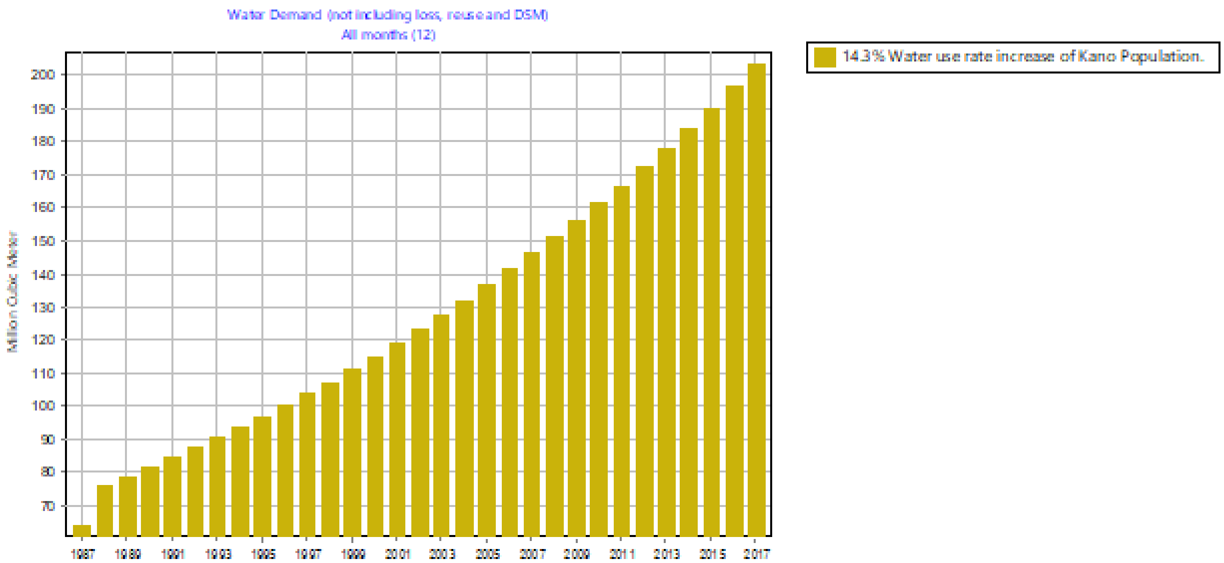

Figure 4.5: Scenario water demand for Kano city population

4.1.1.3 Water Demand for Kano Industries

Figure 4.6 represents industrial water demand while Figure 4.7 shows the Kano industrial water demand scenario with 30.4% increase from 1987 to 2017.

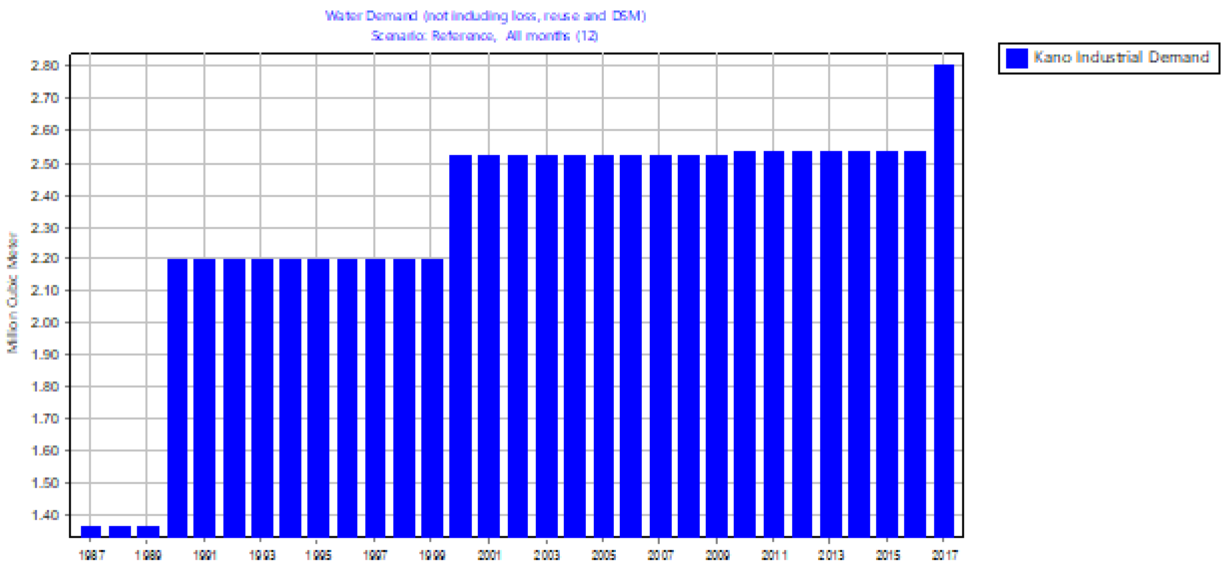

Figure 4.6: Industrial water demand

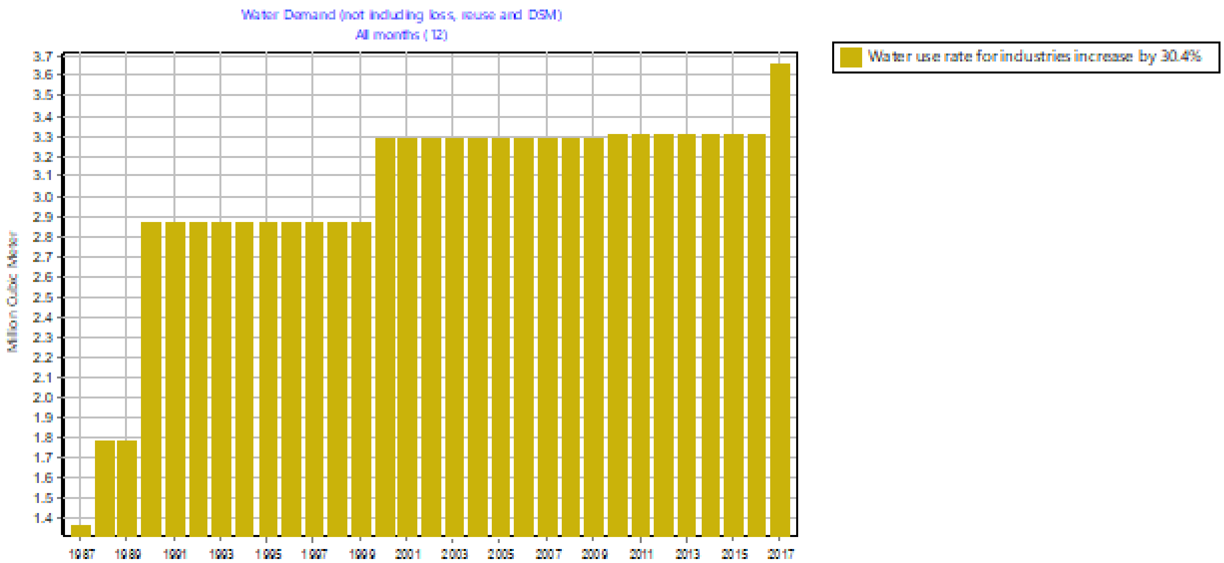

Figure 4.7: Scenario Kano industrial water demand

Furthermore, Table 4.1 summarizes the entire water demand for different purposes and including all the scenarios, in which agricultural demand has annual average of 126 Mm^{3}., Agricultural scenario has annual average of 166.8 Mm^{3}, water supply has annual average of 112.7 Mm^{3}and population scenarios has annual average of 128.4 Mm^{3}. However industrial demand has annual average of 2.3 Mm^{3} with industrial scenario of 3 Mm^{3}.

The model performance was excellent as it was in good agreement with the result obtained by Bello and Tuna (2014) in their studies. That total water demand of Kano state is 975 million liters per day (Mld) which is equivalent to 355.1 million cubic meter per year (Mm^{3}/yr). Similarly, for the water supply(population) demand from Tiga Dam is 118 million cubic meter per year (Mm^{3}/yr).This research found that Kano city demanded 178 Mm^{3}/yr with annual average of 128.4 Mm^{3} as shown in Table 4.1. It is good to know that Bello and Tuna (2014) only consider domestic supply water while current research consider domestic, agricultural, industrial and hydropower generation demands.

Table 4.1 Summary of water demand for different purposes and all scenarios

Years	Agricultural demand **(Mm^3)**	Kano population demand **(Mm^3)**	Kano industrial demand **(Mm^3)**	Scenarios water demand **(Mm^3)**		
				Agricultural	Kano population	Kano industrial
1987	108	64	1.4	108	64	1.4
1988	108	67	1.4	144	77	1.8
1989	108	69	1.4	144	79	1.8
1990	108	72	2.2	144	82	2.9
1991	108	74	2.2	144	85	2.9
1992	108	77	2.2	144	88	2.9
1993	126	79	2.2	168	91	2.9
1994	126	82	2.2	168	94	2.9
1995	126	85	2.2	168	97	2.9
1996	126	88	2.2	168	101	2.9
1997	126	91	2.2	168	104	2.9
1998	126	94	2.2	168	108	2.9
1999	126	97	2.2	168	111	2.9
2000	126	101	2.5	168	115	3.3
2001	126	104	2.5	168	119	3.3
2002	126	108	2.5	168	123	3.3
2003	126	112	2.5	168	128	3.3
2004	126	116	2.5	168	132	3.3
2002	126	120	2.5	168	137	3.3
2006	135	124	2.5	180	141	3.3
2007	135	128	2.5	180	146	3.3
2008	135	132	2.5	180	151	3.3
2009	135	137	2.5	180	156	3.3
2010	135	141	2.5	180	161	3.3
2011	135	146	2.5	180	167	3.3
2012	135	151	2.5	180	172	3.3
2013	135	156	2.5	180	178	3.3
2014	135	161	2.5	180	184	3.3
2015	135	167	2.5	180	190	3.3
2016	135	172	2.5	180	197	3.3
2017	135	178	2.8	180	203	3.7
Average	126	112.7	2.3	166.8	128.4	3

4.1.2 Water Supplied

Figure 4.8 represent water supplied for all purpose while which shows that the dam met the demand for all purposes in the past (from 1987 to 2017).

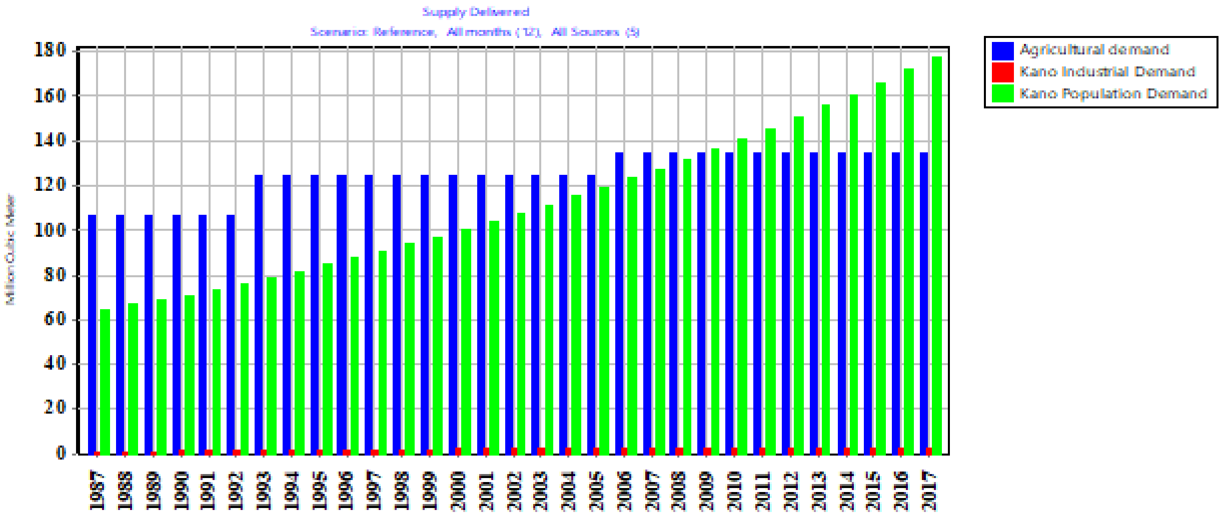

Figure 4.8: Water supplied for all purposes

Table 4.2 present the result of all the demands in the previous years (1987 to 2017) in Tiga Dam. It can be understood from the result obtained that agricultural sector has highest supplied because of highest demandedof water out of the three sector the least was industrial demand due to low industrial growth. The Table 4.1 and 4.2 results show that the dam served the need of different purposes including all the scenarios (as a result of zero water deficit) from 1987 to 2017.

