EFFECTS OF CLIMATE CHANGE ON GROUNDWATER RESOURCES IN KOGI STATE, NIGERIA USING WATER BALANCE METHOD

BY

COULIBALY, Gnenakantanhan
MTECH/SNAS/2013/4211

WEST AFRICAN SCIENCE SERVICE CENTRE FOR CLIMATE CHANGE AND ADAPTED LAND USE,
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

SEPTEMBER, 2015

EFFECTS OF CLIMATE CHANGE ON GROUNDWATER RESOURCES IN KOGI STATE, NIGERIA USING WATER BALANCE METHOD

BY

COULIBALY, Gnenakantanhan
MTECH/SNAS/2013/4211

THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTECH DEGREE) IN CLIMATE CHANGE AND ADAPTED LAND USE

SEPTEMBER, 2015

DECLARATION

I, hereby declare that this thesis titled: “Effects of Climate Change on Groundwater Resources in Kogi State, Nigeria Using Water Balance Method” is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

COULIBALY, Gnenakantanhan ………………………………….

MTECH/SNAS/2013/4211 SIGNATURE & DATE

FEDERAL UNIVERSITY OF TECHNOLOGY,
MINNA, NIGERIA.

CERTIFICATION

This Thesis titled: "Effects of Climate Change on Groundwater Resources in Kogi State, Nigeria Using Water Balance Method", carried out by COULIBALY, Gnenakantanhan (MTECH/SNAS/2013/4211) meets the regulations governing the Award of Master of Technology of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

Dr. Abdullahi Idris-Nda . . . .
Supervisor Signature & Date

Dr. A.A. Okhimamhe . . . .
Director, WASCAL Signature & Date

Prof. M.G.M Kolo . . . .
Dean of Postgraduate school Signature & Date

DEDICATION

This thesis is dedicated to:

Allah, Almighty from Whom my inspiration emanates;

My parents for their lovely support, encouragement and prayers;

ACKNOWLEDGEMENTS

At the end of this work, I would like to humbly thank all the contributions who have made possible this study. This work was fully funded by to the German Federal Ministry of Education and Research (BMBF) through the West Africa Science Service Center on Climate Change and Adapted Land Use (WASCAL). It is an honor to thank Dr Abdullahi Idris-Ndah, my Supervisor for his tolerance, guidance and a critical analysis of my work through the processes of this project. I'm grateful because I have learned a lot during the few months of this thesis. WASCAL MRP programme in FUT, Minna is led by a dynamic and rigorous person of Dr AA Okhimamhe. I would like humbly to say thank Ma for your assistance and encouragement. Assisted in her task by a valuable coordinating team which was helpful to us during the time spent in Nigeria, found here my sincere thankfulness.

This study start with a field work in localities where I have meet wonderful persons. Thanks to brave people who have made perfect my stay in Lokoja (Kogi State). To my guides and interpreters, found here my honest acknowledgment for your efforts. Special thanks to you my friends Ismael Idris Mafo, Shuaibu and Umar for your help. Soil analysis was conducted in Geology Department Laboratory (Hydrogeology Laboratory), FUT Minna. Mr. Abdul Jalil, Mr. Abdul Fatah and Mr. Tobias Onyeabor guide me through laboratory processes. Thanks for your indispensable help. All my colleagues (Batch A and Batch B) of WASCAL MRP CC&ALU programme from different countries, but the same goal which is to tackle vigorously climate change adverse effects over West African countries in specific way and all over the world, were source of motivation for me. Life were sometimes complicated but it was really interesting to share daily challenges with you. I would like to sincerely thank all of you. To all those wonderful people who supported me during this work, and during my stay in Nigeria, I wish to express my profound gratitude.

ABSTRACT

This study “Effects of Climate Change on Groundwater Resources in Kogi State using Water balance Method” was carried out to understand how change in climate condition affect the quantity aspect of groundwater. In order to achieve this goal, questionnaires, climate data and soil samples were collected during the field work. Questionnaires were used to assess inhabitants’ perception about climate change and its potential impact on groundwater. Responses from questionnaire administered were used to calculate a percentage of answers and then bar charts were plot for each question. Historical climate data were analyzed to confirm population perception about the change in climate condition. Descriptive statistic, box plot, trend analysis and bar charts were used to visualize the data distribution characteristics and displays the direction of the change. From climate data, monthly and annual aquifer recharge were estimated using water balance equation and then correlation and regression statistic were performed among parameter used for recharge estimation. Soil analysis using dry sieve analysis technique was implemented to appraise natural soil hydraulic conductivity or the rate of aquifer recharge. The results reveals that hand dug wells, boreholes, stream and rivers were the water sources mostly used in the study area. Respondents estimate that the rainfall amount is becoming low over years with variations in the start and end of raining season. For some respondents, the rainy season is becoming shorter with large amount of rainfall. Respondents also notice that the sun is now very hotter (86.7%) than before. Most of respondents (80%) cannot explain what climate change is but they believe strongly (95.6%) that climate is changing. Those change in climate according to them affect the groundwater quantity and quality observed through change in taste (42%), odor (40%), and color (53%). General upward trend was found in annual rainfall data and also intensification in amount of rain from one decade to another. Minimum and maximum temperature data displayed increase in mean value over year shows by time series plots. Monthly aquifer recharge computation reveal that it occurred between April to October with high amount of water recharge during the month of June, July and August. Annual aquifer recharge amount were strongly dependent on the amount of rainfall. Hydraulic conductivity estimated from grain size distribution analysis was characterized by low natural capability of soil to let water flow through it.

TABLE OF CONTENTS

CONTENTS **Page**

COVER PAGE	i
TITLE PAGE	ii
DECLARATION	iii
CERTIFICATION	iv
DEDICATION	v
ACKNOWLEDGEMENTS	vi
ABSTRACT	vii
TABLE OF CONTENTS	viii
LIST OF FIGURES	xiii
LIST OF TABLES	xv
LIST OF PLATES	xvi
ABBREVIATIONS	xvii
CHAPTER ONE	**1**
1.0 INTRODUCTION	**1**
1.1 Background	1

Page

1.2 Problem Statement 5

1.3 Aim, Objectives and Research Questions 5

1.4 Significance of the Study 6

1.5 Scope and Limitations of the Study 7

1.6 Study Area 8

1.6.1 Location and Description of the Study Area 8

1.6.2 Geology and Mineral Deposit 10

1.6.3 Topography 12

1.6.4 Vegetation 13

1.6.5 Climate 14

1.7 Organization of the Thesis 14

CHAPTER TWO 16

2.0 LITERATURE REVIEW 16

2.1 Conceptual Framework 16

2.1.1 Climate Change and Climate Variability 16

2.1.2 Groundwater Resources 18

Page

2.1.3 Physical Framework of Groundwater Resources 19

2.1.4 Occurrence and Storage of Groundwater 20

2.1.5 Groundwater Recharge 21

2.2 Review of Previous Studies 21

2.2.1 Climate Change Impact on Groundwater 22

2.2.2 Recharge Estimation Methods 24

2.3 Gaps from the Reviewed Literature 25

CHAPTER THREE 27

3.0 MATERIALS AND METHODS 27

3.1 Materials 29

3.2 Data Collection Methods 30

3.2.1 Questionnaire Administration 30

3.2.2 Climate Data 32

3.2.3 Wells and Boreholes Data 33

3.2.4 Soil Sampling Procedure and Laboratory Analysis 33

3.3 Data Analysis Methods 35

Page

3.3.1	Climate Perception	36
3.3.2	Evidence of Climate Change	36
3.3.3	Recharge Estimation	38
3.3.4	Soil Analysis	41
CHAPTER FOUR		**42**
4.0	**RESULTS AND DISCUSSION**	**42**
4.1	Climate Perception in the Study Area and it Impact on Groundwater	42
4.1.1	Socio-Demographic Information about Respondent	42
4.1.2	Water Sources for Domestic Need	44
4.1.3	Respondents’ Perception about Change in Climate Condition	47
4.1.4	Perception of Climate Effect on Groundwater	51
4.2	Signal of Climate Change	56
4.2.1	Rainfall Data Analysis	56
4.2.2	Temperature Data Analysis	61
4.3	Groundwater recharge	67
4.4	Sieve Analysis Results	76

Page

CHAPTER FIVE **79**

5.0 CONCLUSION AND RECOMMANDATIONS **79**

5.1 Conclusion 79

5.2 Recommendation 80

REFERENCES **81**

APPENDICES **87**

LIST OF FIGURES

Figure		Page
1.1	Map of Nigeria showing the study area	9
1.2	Topography map of the study area	13
4.1	Sex and age of respondents	43
4.2	Respondents level of education and nativity	44
4.3	Domestic water for population daily needs	45
4.4	Uses and distance of water sources from habitations	46
4.5	Water adequate and monetary aspect of the availability for population use	46
4.6	Rainfall amount and start period in the study area	47
4.7	End of raining season behavior and sun intensity perception	48
4.8	Occurrence of drought	49
4.9	Occurrence of flooding event	50
4.10	Knowledge and belief on climate change	51
4.11	Climate and water relationship	52
4.12	water level in wells during rainy and dry season	53
4.13	Water level in dry season in wells and change in groundwater taste	54
4.14	Change in groundwater color and odor over the years	55
4.15	Period of change on groundwater availability	56

Page

4.16	Rainfall monthly distribution over 1971-2014 using box plot	57
4.17	Comparison of mean monthly rainfall over the decades	58
4.18	Time series analysis of mean annual rainfall (1971-2014)	59
4.19	Standardized Precipitation Index of mean annual rainfall	60
4.20	Rainfall amount per decade	61
4.21	Monthly distribution of minimum temperature (1975-2014)	62
4.22	Time series of Minimum Temperature	62
4.23	Bar chart of decadal minimum Temperature	63
4.24	Monthly Distribution of Maximum temperature over the study period	65
4.25	Time series of Maximum Temperature	66
4.26	Decadal change in mean maximum temperature	67
4.27	Mesn Monthly aquifer recharge	70
4.28	Annual rainfall and recharge fluctuation	73
4.29	Visual relationship between annual rainfall and annual recharge	74
4.30	Regression analysis of recharge and rainfall	76

LIST OF TABLES

Table		Page
1.1	Main Source of Water Supply for Domestic Use in Kogi State, Nigeria (NPC, 2010)	4
1.2	Villages visited in the study area during field work by LGA	10
3.1	Flowchart of research methodology	28
3.2	Summarize of materials used during this work	30
3.3	Climatic data utilized	33
3.4	Sieves opening used for soil analysis	35
3.5	SPI classes (WMO, 2012)	38
4.1	Descriptive statistic of annual rainfall from 1977 to 2014	58
4.2	Decadal Mean Minimum Temperature	63
4.3	Decadal difference of Mean Minimum Temperature	64
4.4	Decadal Mean Maximum Temperature	65
4.5	Monthly recharge value (1985-2010)	69
4.6	Annual recharge values (1985-2010)	71
4.7	Descriptive statistic of annual recharge	72
4.8	Kendall’s tau b correlation among water balance parameter	75
4.9	Hydraulic Conductivity (K)	77
4.10	Descriptive statistic of Hydraulic conductivity	78

LIST OF PLATES

Plate		Page
I	Section of patti formation at Banda, Lokoja LGA (Source: Author Field work)	11
II	Tropical vegetation characteristic of the Guinea Savannah zone in Bassa LGA.	14
III	Sieve analysis materials	29
IV	Questionnaire administration at Onumaye Kotonkarfe LGA	32
V	Soil samples spread in the Laboratory	34

ABBREVIATIONS

BNRCC	Building Nigeria's Response to Climate Change
FME	Federal Ministry of Environment
IPCC	Intergovernmental Panel on Climate Change
LGAs	Local Government Areas
NiMet	Nigerian Meteorological Agency
SCCU	Special Climate Change Unit
SPSS	Software Package used for the Social Sciences
UNFCCC	United Nations Framework Convention on Climate Change
WASCAL	West African Science Service Centre on Climate change and Adapted Land use

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Freshwater resources are vital component of the earth's hydrosphere and an indispensable part of all terrestrial ecosystems. It is universally recognize that water is life because every aspect of human society depends on it sustainable use (Belkhiri, Boudoukha, Mouni, 2010; Alaci, Jiya and Omata, 2013). The quick increase in the world population, has caused amplification in demand for freshwater resources (Obuobie, 2008). International consensus on their rigorous management have been developed a few decade ago and was marked by significant events. One most meaningful event was the international decade of adduction and drinking water of United Nations (1981 to 1990) also named “the decade of water” emerged from the 1977 Mar del Plata (Argentine), United Nations Water Conference. The stated objective of this decade was to "provide all people with water of harmless quality in sufficient quantity and elementary sanitation facilities by 1990. Following this decade, the international conference on water and environment took place in Dublin (Ireland) in 1992. The first principle of this last conference stipulate that “fresh water is a finite and vulnerable resource essential to sustain life, development and the environment”. Accordingly, freshwater should be given all attention. In the same viewed, the United Nations General Assembly in December 2003, stated the decade 2005-2015 as the International Decade for Action ‘Water for Life’. This decade primary objective was to boost efforts to accomplish international commitments made on water and water–related subjects in the United Nations Millennium Development Goals (MDGs) by 2015. All these events show how much freshwater resources are extremely vital for humanity.