Table 4.2 summary of water supplied for different purposes and all scenarios

Years	Agricultural supplied **(Mcm)**	Kano population supplied **(Mcm)**	Kano industrial supplied **(Mcm)**	Scenarios water supplied **(Mcm)**		
				Agricultural	Kano population	Kano industrial
1987	108	64	1.4	108	64	1.4
1988	108	67	1.4	144	77	1.8
1989	108	69	1.4	144	79	1.8
1990	108	72	2.2	144	82	2.9
1991	108	74	2.2	144	85	2.9
1992	108	77	2.2	144	88	2.9
1993	126	79	2.2	168	91	2.9
1994	126	82	2.2	168	94	2.9
1995	126	85	2.2	168	97	2.9
1996	126	88	2.2	168	101	2.9
1997	126	91	2.2	168	104	2.9
1998	126	94	2.2	168	108	2.9
1999	126	97	2.2	168	111	2.9
2000	126	101	2.5	168	115	3.3
2001	126	104	2.5	168	119	3.3
2002	126	108	2.5	168	123	3.3
2003	126	112	2.5	168	128	3.3
2004	126	116	2.5	168	132	3.3
2002	126	120	2.5	168	137	3.3
2006	135	124	2.5	180	141	3.3
2007	135	128	2.5	180	146	3.3
2008	135	132	2.5	180	151	3.3
2009	135	137	2.5	180	156	3.3
2010	135	141	2.5	180	161	3.3
2011	135	146	2.5	180	167	3.3
2012	135	151	2.5	180	172	3.3
2013	135	156	2.5	180	178	3.3
2014	135	161	2.5	180	184	3.3
2015	135	167	2.5	180	190	3.3
2016	135	172	2.5	180	197	3.3
2017	135	178	2.8	180	203	3.7
Average	126	112.7	2.3	166.8	128.4	3

4.1.3 Past Hydropower Generated

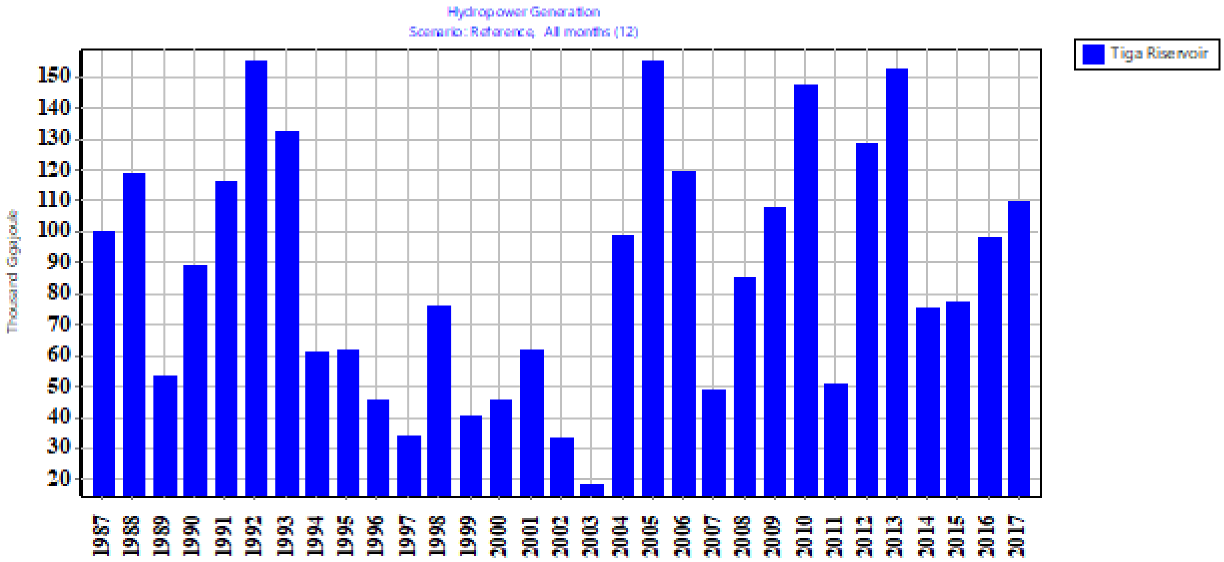

Figure 4.9: Annual hydropower generated

From Figure 4.9 it can be observed that the annual fluctuation of hydropower generated is as a result of released to turbines which depend on amount of water discharge to downstream, volume of water in the reservoir and tail water elevation. The reservoir was able to generate annual average of 87 thousand gigajoule (GJ) in the past (from 1987-2017). This reservoir met annual power demand because of zero unmet annual hydropower generated.

Figure 4.10 show average monthly hydropower generated, the lowest hydropower generated is 1.7 thousand GJ in February and the highest was 14.8 thousand GJ generated. The result agree with the historical runoff and rainfall occurring in northern Nigeria.

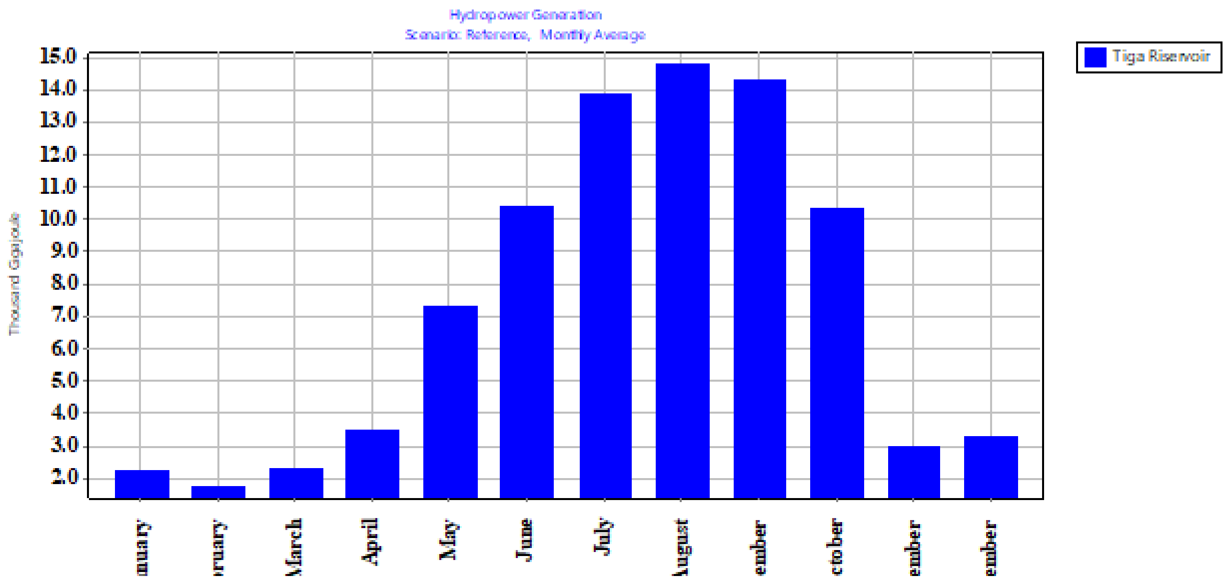

Figure 4.10: Monthly hydropower generated

4.2 Future Water Demand to Different Purposes and scenarios

Figure 4.11represents the projected water demand for different purposes, agricultural sector has highest water demand from 2026 to 2050, follow by water supply and finally industrial demand.

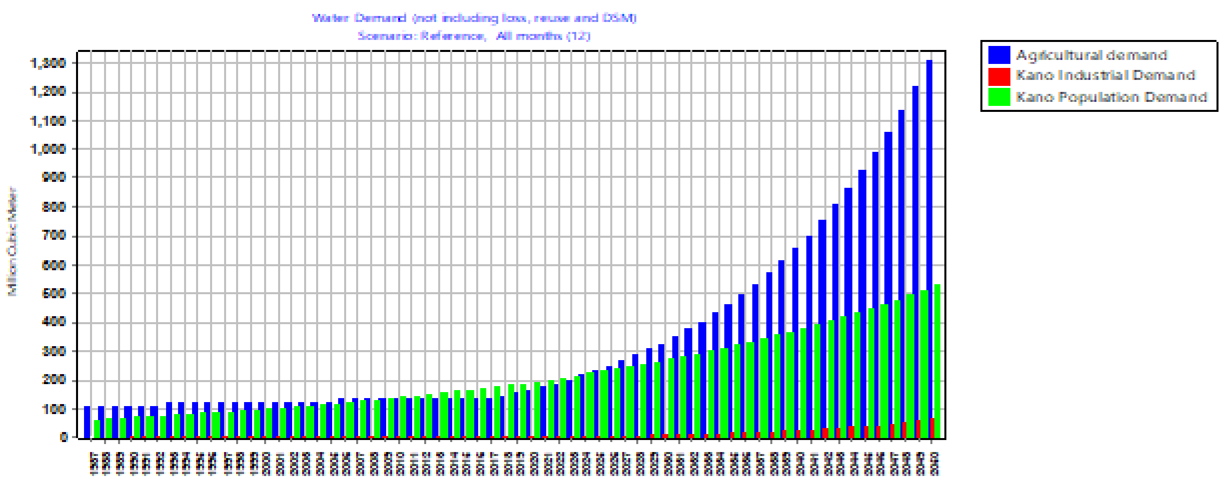

Figure 4.11: Future water demand for entire purposes

4.2.1Future Agricultural Water demand

Figure 4.12 represents future water demand to agricultural purpose from 2018 to 2050 whereas increase of irrigation area is a leading factor of the annual increase of water demand. Figure

4.13shows the future scenario of agricultural water demand per hectare with an increase of 33.9% as a result, water demand is more than annually agricultural water demand.

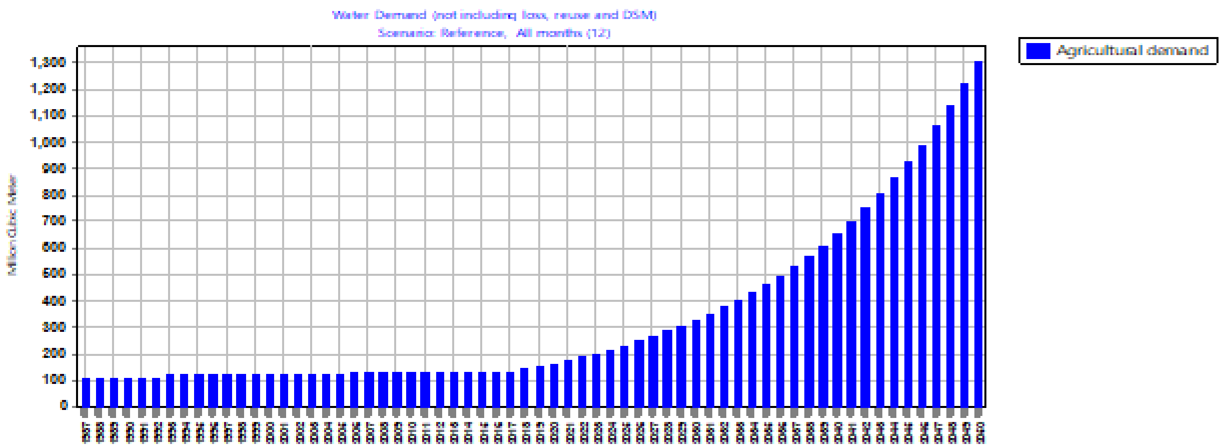

Figure 4.12: Future agricultural water demand

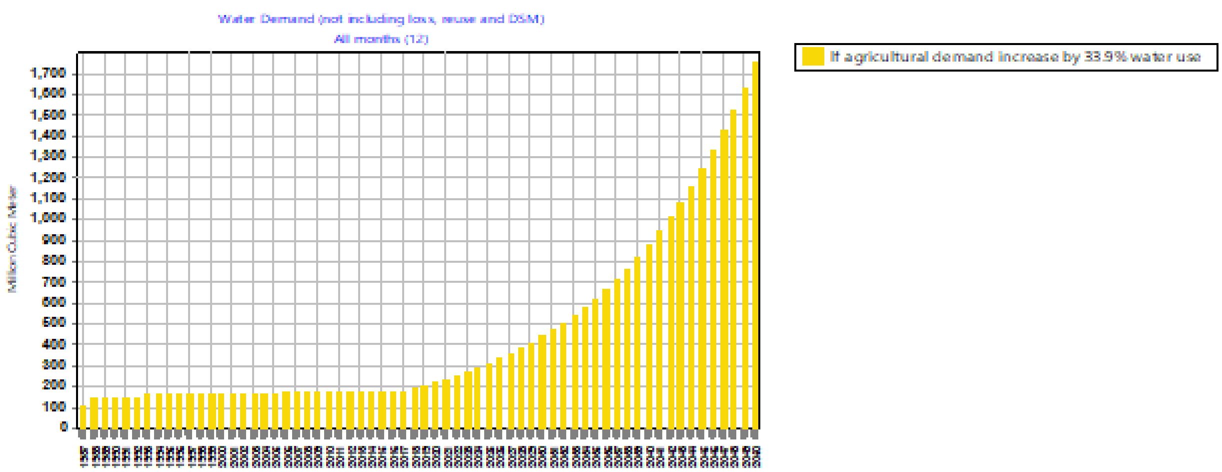

Figure 4.13: Future scenario water demand for agricultural purpose

4.2.2 Future Kano City Water Demand

The projected domestic water demand for water supply in Kano City from 2018 to 2050 increases periodically as a result of rapid population growth and consumption per capital as shown in Figure 4.14. The water demand for this purpose is less than that of future scenario demand present in Figure 4.15because of difference in per capital consumption.