The availability and the quality aspect of these resources depend strongly on climate and human activities (Kumar, 2012). The Intergovernmental Panel on Climate Change (IPCC, 2007) estimates that the global mean surface temperature has increased 0.6 ± 0.2^{o}C since 1861, and predicts an increase of 2 to 4^{o}C over the next 100 years. This intensification in temperature condition disturb the hydrological cycle by directly increase evaporation of surface water and vegetation transpiration. Subsequently, these changes may influence precipitation amounts, timings and intensity rates, and indirectly impact the flux and storage of water in surface and subsurface reservoir (Bokar *et al.*, 2012). Agreeing to Obuobie, Diekkrueger, Agyekum and Agodzo (2012), due to high variability in space and time related with rainfall, surface water sources cannot be trusted for water supply, because matter to great evaporation rate and easily polluted by anthropogenic activities. According to the same authors, groundwater sources are more appropriate to meet the dispersed demand of the growing rural population, which forms important proportion of world total population.

Groundwater is one of the most important component of natural freshwater resources (Philip and Batalaan, 2009; Bovolo, Parkin and Sophocleous, 2009), which is part of the global freshwater supply. Groundwater constitutes about 95 per cent of the freshwater on our planet (discounting that locked in the polar ice caps), making it fundamental to human life and economic development (Morris *et al.*, 2003). It is the main source of water in arid and semi-arid regions. Groundwater provides much of the public and domestic water supply, agricultural and industrial economies, and contributes sometimes (Bokar *et al.*, 2012) by its flow to rivers, lakes and wetlands; and this helps in maintaining a balance in the ecosystem (Aizebeokhai, 2011, Mogheir and Ajjur, 2013). In rural areas, life depends on it low-cost through the domestic (private) boreholes and/or hand-dug wells. The situation is almost the same in most rural population around the world particularly in Africa.

The most important menace to the sustainable development in all West Africa countries especially as Nigeria is climate change. According to Oladipo (2010), Nigerian's institutional capacity to respond effectively to climate change is too weak. Apart the West African Science Service Centre on Climate Change and Adapted Land Used (WASCAL MRP in the Federal University of Technology, Minna and Graduate Research Program on West African Climate system in Federal University of Technology, Akure), Nigerian Meteorological agency (NIMET) and the Special Climate Change Unit (SCCU) in the Federal Ministry of Environment, there is no formal institutional structured at state and local government levels to undertake detailed vulnerability assessment of various sectors to climate change (Oladipo, 2010). Despite the important work (FME, 2009; BNRCC, 2011) in climate change studies, existing institutions lack of people with proven competencies in the unit and facilities remain inadequate to tackle the broad concept of climate change. The sectors which are considered most vulnerable to climate change in Nigeria, are agriculture and food security, water resources, public health, and habitat particularly the urban centers along the coast (Oladipo, 2010). For example, the rain-fed food production may be devastate if important change occur in rainfall amount or intensity on which majority of Nigerian's depends to stay alive. Increased occurrence of drought may provoke decrease in agriculture yields and reduced food security. Water supplies may also be altered, primarily through changes in temperature and rainfall. High change in temperature will affect evapotranspiration, the volume of water runoff which in turn affects groundwater recharge. Similarly, decreased rainfall leads to decrease in water tables which may intensify the water stress and problems of environmental sustainability and water resources management futures.

All aspects of Kogi State inhabitant's life especially domestic water supply (Alaci *et al.*, 2013) is facing that severe effect of climate change. The National Population Commission (NPC, 2010) census and housing survey report thar (Table 1.1), only around 7.04 % of households in Kogi State have access to pipe-borne water supply (pipe borne inside dwelling(3.22%) and outside dwelling(3.82%)). This number includes those who access water from public stand pipes and or the kindness of neighbors (Alaci *et al.*, 2013). The same report shows that 14.67 % of households obtain water from vendors; 35.22 % from rivers and streams; 7.46 % from boreholes and 27.36 % from wells. The emerging scenario is that majority represented by at least 90% of households in Kogi state obtain water from sources under climate change threat (River, Stream. Spring, Borehole and Well).

Table1.1 Main Source of Water Supply for Domestic Use in Kogi State, Nigeria (NPC, 2010)

Source of Water Supply for Domestic Purpose	Number	Percentage (%)
Pipe borne inside dwelling	20637	3.22
Pipe borne outside dwelling	24564	3.82
Tanker supply/ Water vendor	94089	14.67
Well	175551	27.36
Borehole	47841	7.46
Rain water	26305	4.10
River/ Stream/ Spring	225954	35.22
Dugout/ Pond/Lake /Dam/Pool	6342	0.99
Other	20273	3.16
TOTAL	641556	100

1.2 Problem Statement

Many studies throughout the world have shown the evidence of climate change since industrialization period. IPCC (2007) confirm that change and project the continuous increase in change with alarming consequences in all human life aspect. Consequences are not the same everywhere, due to local climate condition. Unfortunately, evaluation of climate change effects on groundwater have not been given enough attention especially in developing countries such as Nigeria. The rate of climate change, population rapid growth, industrialization and urbanization contribute to increase human water needs in the whole country as well as in Kogi State (Obuobie *et al.*, 2012; Alaci *et al.*, 2013) where population grow at an important rate. Therefore, appropriate management of existing water bodies (surface water, groundwater) will have to be developed to cope with the likely increase in water stress (Okeola and Salami, 2014).

Kogi State is made up of predominantly rural settlements, with few small and medium sized urban towns. Water for inhabitant's domestic need is therefore mainly groundwater. In these conditions, effectively preventing or reducing groundwater vulnerability to climate change effects is an important component in freshwater management in the State. Consequently, there is a need to assess climate change effects on groundwater.

1.3 Aim, Objectives and Research Questions

The aim of this study is to assess groundwater potential vulnerability to climate change in a part of Kogi State (Rivers Niger and Benue confluence). In order to achieve this aim the following objectives were pursued:

1) Evaluate population perception and knowledge about climate change and its potential impact on domestic water sources;
2) Identify and detect signal of climate change from 1971-2014 (44 years) in the study area.
3) Investigate groundwater vulnerability to climate change through aquifers recharge and hydraulic conductivity assessment in sedimentary basin.

This study attempts to answers the following research questions:

i. What is the degree of awareness of population about climate change and how it affects domestic water sources especially groundwater?
ii. Is there any evidence and considerable change in Kogi State climate parameters (rainfall and temperature) over the years?
iii. If yes (precedent question), what is the consequences of those changes on groundwater recharge?

1.4 Significance of the Study

Groundwater vulnerability assessment to climate change is more meaningful in areas where water resources are under stress (Bovolo *et al.*, 2009) due to high population growth rate, urbanization, industrial or agricultural activities like in Kogi State. Climate change impacts on groundwater have been generally unstudied (Holman, 2006; Bovolo *et al.*, 2009; Philip and Batelaan, 2009; Green *et al.*, 2011) over the world. As highlighted by the IPCC (2007), knowledge of how groundwater systems respond to changes in climate and abstraction remains profoundly limited. Yet few studies have been carried out also on climate change impact on groundwater in Nigeria (Oladipo, 2010) and especially in Kogi State. This study will allow better understanding of climate change impacts on groundwater quantity. It will provide valuable information for water managers and decision makers in planning and prevention populations to groundwater shortage. In addition, this study may contribute immensely to knowledge and may also become a platform for further research.

1.5 Scope and Limitations of the Study

This study is focused mainly on climate change impacts on groundwater quantity. The scope therefore encompasses the following:

i. Field work, which involves soil sampling and questionnaire administration;
ii. Climate data collection from NiMet Agency, Abuja;
iii. Laboratory work which include sieve analysis of soil samples in Hydrogeology Laboratory (Geology Department, FUT Minna).

Groundwater potential vulnerability to climate change in Kogi State, aim of this study present many limitations which are important to specify. Numerous factors such natural process (flood, drought, desertification, climate change), land cover change and land use change interfere to define environment conditions. These complex interactions which affect freshwater availability and quality in general and groundwater in specific way, constitute limitations of this work. This study was conducted only in a part of Kogi State because of insufficiency of fund and time to extend this work to the whole State. Insufficient information or data on hydrologic parameters (such as runoff, groundwater level, historical water quality data and surface water level fluctuations) in the areas is also a limitation. Within the time framework, it was not possible to take inventory of all boreholes and wells. However all care has been take to ensure that these limitations do not affect the potential outcome of the research work.

1.6 Study Area

1.6.1 Location and Description of the Study Area

Kogi State is located in the North central region in guinea savanna zone, it has a total landmass of 29,581.885 square kilometer, and a population of 3,314,043 (NPC, 2010). This state is bounded by the Federal Capital of Nigeria, Abuja and Niger State in the North, Nassarawa state in the North-East, Benue State in the East, Enugu State in the South-East, Anambra state in South, Edo State in the South-West, Ondo State and Ekiti State in the West and Kwara state in the North-West (Figure 1.1). Kogi is a Haussa word which mean "River" because of the confluence of Rivers Niger and Benue at its capital, Lokoja (Audu, 2012). The state is subdivided into twenty one (21) Local Government Areas with three (3) main ethnics groups (Igala, Ebira and Okun (a Yoruba group)) and others minorities such as Bassa, Nupe, Gwari, Kakanda, Oworo, Ogori magongo and Eggan. The study will be conducted in localities around the confluent of rivers in Lokoja, Bassa and Kogi (Koton Karfe) LGAs as shown in Figure 1.1.