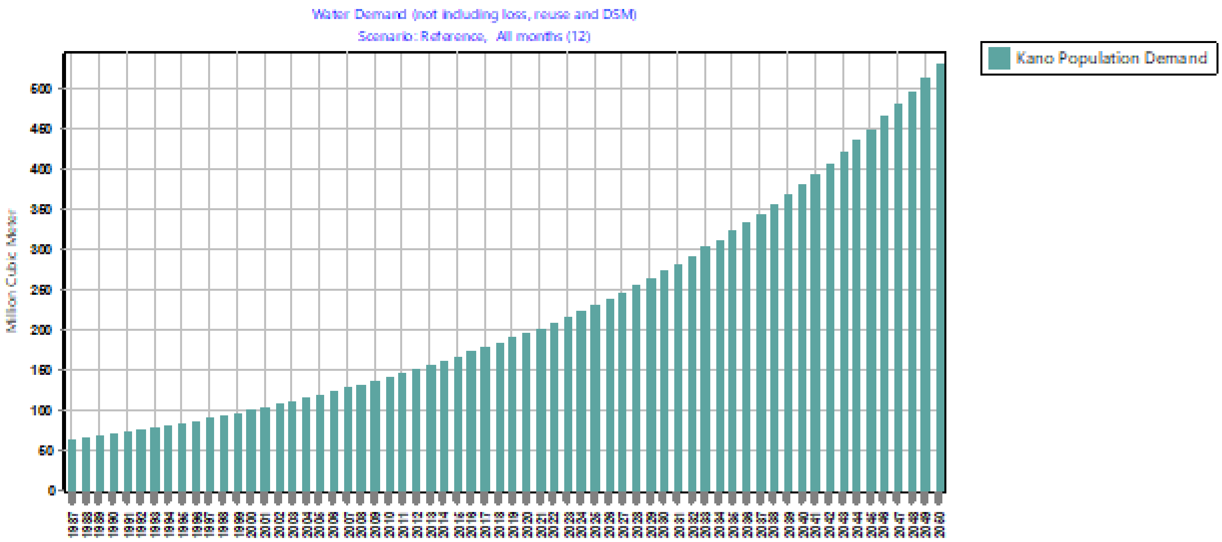

Figure 4.14: Future Kano population water demand

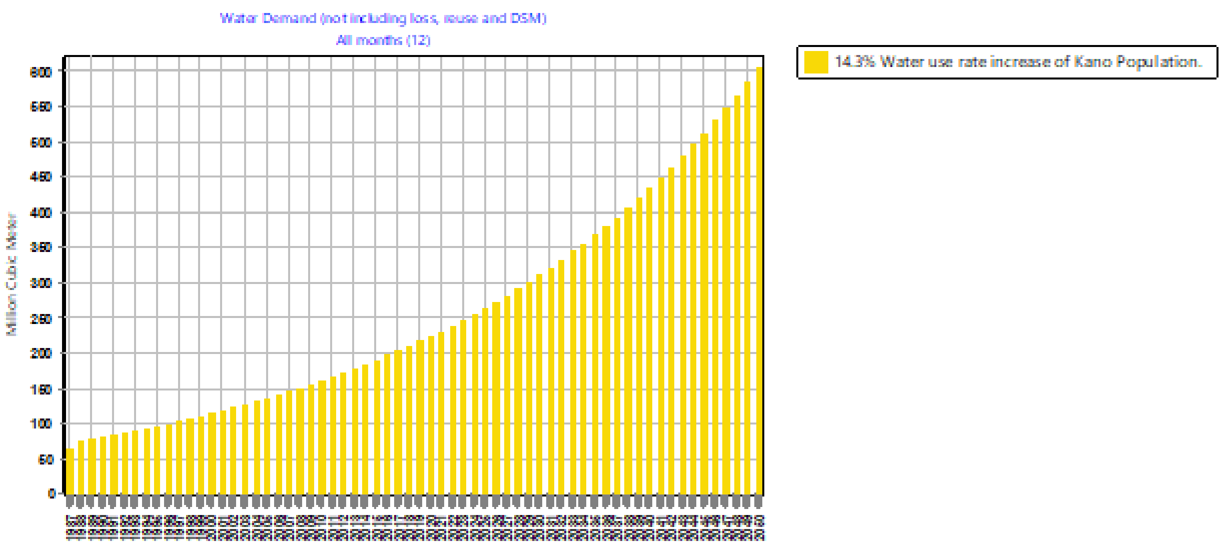

Figure 4.15: Future scenario Kano population water demand

4.2.3 Future Kano Industries Demand

As a result of low industrial density and poor industries growth the future water demand for industrial sector is low compare to other demands. Also when compared with Figure 4.16 and 4.17 there are variation of annual water demand from 2018 to 2050.

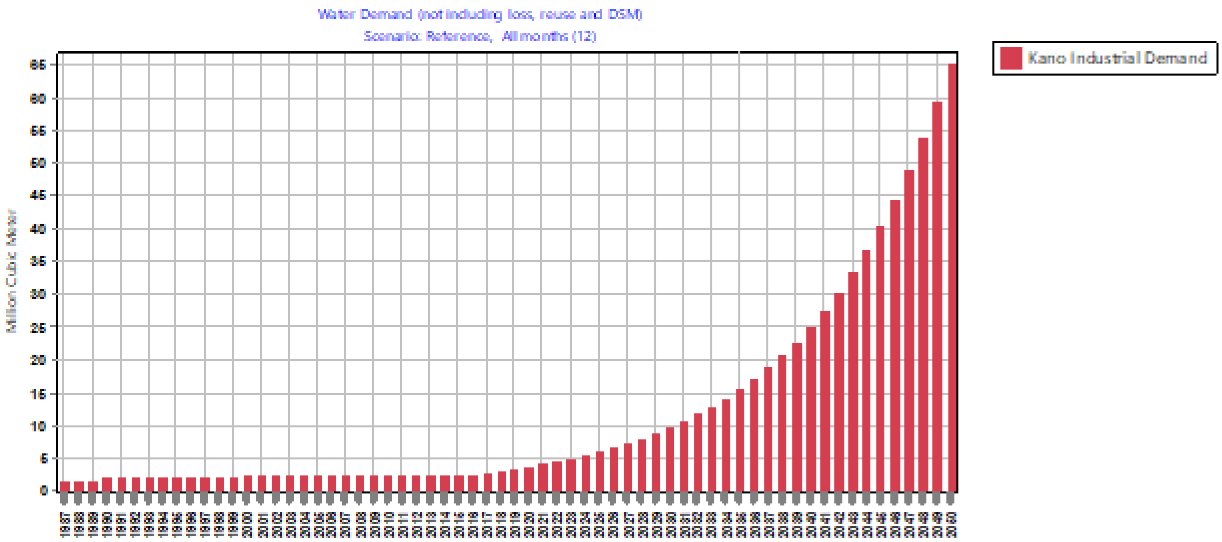

Figure 4.16: Future annual Kano industries demand

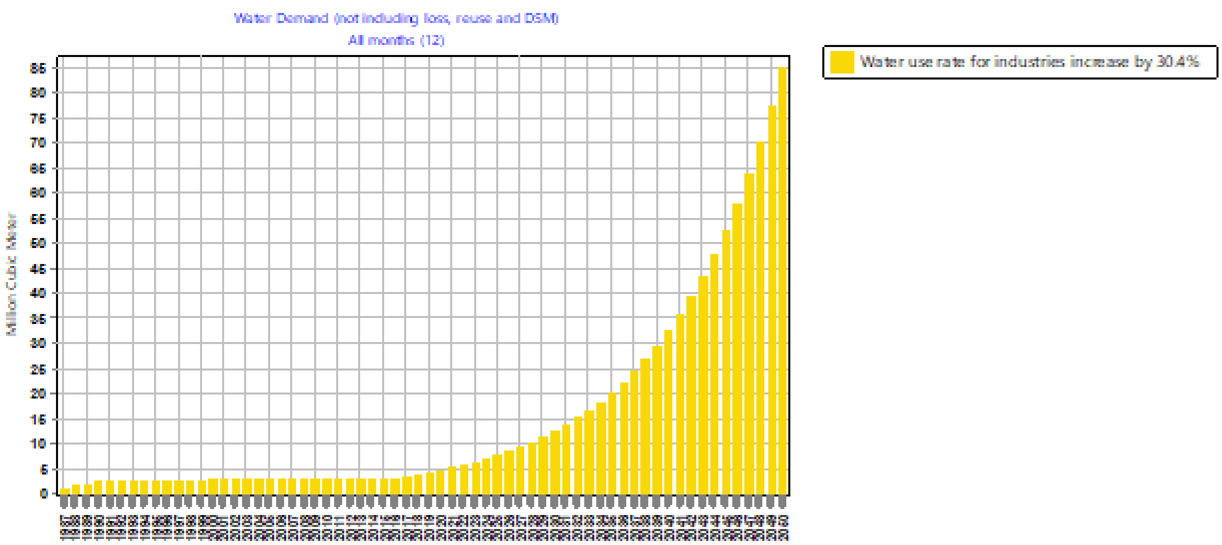

Figure 4.17: Scenario Kano industrial water demand

Table 4.3 summarizes different projected scenarios for water demand, as observed is more than the required demand. It was observed from the Table 4.3 that agricultural sector has annual average demand of 534.1 Mm^3 in the future water supply for Kano has yearly average of 327.9 Mm^3 and industrial sector has annual average of37 Mm^3 from 2018 to 2050. Figure 4.11 to 4.17 represent the results obtained in Table 4.3.

Table 4.3 Future water demand for different purposes and all scenarios

Years	Agricultural demand **(Mm^3)**	Kano population demand **(Mm^3)**	Kano industrial demand **(Mm^3)**	Scenarios water demand **(Mm^3)**		
				Agricultural	Kano population	Kano industrial
2018	144	184	3	193	210	4
2019	154	190	3	207	217	4
2020	165	197	4	221	224	5
2021	177	203	4	237	232	5
2022	190	210	5	254	240	6
2023	203	217	5	272	248	7
2024	218	224	6	292	256	7
2025	233	232	6	313	265	8
2026	250	240	7	335	274	9
2027	268	248	7	359	283	10
2028	287	256	8	384	293	10
2029	308	265	9	412	302	12
2030	330	273	10	441	313	13
2031	353	283	11	473	323	14
2032	378	292	12	507	334	15
2033	405	302	13	543	345	17
2034	434	312	14	581	357	19
2035	465	323	16	623	369	20
2036	499	333	17	667	381	22
2037	534	345	19	715	394	25
2038	572	356	21	766	407	27
2039	613	368	23	821	421	28
2040	657	381	25	879	435	33
2041	704	393	28	942	450	36
2042	754	407	30	1009	465	40
2043	808	420	33	1082	480	44
2044	866	434	37	1159	496	48
2045	927	449	40	1241	513	53
2046	994	464	45	1330	530	58
2047	1064	480	49	1425	548	64
2048	1140	496	54	1527	566	70
2049	1222	512	59	1636	586	77
2050	1309	530	65	1753	605	85
Average	534.1	327.9	20.6	715.1	374.6	27.1

4.3 Future Water Supply for Different Purposes and Scenarios

Tiga Dam is capable of supplying sufficient amount of water annually considering future demands and scenarios(2018 to 2050) and with unmet demandsas presented in Figures 4.18 to4.29.

Table 4.4 and Table 4.5 were used to produce Figures 4.18 to 4.29, it can also be observed from the table that annual average volume of water allocated to agriculture is 410.5 Mm^3 for agriculture scenario is 658.8 Mm^3, Kano population is 266.3 Mm^3 with 301.8 Mm^3 for scenario and industries is 15.5 Mm^3 with 20.1 Mm^3 for scenario.

In general we can observe from the two Tables that Tiga Dam alone can't meet the demand for all purposes from 2031. The resultsshow that it is in consistent with the result obtained by Bello and Tuna(2014) who found that Kano has 36% water deficit andDaniyal*et al.* (2017)also show that, if the population, industrial and agricultural sectors continue to grow, by 2050 there would be water shortage in the study area. Similarly Yunana*et al.*(2017)stated that additional pressure would be imposed on water availability, water accessibility and water demand in Africa because population in Sub-Sahara Africa is expected to increase from 700 million in 2007 to 1.1 billion in 2030 and 1.5 billion by 2050. In general this will to result water crisis couple with hydrological change observed by Matthew (2019) that lead to decrease in reservoir storage.