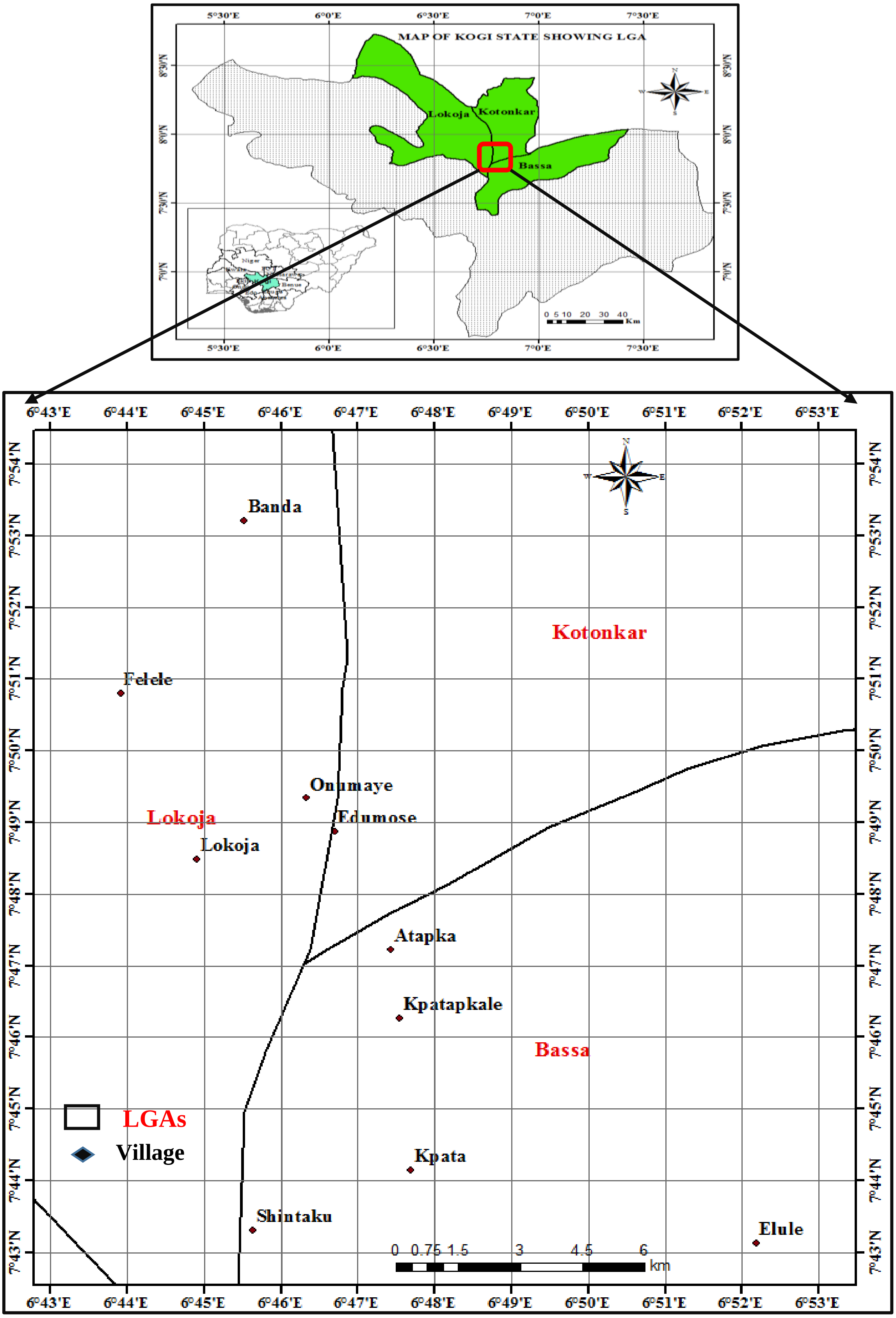


Figure 1.1: Nigeria showing the study area

The study area is a small square (Figure 1.1) space within Kogi State in the Guinea Savanna especially around rivers Niger and Benue confluent. The most significant LGA in the area are Lokoja, Bassa and Kogi (Koton karfe). The boundaries of the site are between 6°43′ and 6°53′ longitude east and between 7°43' and 7°53' Latitude north. The total area is about 176 Km^2. The sampling location distribution within the study area is indicated in the table below:

Table: 1.2: Villages visited in the study area during field work by LGA

Local Government Area (LGA)	Villages concerned
Lokoja LGA	Lokoja, Felele, Banda
Bassa LGA	Shintaku, Kpata, Kpatapkale, Atakpa, Elule
Koton Karfe LGA	Onumaye, Edumose

The area concerned by the study is greatly diverse in term of geology, vegetation and physical characteristics.

1.6.2 Geology and Mineral Deposit

Two main rock types are found in Kogi state, namely, basement complex rocks of the Precambrian age in the western half of the state and extending slightly eastwards beyond the lower Niger valley and the sedimentary rocks in the eastern half. The various sedimentary rock groups extend along the banks of Rivers Niger and Benue and southeastwards through Enugu and Anambra states, to join the Udi Plateau.

The geology of the area of study comprise of rocks belonging to the southern Bida Basin. There are sedimentary rock units that were formed during the cretaceous period comprising of sandstone, siltstone, shale, clay and mudstone. Strati-graphically, the basin comprise of three formations, Lokoja sandstone, Patti and Agbaje ironstone. The Agbaje consist of oolitic, pisolitic and concretionary ironstone. The Patti formation comprises of sandstones that are well inter-bedded with siltstones and clay stones (Plate I). The Lokoja formation consists of shales, siltstones and coal measures (Obaje, 2009). Quaternary to recent age alluvial deposit range from thin discontinuous sands to thick alluvial deposits along the Niger and Benue Rivers. The alluvial deposits include gravel, coarse and fine sand, silt and clay (Adelena *et al*., 2008).

Plate I: Section of Patti formation at Banda, Lokoja LGA
(Source: Author Field work)

Groundwater in the basin, occurs within the Patti and Lokoja formations as well as the alluvial deposits. The patti formation has been found to have lower hydraulic conductivity than the Lokoja formation with the value ranges from 6×10^{-2} to 3×10^{-5} m/s (Mends, 1992).

Based on the thickness data (Ojo and Ajakaije, 1989) about 500m for the Lokoja-Abaji section and a void space of 12-18%, the entire groundwater resource is estimated to be in the range of 290-430 km^3 (Adelene *et al.*, 2008).

1.6.3 Topography

The study area is characterized by undulating topography with limited flat terrain. The main high land are located around Okume (mount Patti) and ridge plateau near Agbaja. River Niger rises from Foutha Djallon highlands in Guinea and flow through Mali, Niger Republic and Nigeria before emptying into the Atlantic Ocean. Its main tributary, the Benue River flows from Cameroon and joins River Niger at Lokoja. The confluence of rivers created alluvial fertile soil good for agriculture and others smaller rivers such as river Nyetsu and river Mimi which empty respectively into river Benue and River Niger (Figure 1.2).

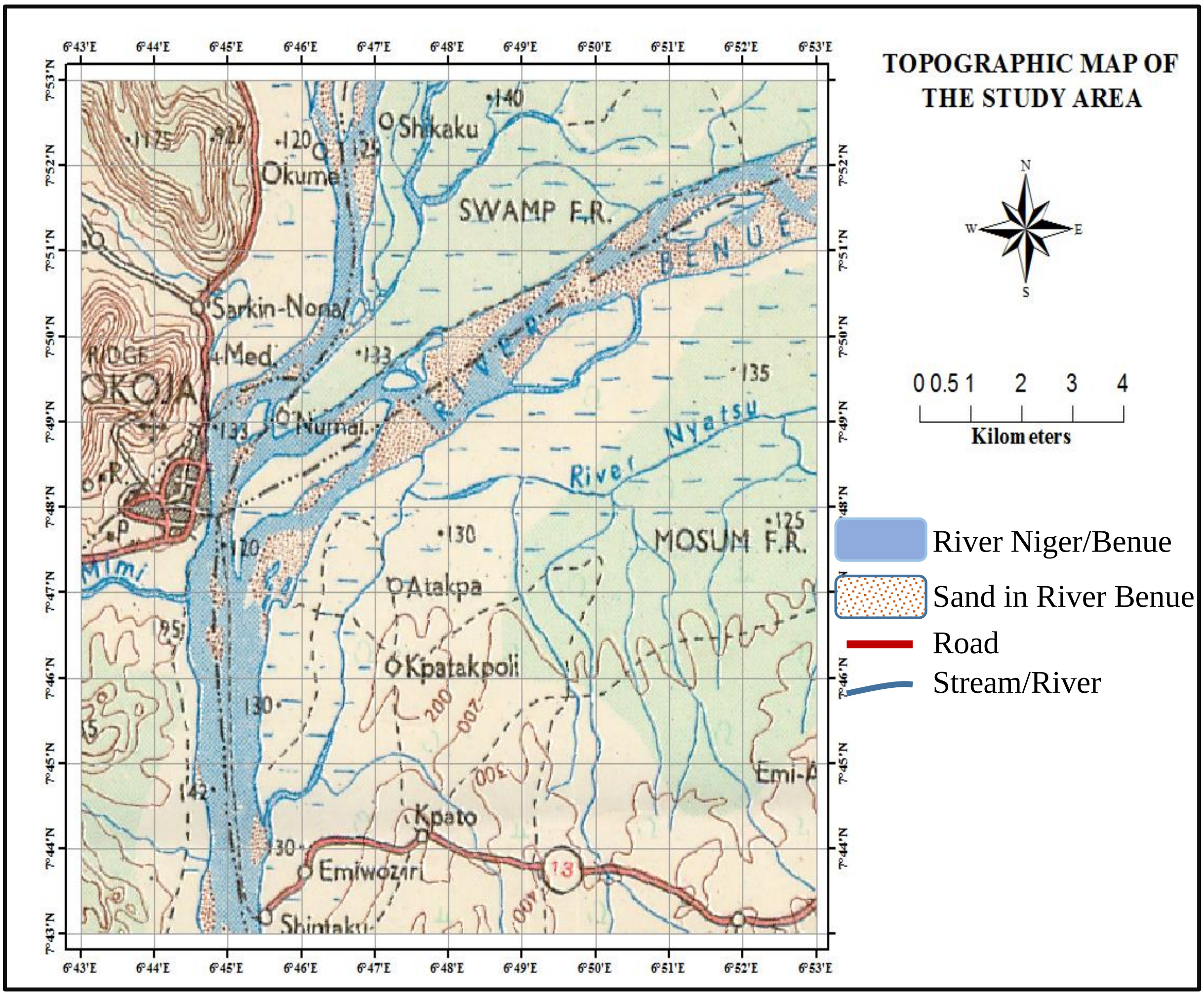


Figure 1.2: Topography map of the study area

1.6.4 Vegetation

Characterize by tropical vegetation, the study area is a mixed formation of trees, shrubs and grasses. This vegetation is green in the rainy season and tall grasses with fresh leaves, but the land is open during the dry season, showing burned trees and the remains of burnt grasses. The different types of vegetation are, however, not in their natural luxuriant state owing to the careless human use of the forest and the resultant derived deciduous and savannah vegetation.

(a) Around Kpatapkale

(b) Around Elule

Plate II: Tropical vegetation characteristic of the Guinea Savannah zone in Bassa LGA.

1.6.5 Climate

Annual rainfall of the state is between 804.5 mm (in 1982) and 1,767.1 mm (in 1999) with a mean value of 1205.2 mm (NIMET rainfall from 1971 to 2014). The rainy season lasts from April to October. The dry season, which lasts from November to March, is very dusty and of cold as a result of the northeasterly winds, which brings in the harmattan. Kogi State weather station data has an average maximum temperature of 33.6°C and an average minimum temperature of 23.0°C.

1.7 Organization of the Thesis

In order to set the stages for this thesis, it was divided into five (5) chapters. Chapter one (1), the general introduction, provides an overview of freshwater, state the problem, the study objectives and expectation. It also provides a justification for why this study was carried out in Kogi State. Chapter two (2) deals with Concepts and Literature Review which focused on scientific view on groundwater vulnerability to climate change. The outline of materials and methodologies which were used to collect and analyze data from the field work is contained in Chapter Three (3). Chapter Four (4) presents result from data analysis and some discussion of these result. Finally, Chapter Five (5) ended the thesis by draws conclusions from the study and suggest some recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

As mentioned in introduction, each chapter focuses on a specific object. This chapter aim is to set the current study in the context of other studies on climate change effects on groundwater. It was conducted following three major directions.

i. First, the review of major concepts and definitions on which this study is based;
ii. Review of previous works, methodologies and findings;
iii. Thirdly, identification of gaps from the reviewed literature that this study will attempt to fill.

2.1 Conceptual Framework

2.1.1 Climate Change and Climate Variability

Climate is a complex system which comprises atmosphere component (such as clouds, aerosols and radioactive gases), hydrosphere (oceans, lakes and wet lands), cryosphere (sea ice, land glaciers and snow), biosphere (vegetation effects on surface albedo, roughness and evapotranspiration, and carbon cycle both over land and in oceans) and land in various and multifaceted interactions like water cycle, carbon cycle and greenhouse effects. Climate in a particular region, represents the long term weather behaviour which changes from one day to another or one season compared to another or from one year to the following. In order to address the issue of climate change in this study, it is essential to understand the meaning of the term “climate change”, as opposed to “climate variability” in scientists’ sphere. Understanding the difference between climate variability and climate change and how scientists study both allows proper interpretation of information on weather and climate in the study area.

Climate change, according to Klove *et al.*, 2014, may be perceived as alterations in the local or global climate on different time scales. IPCC (2007) describe, climate change as modification in climate conditions over time, which may be provoke by natural fluctuation or as a consequence of anthropogenic activity. This usage differs from that of the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as a modification of climate condition attributed directly or indirectly to human activities. Climate change may be detected from historical data by using statistical tests such as changes in the mean and/or the variability of its properties (descriptive statistics), and that persists for an extended period, usually a decades or longer. This change in climate condition may be a result of internal processes and/or external forcing. Some external influences (such as solar radiation and volcanism) occur naturally and contribute immensely to the natural fluctuations of the climate system. Other external changes, such as the change in composition of the atmosphere that began with the industrial revolution are the result of human activities.