Table 4.4: Future water supply to different purposes and scenarios

	Future water allocation (Mm^3)			Future scenarios water allocation (Mm^3)		
Years	Agricultural Demand	Kano population demand	Kano industrial demand	Agricultural	Kano population	Kano industrial
2018	144	184	3	193	210	4
2019	154	190	3	207	217	4
2020	165	197	4	221	225	5
2021	177	203	4	237	232	5
2022	190	210	5	254	240	6
2023	203	217	5	272	248	7
2024	218	224	6	292	256	7
2025	233	232	6	313	265	8
2026	250	240	7	335	274	9
2027	268	248	7	359	283	10
2028	287	256	8	384	293	10
2029	308	265	9	412	302	12
2030	330	273	10	438	313	13
2031	346	277	10	453	314	14
2032	368	285	11	4824	322	15
2033	374	279	12	487	315	16
2034	384	277	13	494	311	16
2035	406	281	14	520	317	18
2036	414	277	14	526	311	19
2036	434	280	15	553	315	20
2038	457	285	17	585	321	22
2039	454	273	17	575	307	22
2040	481	278	18	609	313	24
2041	504	281	20	639	317	26
2042	531	286	22	675	323	28
2043	560	291	23	713	328	30
2044	593	297	25	755	336	33
2045	623	302	27	796	341	35
2046	658	307	30	842	348	38
2047	695	313	32	885	355	42
2048	737	320	35	925	363	45
2040	778	326	38	962	370	49
2050	823	333	41	1004	374	53
Average	410.5	266.3	15.5	658.8	301.8	20.2

Table 4.5: Future water deficit to different purposes and scenarios

	Future water deficit(Mm^3)			Future scenarios water deficit (Mm^3)		
Years	Agricultural demand	Kano population demand	Kano industrial demand	Agricultural	Kano population	Kano industrial
2018	0	0	0	0	0	0
2019	0	0	0	0	0	0
2020	0	0	0	0	0	0
2021	0	0	0	0	0	0
2022	0	0	0	0	0	0
2023	0	0	0	0	0	0
2024	0	0	0	0	0	0
2025	0	0	0	0	0	0
2026	0	0	0	0	0	0
2027	0	0	0	0	0	0
2028	0	0	0	0	0	0
2029	0	0	0	0	0	0
2030	0	0	0	3	0	0
2031	8	6	0.2	20	89	0.3
2032	10	8	0.3	25	11	0.4
2033	31	23	1	56	30	1
2034	51	36	2	88	46	2
2035	60	41	2	102	51	3
2036	85	57	3	141	70	4
2036	101	65	4	162	79	5
2038	115	72	4	181	86	5
2039	159	95	6	246	114	8
2040	176	102	7	271	122	9
2041	200	112	8	303	132	10
2042	223	121	9	335	142	12
2043	248	129	10	369	152	13
2044	273	137	12	403	161	15
2045	304	147	13	445	172	17
2046	335	157	15	488	183	20
2047	369	166	17	540	193	22
2048	403	175	19	602	203	25
2040	444	186	21	674	216	28
2050	486	197	24	748	232	32
average	123.7	61.6	5.4	188	75.3	7

4.3.1 Water supply to agriculture and unmet demand

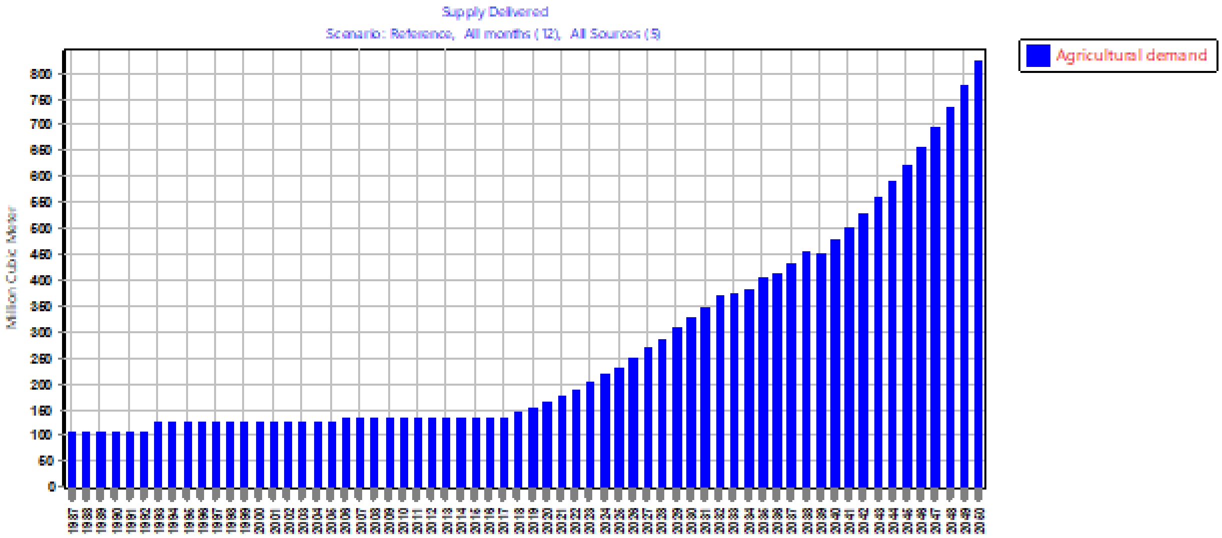

Figure 4.18: Future water allocate to agricultural purpose

Figure 4.18 presented the amount of water in Tiga Dam and its capabilityto supply water for agricultural purpose. The pattern of Figure 4.18 shows that there will be annual increase in water allocation from 2018 to 2034 because of increase of agricultural area, as a result of rainfall variation lead to the annual supply fluctuation from 2034. 33.9% increase per hectare application result to the formation of Figure 4.19 which shows more annual allocation compare with Figure 4.18.

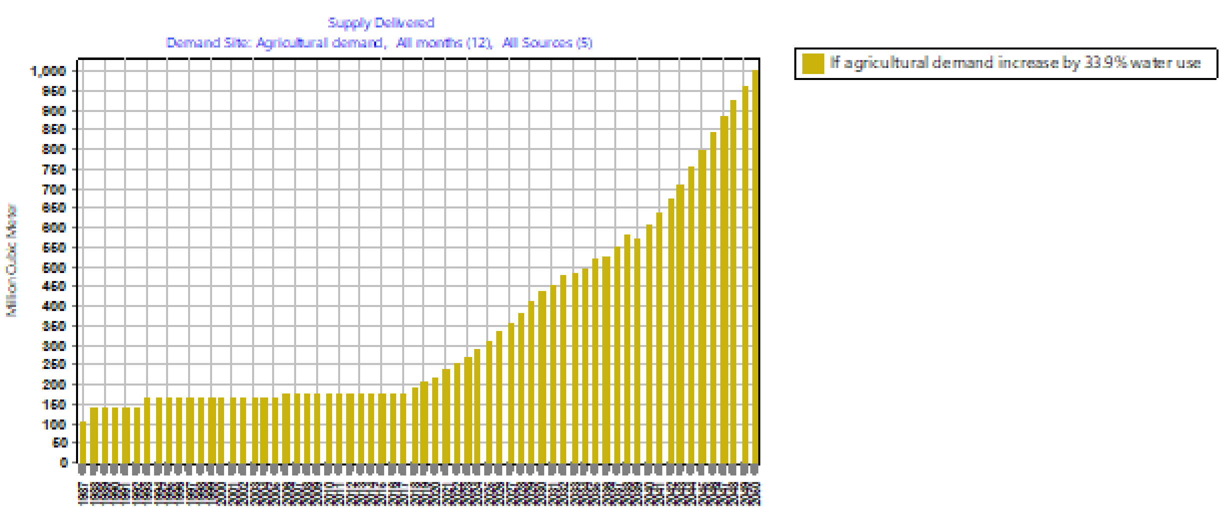

Figure 4.19: Scenario future water allocate to agricultural purpose.

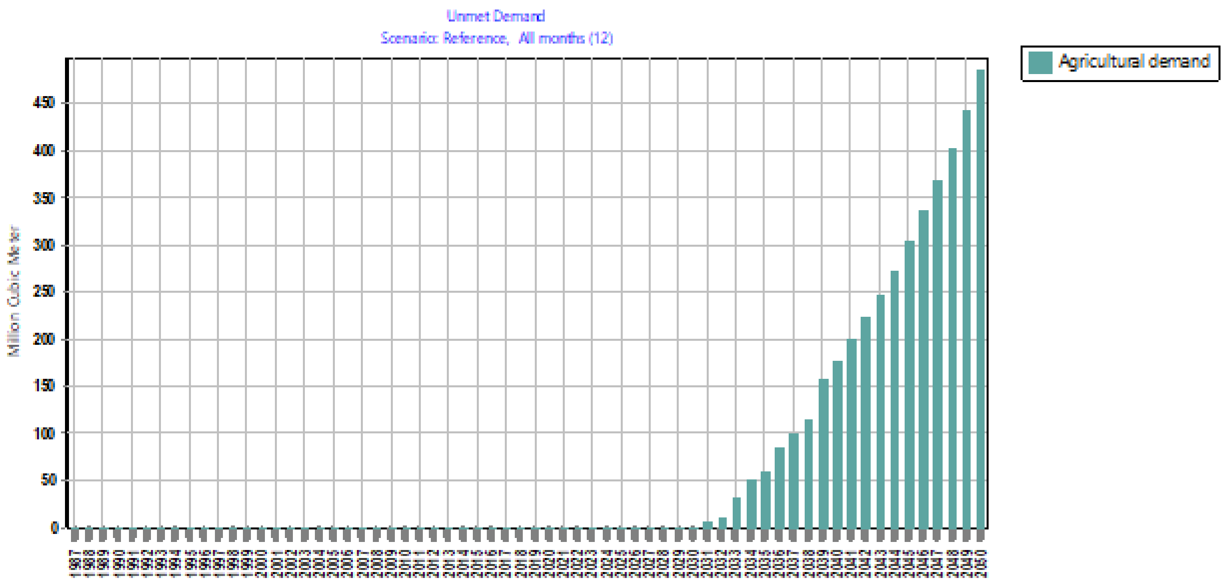

Figure 4.20: Future water deficit for agricultural purpose

Also, Figure 4.20 shows that there will be annual water deficit from 2031 for agricultural purpose but in future agricultural scenario the water deficit will began from 2030 as shown in Figure 4.21.

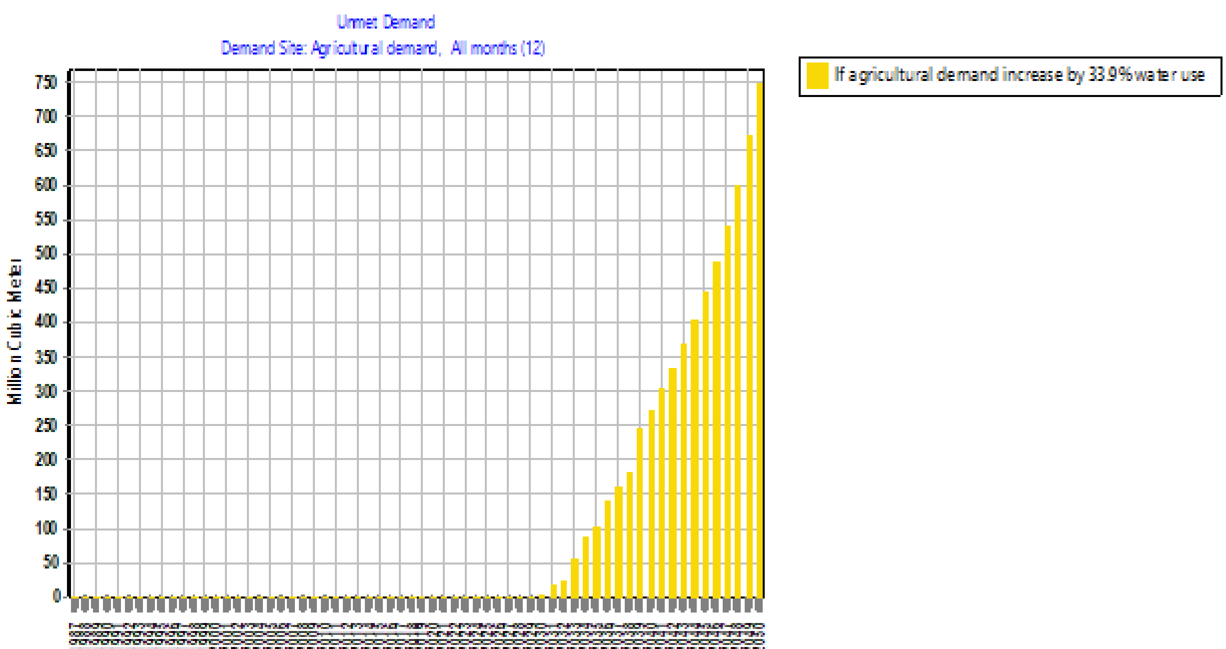

Figure 4.21: Scenario future water deficit for agricultural purpose.

4.3.2 Water Supply to Kano City and Unmet Demand

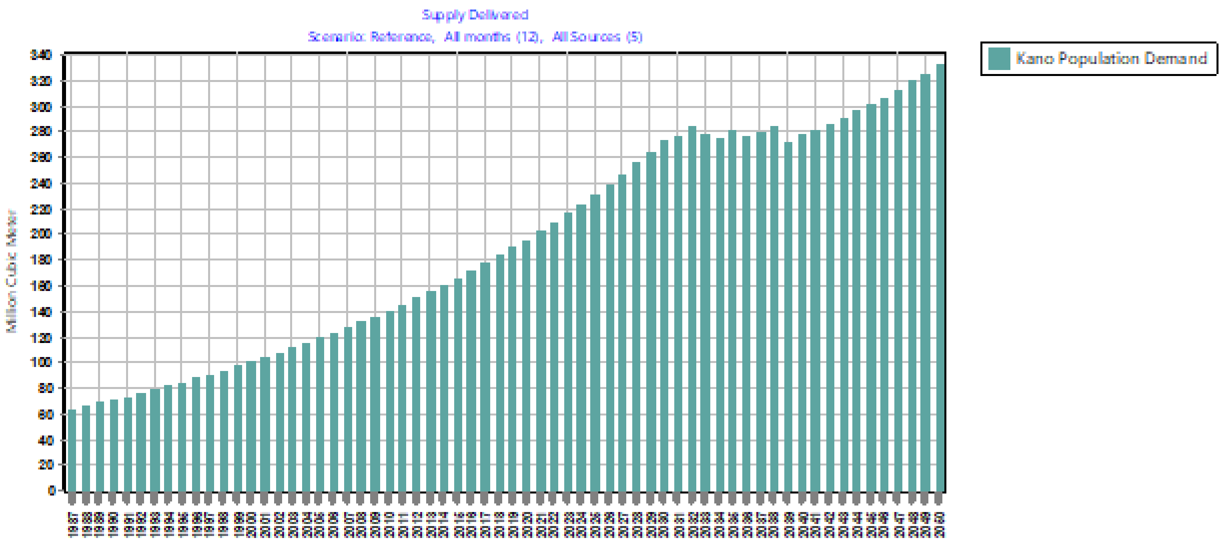

Figure 4.22: Future water allocate to Kano population

Figure 4.22 presents water supply for Kano population while Figure 4.23 present the future scenario for water supply to Kano City. The two Figures indicate the projectedwater supply due to rapid population growth but the pressure is more on future scenario because of increase in per capital as it applied.