Cyclical changes in climate condition in a relative short time perspective are called climate variability (Klove *et al.*, 2014). Climate variability, according to IPCC (2007), describe variations in the mean state of climate and other statistics methods (such as standard deviations, statistics of extremes, etc.) of the historical climate data on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). According to Klove *et al.*, 2014, this variability for groundwater can be illustrated as oscillating changes in recharge (P-ET-R), where the annual recharge varies in a regular or irregular manner that can resemble oscillations.

The climate of the earth is naturally on continuous mutation in all time scales (from one day to another, one month to another or one year to another). However, the balance between incoming solar radiation and outgoing from earth characterize its long-term state and mean temperature, which determines the Earth's energy balance. Climate change is a result of important change on the earth energy balance which may be due to external or internal factors. Factors external or internal to the climate system, are referred to as "climate forcers", invoking the idea that they oblige or drive the climate system in the direction of a new long-term state either cooler or warmer depending on the cause of change. Several natural phenomena related to atmospheric and/or oceanic circulation can affect the climate locally or globally, causing changes and/or variability (Klove *et al.*, 2014). The impacts of climate variability or climate change on groundwater have been less well explored than those on surface water (Green *et al.*, 2011).

2.1.2 Groundwater Resources

Groundwater is water that exists in the pore spaces, fissures and fractures in rocks and sediments beneath the Earth's surface (Chilton and Seiler, 2006; Green *et al.*, 2011; Wallace *et al.*, 2012). Groundwater includes all subsurface water comprising soil water, deeper vadose zone water and unconfined and confined aquifer water (Green *et al.*, 2011). This study interest is on the last two types of subsurface water. It is an important part of freshwater for human throughout the world. Indeed, one third of the world population depends on groundwater for their domestic water in urban as well as rural areas. In rural areas in arid and semi-arid regions particularly, life depends on it. However, this importance of groundwater is neglected or have not given enough attention especially in developing countries. According to Olasehinde (2010), many people underestimate the value of groundwater in supporting water supply because it is not visible on the surface and probably because of misinformation about groundwater.

2.1.3 Physical Framework of Groundwater Resources

The rocks pores, fissures or fractures on which groundwater is stored or flows are called aquifers. Aquifers may therefore, be defined as layers of rock or sediments with adequate pores to store water and permeable enough to allow water to flow through them in economically viable quantities (Chilton and Seiler, 2006). Olabode, Eduvie and Olaniyan, (2012) affirm that the spatial spreading and circulation of groundwater is organized by geological features such as the lithology, texture and structure of the rocks and by hydrological and meteorological factors such as stream flow and rainfall. Aquifers may occur in both unsaturated and saturated zones. The unsaturated or vadose zone contains both air and water, while in the saturated zone all of the voids are full of water (Chilton and Seiler, 2006). The water table or phreatic level represent the limit between the two zones, and is the surface at which fluid pressure is exactly equal to atmospheric pressure. The groundwater above the phreatic level contains soil water, intermediate zone water and capillary water. Below the phreatic level, usable groundwater is mainly the one in saturated zone. Generally hand-dug wells are made in a few meters under the ground in the unsaturated zone and are more affected by climate condition. These wells usually are full of water in rainy season and dry up during the dry season in arid and semi-arid region. In rural areas, this type of wells are more exposed to human activities (pollutants) due to proximity to the earth surface and unfortunately they are most used because of their cost-effectiveness. Boreholes on other hand are generally more profound and made in saturated zone.

2.1.4 Occurrence and Storage of Groundwater

Groundwater is formed principally by the infiltration of precipitation or by other surface water bodies. Climate change and the global water cycle are closely linked. Changes in the spatial and temporal distribution of precipitation, temperature and evapotranspiration as well as the implementation of adaptation strategies in agriculture and by ecosystems will have a direct impact on water resources (Stoll, Hendricks, Butts and Kinzelbach, 2011). Additionally, an increase of air temperature will increase potential evapotranspiration. These phenomena will affect the hydrological system leading to changes in the temporal variability of discharge, changes in the spatio-temporal distribution of soil moisture and groundwater recharge and changes of water quality.

Groundwater is stored or flows through pores in geologic formations. Some geologic formations contain pores with interconnection between them. Such formations are called aquiclude (such as clay). Those with interconnected pores but not enough to allow significant horizontal flow through them are termed aquitard (Such as silt). There is another type of geologic formations without pores or voids. These are titled aquifuge (such as granite). Depending on the geology of the rock in which water is stored or flows many types of aquifers were identified by authors (Kruseman, De- Ridder and Verweij, 2000; Rushton and Kruseman, 2004). When aquifer is formed between two impermeable aquiclude, such aquifer is termed “confined aquifer”. Groundwater exists in three major rocks in Nigeria named igneous rocks, sedimentary rocks and metamorphic rocks (Olasehinde, 2010).

2.1.5 Groundwater Recharge

The rate of aquifer recharge is the most important factor for groundwater management particularly in arid and semi-arid regions (Allen, Mackie and Wei, 2004) like the Guinea Savanna zone in West Africa. Groundwater occurs in rainy season when the amount of rainfall is enough to infiltrate. When the rain falls, some are intercepted by plants leaves, some flow as surface runoff (depending of topography and soil cover) and the remaining infiltrate. Much of this moisture (in unsaturated zone) is taken up due to evapotranspiration from the soil zone by the roots of plants and some become interflow drainage to streams and rivers. Surface water (runoff) and open water bodies (stream,rivers, lakes) also are subject to evaporation. Since recharge is from rainfall, in humid areas, increased variability in rainfall may lead to decrease groundwater recharge (BGR, 2008) because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby inceasing surface runoff. However, in semi-arid and arid areas increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations (Bates *et al*., 2008). Changing in precipitation patterns together with increased temperatutre (IPCC, 2007), which linked to evapotranspiration will affect groundwater recharge amount and groundwater table dephts (Bovolo *et al.*, 2009).

2.2 Review of Previous Studies

To understand the crucial effects of climate change on groundwater, review of some studies have been done under different predicted climate change scenarios. The literatures reviewed in this study, follow two major interest; climate change impact on groundwater recharge and quality aspect.

2.2.1 Climate Change Impact on Groundwater

Climate change has direct and indirect effect, and will continue to affect, groundwater quantity in many complex and unprecedented ways (Treidel, Bordes and Gurdak, 2012). Climate change effects studies on water resources has extended in the last few periods in the world. Predicted changes in temperature and precipitation due to climate change are expected to significantly alter hydrologic systems. One expected impact of climate change will be on groundwater levels due to changes in the rate of recharge.