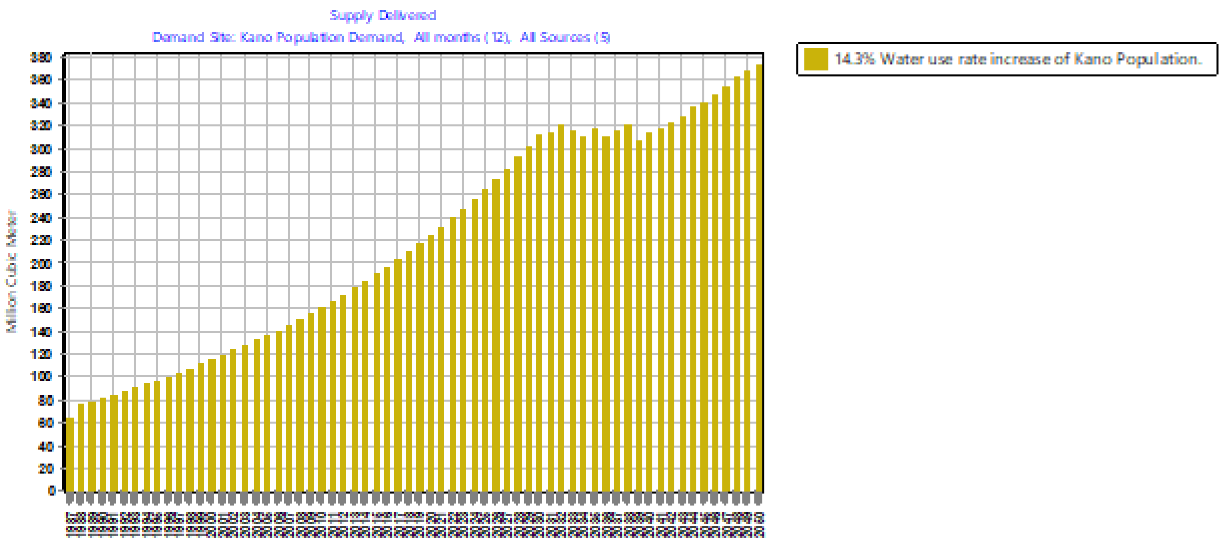

Figure 4.23: Scenario future water allocate to Kano population

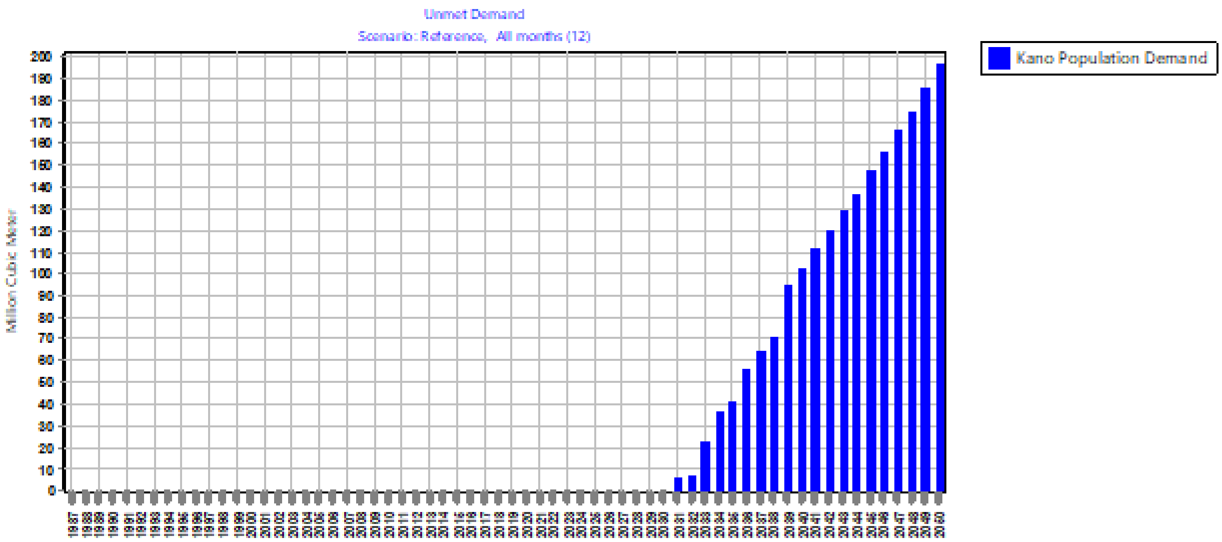

Figure 4.24: Future water deficit to Kano population

Moreover Figure 4.24presents unmet water supply demand while Figure 4.25 shows scenario water deficit. The two Figures show that there will be no satisfied supply from 2031 to 2050 as observed. This is due to the increase in demand on water as a result of rapid population growth and climatic variation.

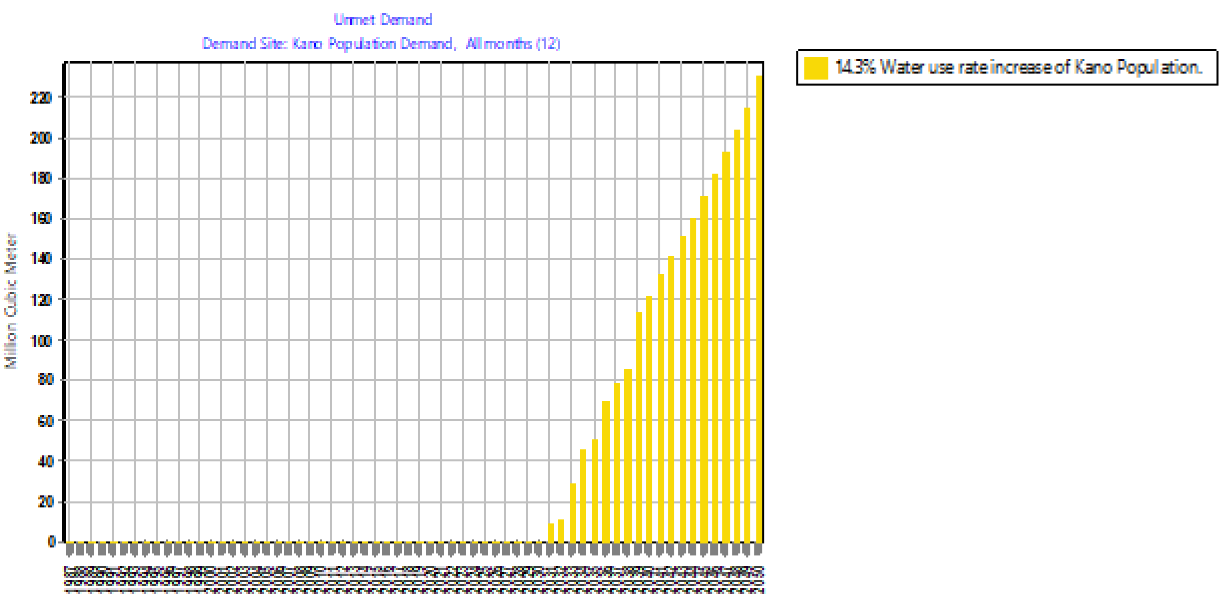

Figure 4.25: Future scenario water deficit to Kano population.

4.3.3 Water Supply to Kano Industries and Unmet Demand

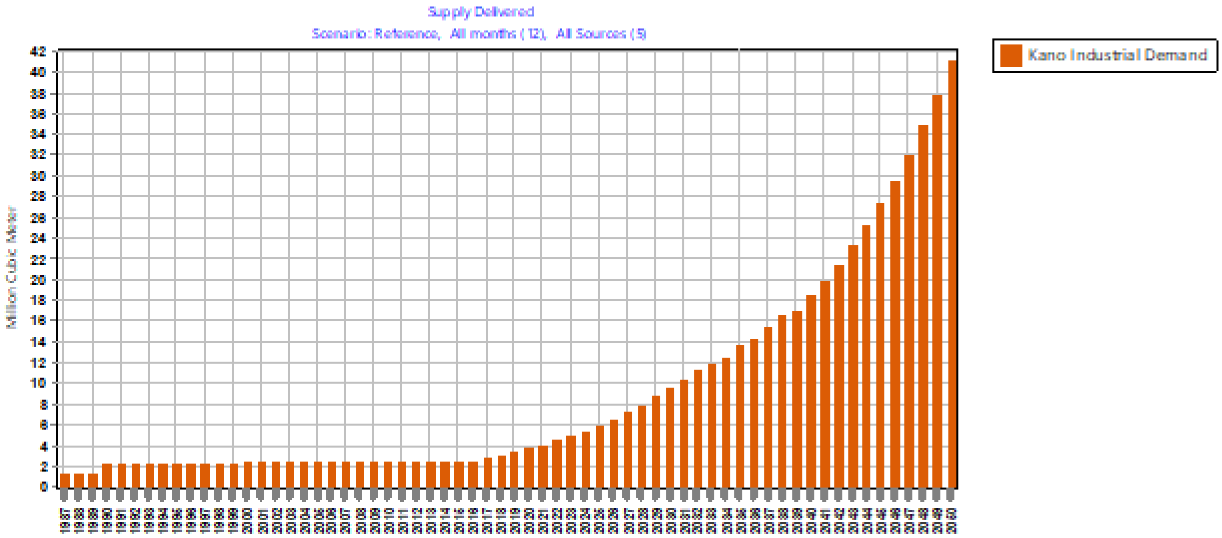

Figure 4.26: Future water allocate to Kano industries

Supply for industrial purpose increases from 2018 as shown in Figure 4.26 likewise Figure 4.27, show a less annual water allocation compare with other purposes because of low industries, rapid population growth and agricultural area.

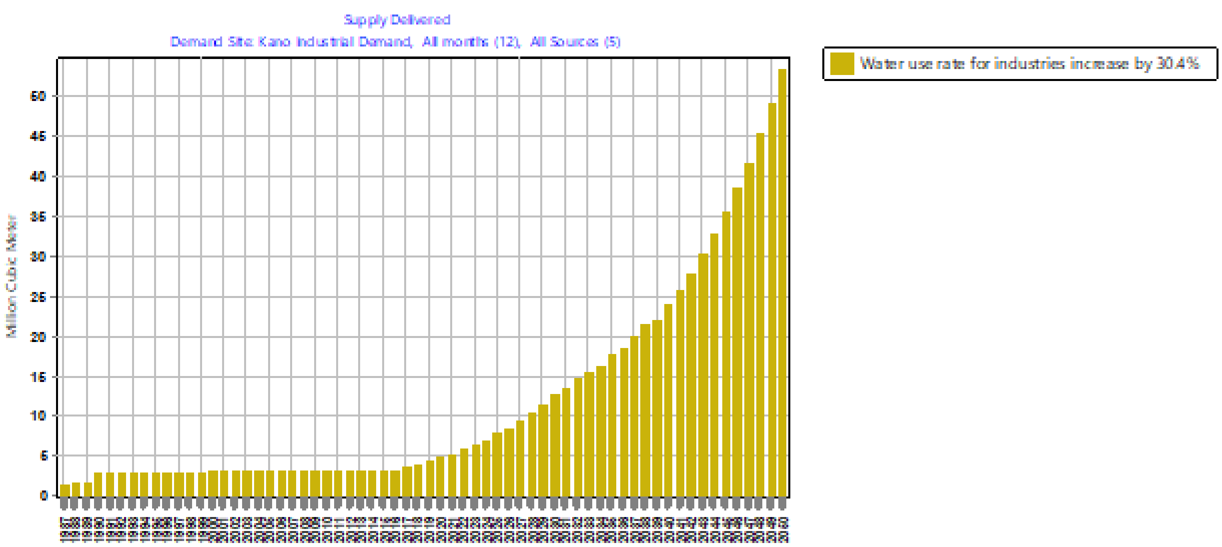

Figure 4.27: Future water allocate to Kano industries.

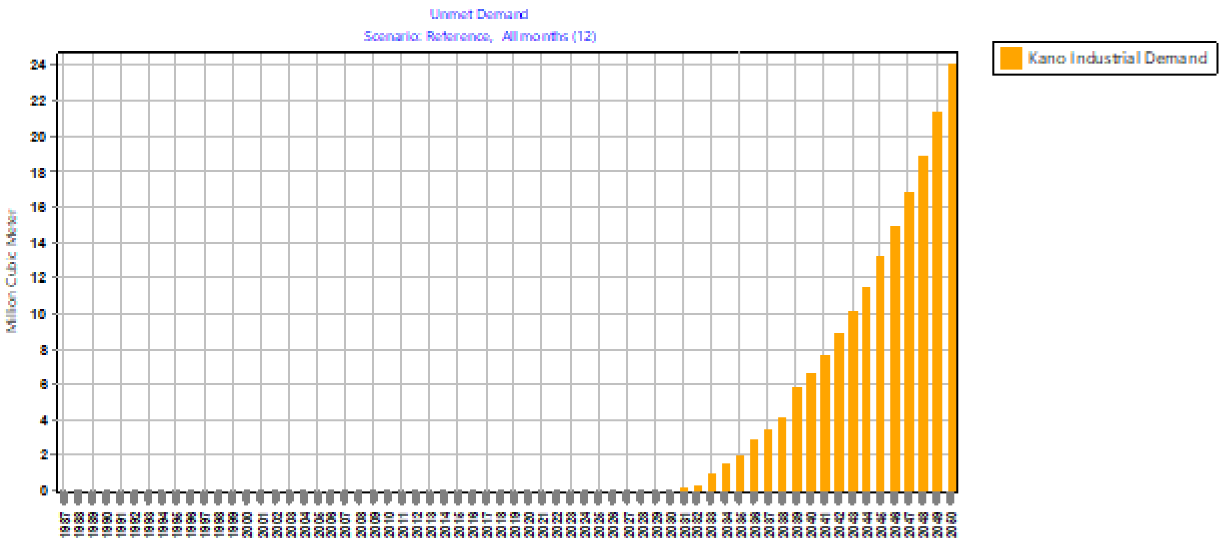

Figure 4.28: Future water deficit to Kano industries

Figure 4.28 and 4.29 indicate that the dam will not meet the industrial demand in the future from 2031.

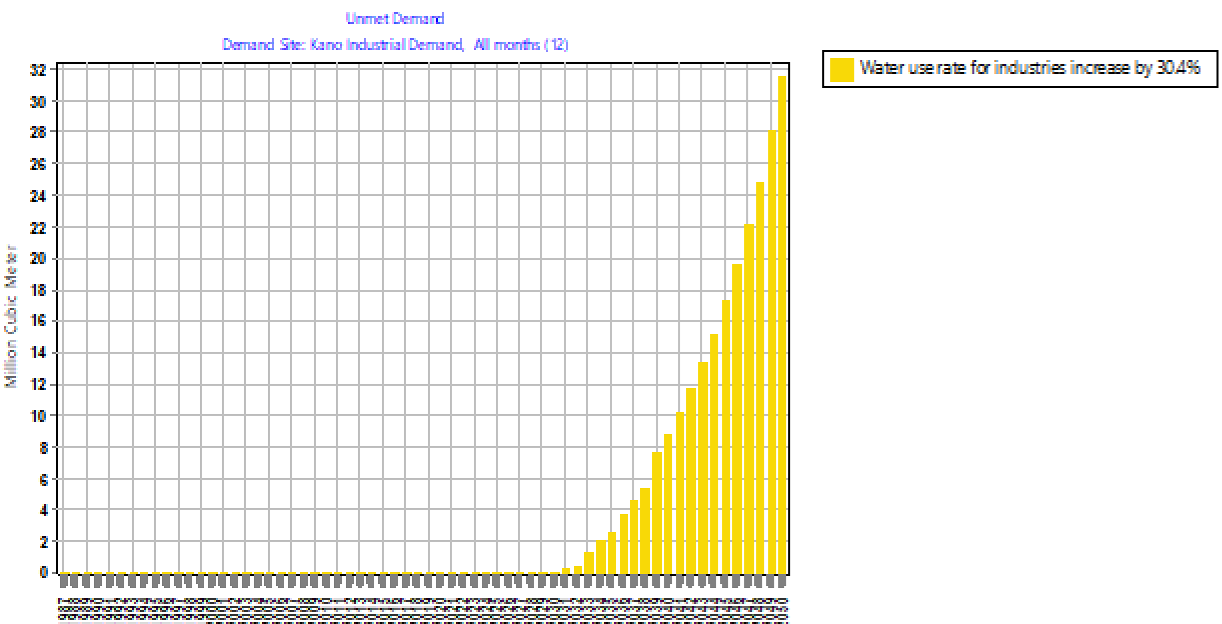

Figure 4.29: Future scenario water deficit to Kano industries

4.3.4 Demand Site Reliability

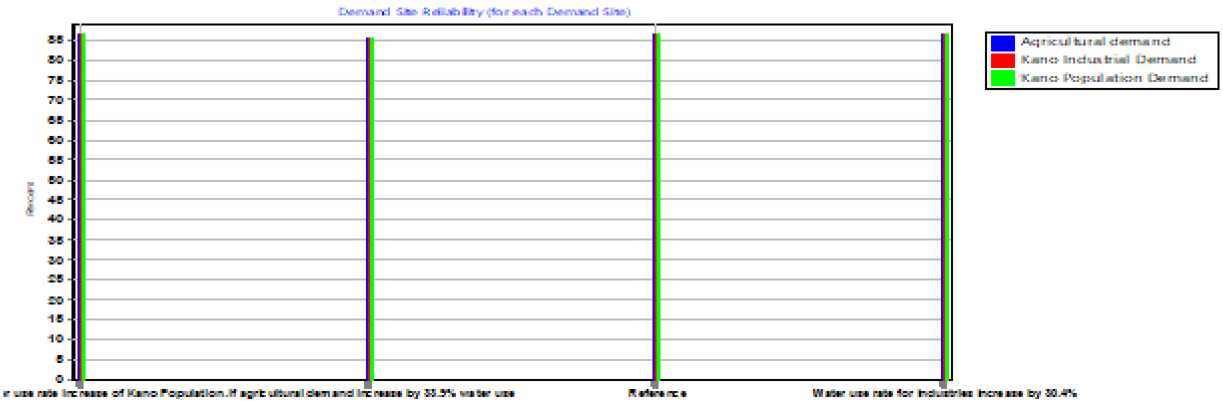

Figure 4.30: All future demand site reliability

Figure 4.30 and Table 4.6 show future supply reliability of entire system

Table 4.6: Future demand site reliability for different purposes and scenarios

Types	Reference (%)	If agricultural demand increase by 33.9% water use (%)	14.3% Water use rate increase of Kano Population (%)	Water use rate for industries increase by 30.4% (%)
Agricultural demand	86.6	85.4		
Kano Industrial Demand	86.9		86.5	
Kano Population Demand	86.6			86.6

4.4 Future Hydropower Generate and Unmet Hydropower Generation

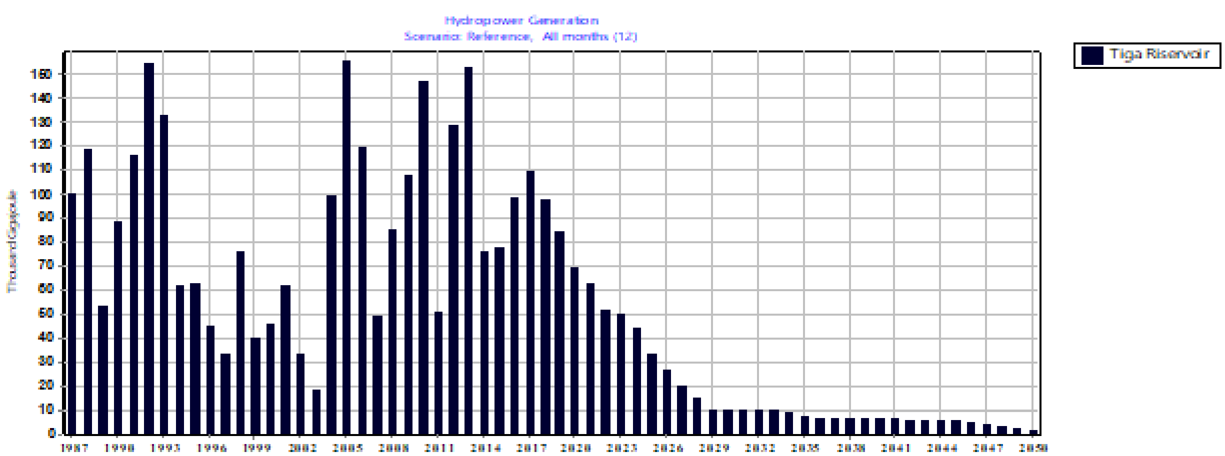

Figure 4.31: Future hydropower generation

Tiga reservoir have the capacity to generate annual average hydropower of 21288.8 GJ from 2018 with average unmet power generation of 161.9 GJ as presented in Figure 4.32 and 4.31

respectively. It clearly shows in Figure 4.32 that annual unmet power generation will begin in 2027. Figure 4.31 shows that difference in annual power generation which is fluctuating as a result in change in discharge.

However these result agree with what Zakaria*et al.*, 2011 conclude, they suggest that it will be good if a hydro-electric dam could be constructed on the Niger River, which will help to control the flows of water fall and low water levels on the river. Figure 4.31 shows the characteristic of water and variation of rainfall and flow in to the reservoir which lead to fluctuation in release downstream.

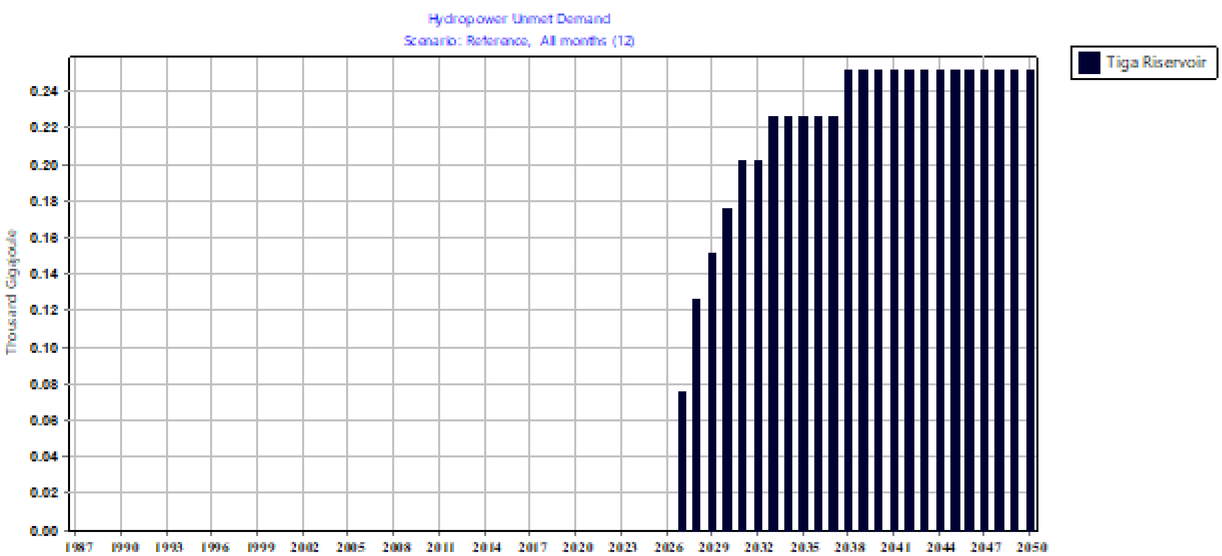

Figure 4.32: Unmet future hydropower generation

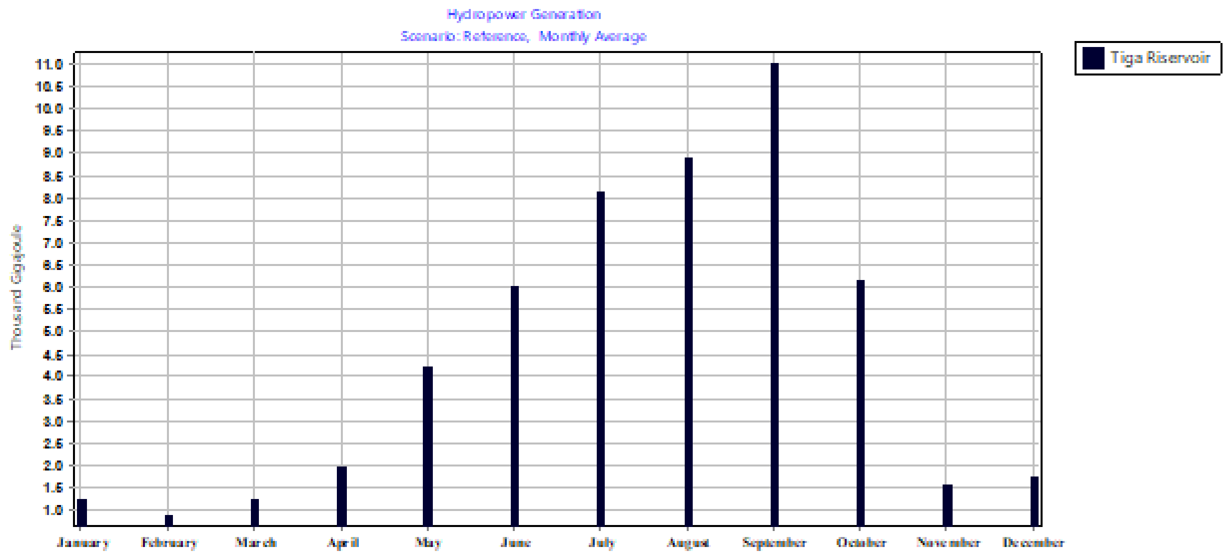

Figure 4.33: Future monthly hydropower generation

Tiga reservoir have the capacity to generate monthly average power of 28000GJ with unmet power generation of 8.6 GJ as presented in Figure 4.32. The future average monthly hydropower generated and the result obtained agree with the seasonal variation of rainfall and monthly reservoir storage which may lead to the variation of flow in to the turbine.

Also Figure 4.33 represent monthly hydropower deficit which show that at December and October there are no hydropower deficit.

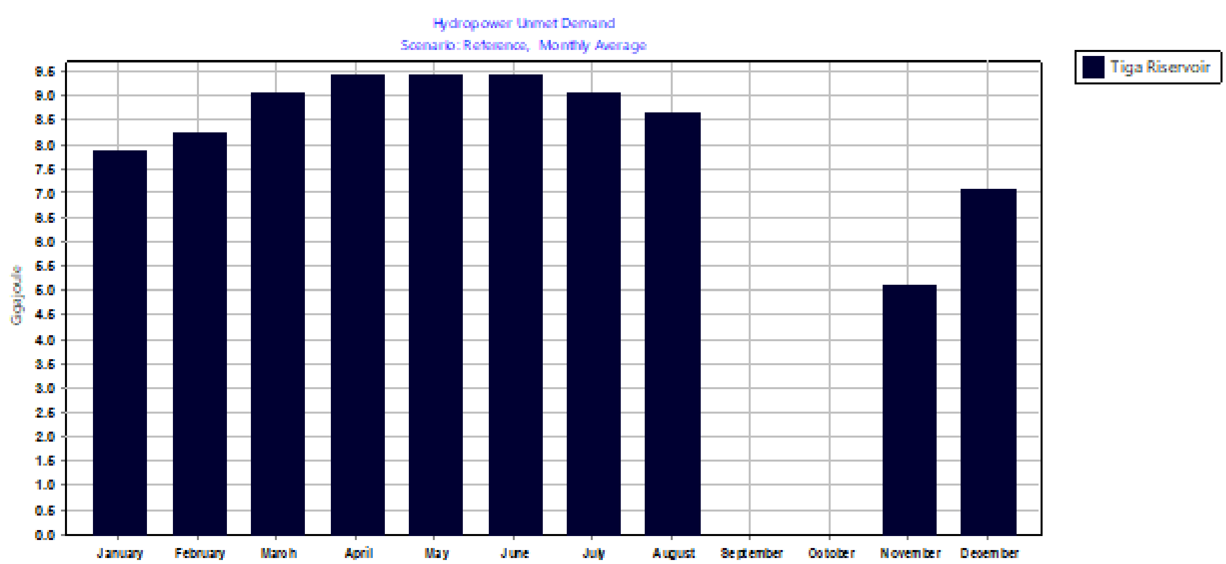

Figure 4.34: Unmet monthly future hydropower generation

4.5 Statistical Analysis for Questionnaires

The following sub-headings explain statistical analysis for the questionnaire

4.5.1 Demographic Data

Table 4.7 represent statistical analysis response of people between the age of 30-39 shows the highest responded of 180 population while population of responded and percentage of population of responded are represent in Figures 4.35 and 4.36 respectively

Table 4.7: Age group distribution of responded

Age Group	Population	Percentage(%)
10-19	60	10
20-29	156	26
30-39	180	30
40-49	84	14
50-59	72	12
60-69	48	8
Total	600	100

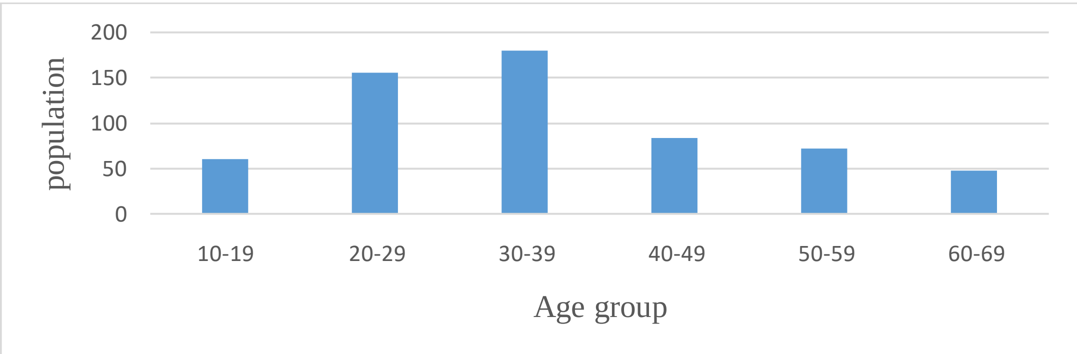

Figure 4.35: Population of response

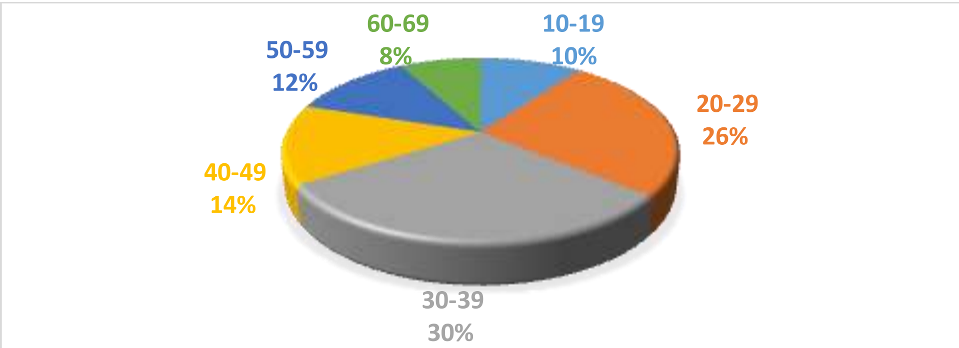

Figure 4.36:Percentage of population of response

Table 4.8 shows the gender of responded, the lowest responded were females and the higher responded were male. Figures 4.37 and 4.38 represent gender of population responded and percentage of gender responded respectively.

Table 4.8: Gender of responded

Gender of respondent	Population	Percentage(%)
Male	426	71
Females	174	29
Total	600	100

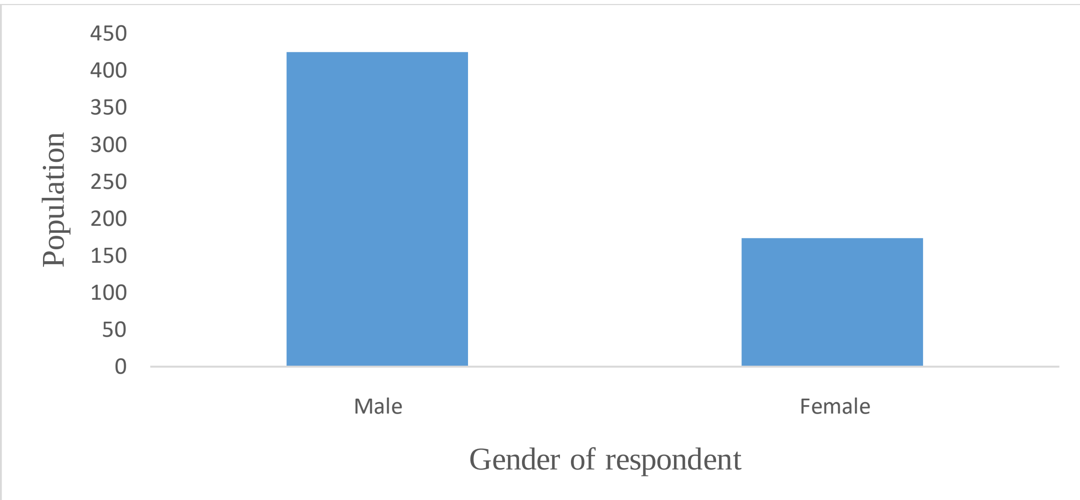

Figure 4.37: Gender of population responded

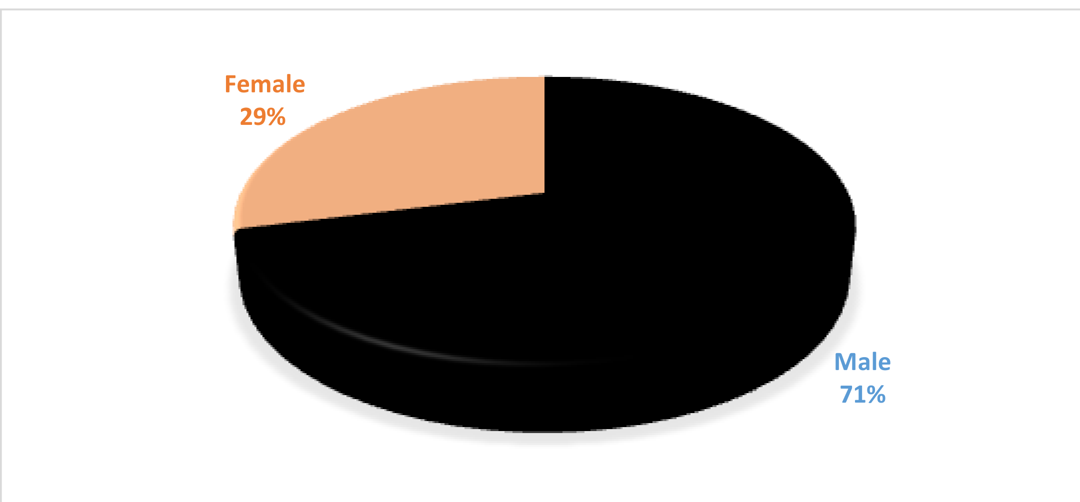

Figure 4.38: percentage of gender responded

4.5.2 Domestic Water Demand

Table 4.9shows types of domestic water need per person, while Figure 4.39 and 4.40 are represent population and percentage of population used the water for different domestic activities respectively.

Table 4.9: Domestic water use

Domestic water use	Population	Percentage(%)
Drinking, flushing toilet, ablution, bathing, washing clothes, cooking and others (1)	102	17
Drinking, flushing toilet, ablution, bathing, washing clothes, and others (2)	54	9
Drinking, flushing toilet, ablution, bathing, and others (3)	102	17
Drinking, ablution, bathing, washing clothes, and others (4)	48	8
Drinking, ablution, bathing, washing clothes, cooking and others (5)	54	9
Drinking, flushing toilet, bathing, washing clothes, cooking and others (6)	60	10
Drinking, flushing toilet, bathing, washing clothes, and others (7)	30	5
Drinking, flushing toilet, ablution, bathing, washing clothes, and cooking (8)	108	18
Drinking, flushing toilet, ablution, and bathing (9)	18	3
Drinking, ablution, bathing, washing clothes, and cooking (10)	6	1
Drinking, flushing toilet, ablution, bathing, washingand cloths (11)	6	1
Drinking, flushing toilet, bathing, washing clothes, and cooking (12)	12	2
Total	600	100

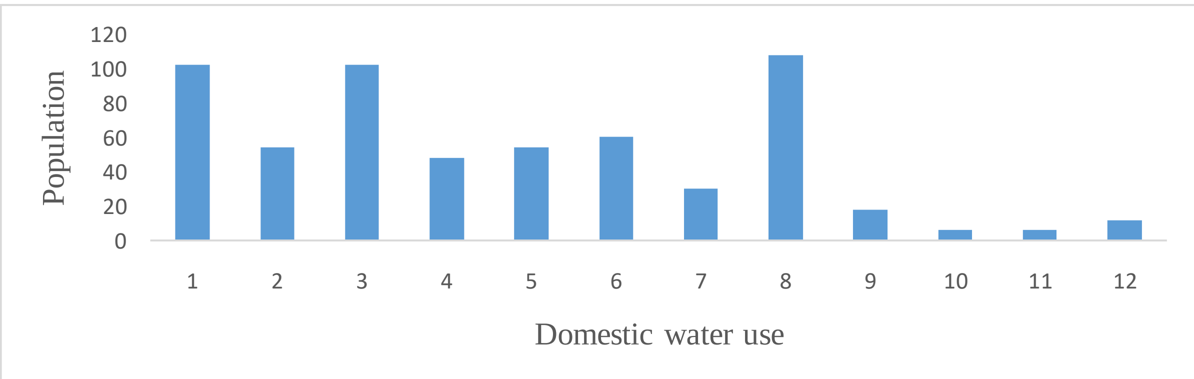

Figure 4.39: Domestic water use by the population

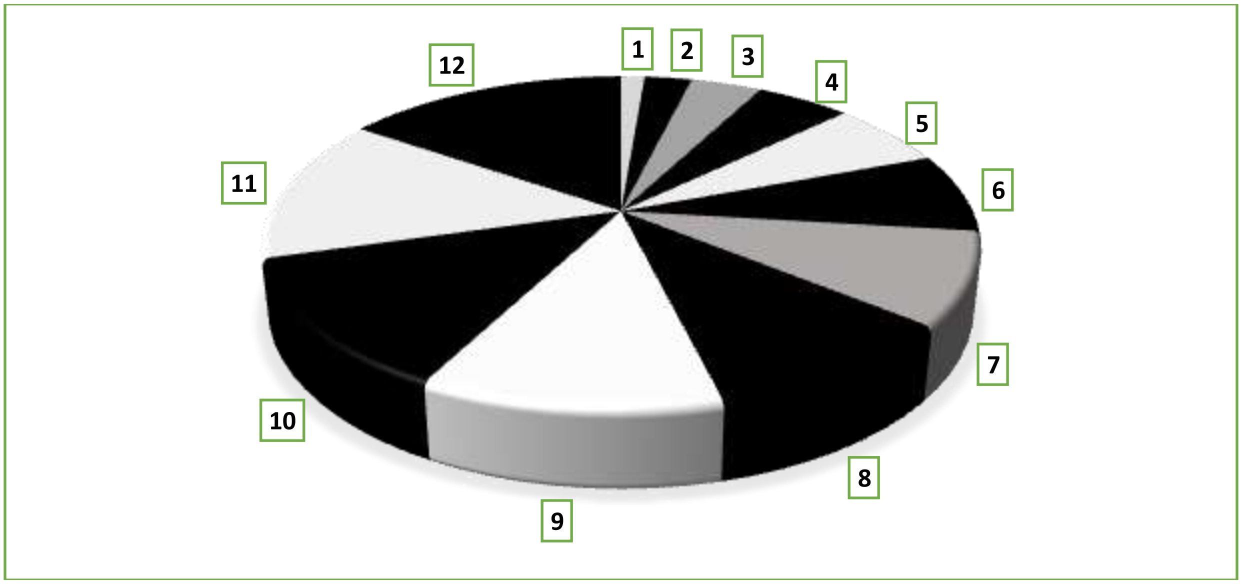

Figure 4.40: Percentage of domestic water use by the population

Table 4.10 represent average domestic water use per capital. It was observed from Table 4.10 and Figure 4.41 that all the people are using the water for drinking and bathing but only few people that are not using the water for ablution.

Table 4.10: Average domestic water use per capital

Domestic water use	Range of water use (L)	Average water use (L)	Population
Drinking	2-4	3	600
Flushing toilet	34-40	30	492
Ablution	3-6	5	498
Bathing	10-50	36	600
Washing cloths	10-30	18	480
Cooking	2-10	6	396
Others	3-15	7	348
Total		105	

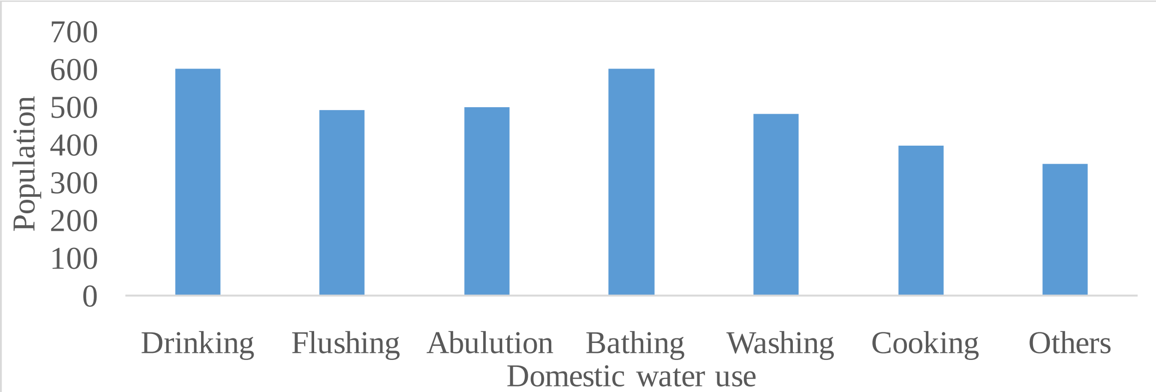

Figure 4.41: Population use of water per domestic activity

4.5.3 Comparison of WEAP Model Simulated with Calculated Domestic Water demand

To calculate water demand at 2050

$$W_y = W_a \times P_y \times 365$$

Where W_y = water demand at a given year, W_a = average per capital per day water demand and P_y = Population at a given year

$$W_y = 0.105 \times 13815942 \times 365$$

$$W_y = 529.5\ Mcm$$

Therefor the model performed excellently since that the simulated domestic demand at year 2050 is 530 Mm^3 is in agreement with manual calculated value 529.5 Mm^3.

4.6 Calibration and Validation Result

The meteorological data of 1987 to 2007 was used to set up the model and calibrated by visual observation and adjusting some values until the simulated net-evaporation values comes to an agreement with the observed net-evaporation data of 2008 to 2017. An obvious validation is first made by comparing graphically, the simulated values with the observed values. The efficiency criteria and R^2were applied to assess how well the model it is. This is to reinforce the confidence in the results of the model simulations.

Figure 4.42 shows comparison of simulated and measured net-evaporation value. Table 4.9 shows the calculation of the objective functions that were used for the determination of efficiency parameters of model. The values obtained for coefficient of determination (R^2) is 0.76 andfor Nash-Sutcliffe coefficient of efficiency (NCE) is 76%,

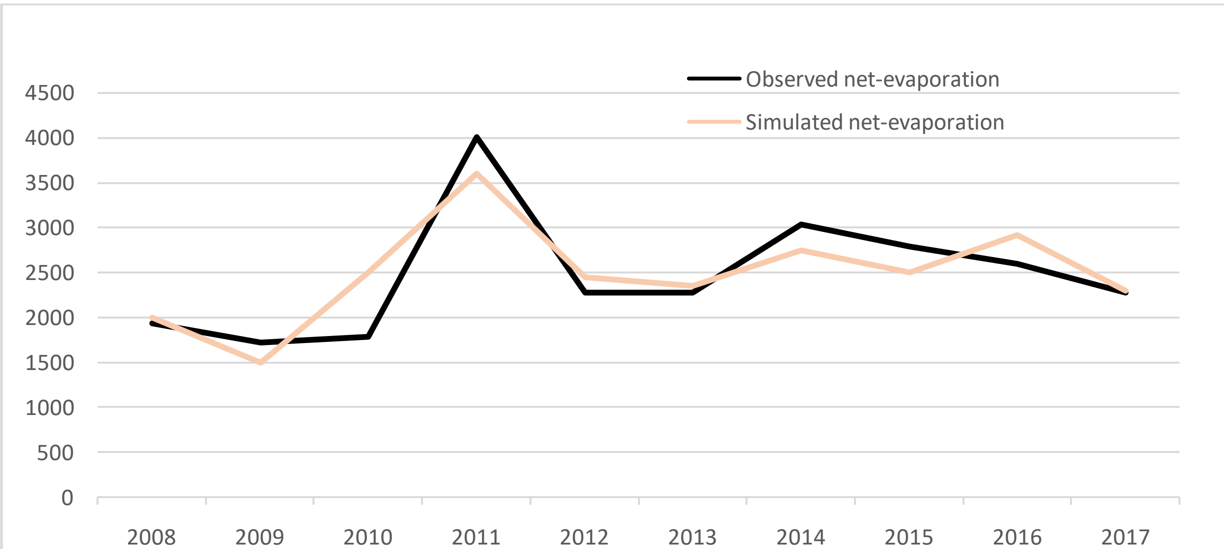

Figure 4.42: Comparison of Simulated and Observed net-evaporation of Tiga Dam

Table 4.11: The Analysis of Simulated verses Observed net-evaporation value

Years	Observed value (mm)	Simulated value (mm)	$Q_{obs,i}-\bar{Q}_{obs}$	$(Q_{obs,i}-\bar{Q}_{obs})^2$	$Q_{sim,i}-\bar{Q}_{sim}$	$(Q_{sim,i}-\bar{Q}_{sim})^2$	$(Q_{obs,i}-\bar{Q}_{obs})(Q_{sim,i}-\bar{Q}_{sim})$	$Q_{obs,i}-Q_{sim,i}$	$(Q_{obs,i}-Q_{sim,i})^2$
2008	1928	2000	-537	288369	-487	237169	261519	-72	5184
2009	1716	1500	-749	561001	-987	974169	739263	216	46656
2010	1785	2500	-680	462400	13	169	-8840	-715	511225
2011	4001	3600	1536	2359296	1113	1238769	1709568	401	160801
2012	2269	2450	-196	38416	-37	1369	7252	-181	32761
2013	2266	2350	-199	39601	-137	18769	27263	-84	7056
2014	3031	2750	566	320356	263	69169	148858	281	78961
2015	2786	2500	321	103041	13	169	4173	286	81796
2016	2595	2920	130	16900	433	187489	56290	-325	105625
2017	2273	2300	-192	36864	-187	34969	35904	-27	729
Total	24650	24870	0	4226244	0	2762210	2981250	-220	1030794
Mean	2465	2487							

The Correlation Coefficient for the Table 4.7 is calculated as follows:

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

$$\left[\frac{Total\ \ of\ \ column\ \ Eight\,(2981250)}{\sqrt{Total\ \ of\ \ column\ \ Five\,(4226244)}\ X\sqrt{Tota\,l\ of\ \ Column\ \ Seven\,(2762210)}}\right]^2 = 0.76$$

The Nash-Sutcliffe coefficient of efficiency (NCE)for the Table 4.7 is calculated as follows:

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

$$1 - \frac{Total\ \ of\ column\ \ Ten\ (1020794)}{Total\ \ of\ column\ \ Seven\ (4226244)} * 100\% \quad = \quad 76\%$$

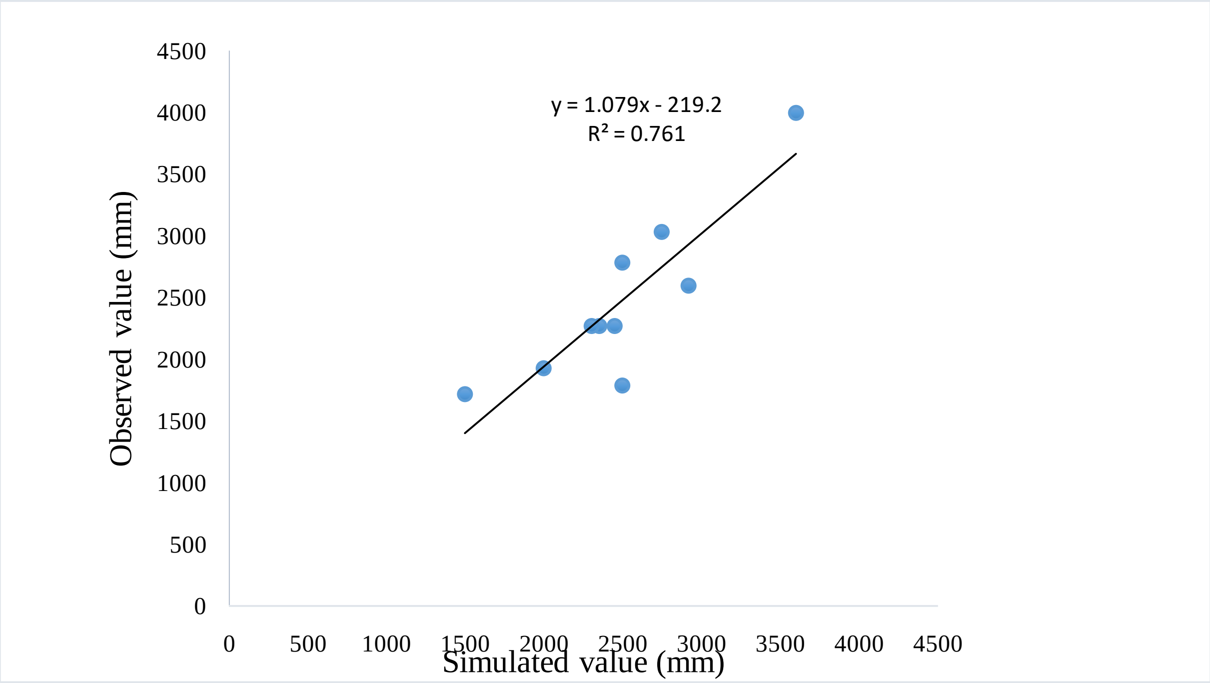

Figure 4.43: Model validation

Graph of observed net-evaporation versus simulated net-evaporation values was used to determine equation of line and R^2 value, this show that the model validation is very good since R^2 value is grater then 70% as shows in Figure 4.43.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research work, an effort has been made to determine past and future water allocation fordifferent scenarios and purposes such as agriculture, Municipal (Kano city) and industrial from Tiga Dam using the WEAP model. With the use of WEAP model software, it can be confirm that the water scarcity and difficulties related to it will arise in Kano state Nigeria as long as mechanisms of management are not put in place to take care of rapid population growth and increase in irrigation.

The water demand and supply with respect to usage and purposes were forecasted as a result it was determined thatin the future (2031 to 2050) the dam cannot meet up with the required total demand, it may only be able to supply annual average of 410.5 Mm^3 for agriculture with unmet demand of 123.7 Mm^3, for agricultural scenario is 658.8Mm^3 with unmet demand of 188Mcm, 266.3 Mm^3 water supply for Kano City with unmet demand of 61.6Mm^3, and 301.3 Mm^3 future water supply scenario with 75.3Mm^3 unmet demand, 15.5 Mm^3 for industries with unmet demand of 5.4 Mm^3 and 20.2 Mm^3 future industrial scenario with 7 Mm^3 unmet demand. The Tiga Reservoir will generate 21288.8 GJ annual average hydropower with 161.98 GJ unmet power from 2026.In general, this model predicts that the annual average future water supply from 2018 to 2050 for all purpose is 692.4 Mm^3 with unmet demand of 190.8Mm^3 from 2031 but 980.3 Mm^3 for all scenarios with unmet demand of 270.5 Mm^3.

The modelperformed excellently since validation results were in good agreement with the objective functions.

The result of the model predict is in good agreement with the manual computation of water demand survey data which show that Kano population scenario has annual average of 91 Mm^3 for future water demand, industrial scenario of 27.4 Mm^3 future water demand from and 715.1$Mm^3$for agricultural scenario 2018 to 2050.

5.2 Recommendations

The recommendations on adaptation measures to mitigate water deficit were suggested from the findings in the study as follows:

(1) A further study should be carried out to find the management strategies in the three demand studied so that to reduce unmet demand.

(2) Detail study should be carried out to find out why agricultural sector consumed more water.

(3) Wastewater re-use and recycling should be consider in order to reduce unmet demand.

(4) The population control can be adopted to reduce domestic water demand.

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APPENDIX A

SURVEY OFPER CAPITALDOMESTIC WATER CONSUMPTION PATTERNS IN KANO METROPOLIS, NIGERIA

1- What is your name? ______________________________

2- Gender of the respondent? Male ☐ Female ☐

3- Age ☐

4- Local government area: ______________________________

5- Location: ______________________________

6- What domestic activities you use the water for?

i- Drinking ☐

ii- Flushing toilet ☐

iii- Ablution ☐

iv- Bathing ☐

v- Washing cloths ☐

vi- Cooking ☐

vii- Others ______________________________

7- Daily domestic water use for different activities per capital in liter(s) (L)

i- Drinking ☐

ii- Flushing toilet ☐

iii- Ablution ☐

iv- Bathing ☐

☐

v- Washing cloths

vi- Cooking

vii- Others ____