Philip and Batelaan (2009) investigated effects of climate change on aquifers recharge in the upper Ssezibwa basin in Uganda. Historical climate data (temperature and discharge) were subjected to trend analysis in order to establish evidence of climate change. Statistical downscale model (SDSM) were then used to obtain future climate scenarios (A2, B2) data from HadCM3 model. WetSpa hydrological model were used to estimate current (1961-1990) discharge and base flow and to predict future (2020s, 2050s and 2080s) using scenarios A2 (High) and B2 (Low). The results shows considerable variation in predicted precipitation in the wet season (increase of 100% in 2080s) and temperature increase (from 1-4 ˚C). The current base flow is expected to increase by 20-80% between 2020s and 2080s. According to them, those changes will increase recharge rate by 20-100%.

Leterme and Mallants (2011) sought to estimate groundwater recharge for the next millennia in Nete catchment, Belgium. Results show that future warmer climate condition will decrease (-9%) groundwater recharge. Furthermore, the authors found out that land use change to croplands (maize) will lead to increase aquifer recharge by 31% while conversion to coniferous forest will result in decrease in the recharge rate by 42%. Strong correlation and feedback between climate change and land use change effects on groundwater recharge were pointed out in this study.

Teklebirhan *et al.* (2012) estimated the spatial distributed groundwater recharge, surface runoff, and evapotranspiration in Illala catchment, Northern Ethiopia. WetSpass model were used as hydrological method for it accurate result from previews studies. Hydrogeological data and physical characteristics of the catchment were used as inputs in the model. They found a low infiltration rate (12% of the total annual rainfall) due to high evapotranspiration (81% of the total annual rainfall). This evapotranspiration were explained by high temperature, dry wind, low rainfall and relative humidity.

Mogheir and Ajjur (2013) used water balance model (WetSpass) and groundwater modeling program (Modflow) to quantify the risks of climate change on groundwater in terms of quantity of Gaza Strip under future climatic condition. The temporal relationships between the most sensitivity parameter; the rainfall and the recharge were studied and the results showed a high correlation (0.96 to 0.99) between them. It highlight the fact that any change in rainfall mode affects the quantity of groundwater. WetSpass model was used to simulate seasonal and annual water balance component including groundwater recharge in this study. Groundwater elevation and discharge (seasonal aspect) and its spatial aspect were also simulated with Modflow model. Mogheir and Ajjur noticed that, after 1995 rainfall decreased by 63.8 % (Beit Lehia Station) and that caused deficit in recharge values with 87.64 %.

Bokar *et al.* (2012) estimated groundwater level fluctuations and simulated groundwater table in Kolondieba catchment Basin in Sudanese Climate Zone in Mali. Through the groundwater flow model and global climate model (GCM), they found out that groundwater is discharged into network catchment basin and groundwater levels were dependent upon rainfall. The predicted values from 1940 to 2065 showed decrease tendency in water level.

2.2.2 Recharge Estimation Methods

Climate Change is shown to affect intensely groundwater recharge (Philip and Batelaan, 2009; Bokar *et al.*, 2012; Mogheir and Ajjur, 2013) and a lot of methods are used to assess groundwater recharge. Bakundukize, Camp and Walraevens (2011) classified them into two groups, namely physical and chemical methods. Comparative study of all these methods are well describe by Kinzelbach *et al.*, (2002).

According to Bakundukize *et al.*, 2011, physical methods comprise:

i. Direct method: lysimeter and seepage meters (Scanlon *et al.*, 2002; Sophocleous, 2004; Rushton *et al.*, 2006);
ii. The water table fluctuation method (Scanlon *et al.*, 2002);
iii. The catchment water balance method (Sophocleous, 2004; Chilton and Seiler, 2006);
iv. The zero flux plane method (Kinzelbach *et al.*, 2002; Scanlon *et al.*, 2002);
v. The Darcy method (Flint *et al.*, 2002; Sophocleous, 2004);
vi. Inverse modelling (Kinzelbach *et al.*, 2002)
vii. Hybrid water fluctuation method (Kommadath, 2000; Sophocleous, 2004);
viii. Empirical methods (Kommadath, 2000; Sophocleous, 2004), and
ix. Soil water balance models (Rushton *et al.*, 2006; Misstear *et al.* 2008).

Chemical methods consist of tracer methods (Sophocleous, 2004; Flint *et al.*, 2002; Rushton *et al.* 2006; Misstear, 2000; Kommadath, 2000, Kinzelbach *et al.*, 2002) such as

Chloride method, Tritium method, Tritium-Helium 3 method, Stable isotopes, Carbon 14, Bromide in unsaturated zone and New gas tracers CFC and SF_6. Other relevant methods are described by Kinzelbach *et al.*, 2002 such as Remote sensing methods for indicators.

This study estimate groundwater recharge using general water balance approach. Water balance estimation is an important and rapid tool to assess the current status and trends in water available in an area. According to Kinzelbach *et al.*, (2002), water balance approach, as well as others methods, present some advantages and disadvantages. The calculation is conducted using standard climate data and can be done in a spreadsheet such as Excel. Accuracy of the method is relatively low for the simple reason that recharge is estimate by the difference between two inaccurate climate parameters (precipitation and evapotranspiration). Water balance equation in any geographical region can be expressed as:

Precipitation= Runoff +Evapotranspiration + Recharge (or infiltration)

This approach is recognized to be reliable and flexible for routine potential recharge estimation (Kinzelbach *et al.*, 2002, Rushton *et al.*, 2006) and have been applied successfully in Ona River Basin south-western part of Nigeria by Oke *et al.*, (2014).

2.3 Gaps from the Reviewed Literature

Literature reviewed show from past data analysis some signal of climate change which have effects on groundwater level. Most studies used data downscaled from GCM for future predictions of water table. Hydrological models are coupled with GIS tools to estimate groundwater recharge and discharge. Generally, studies conducted on climate change impacts on groundwater are focused on the quantity aspect without adequate consideration to the quality aspect and that because of lack of past data on groundwater quality. In this study area, very little work has been done on climate change impact on groundwater quantity. This study will attempt to fill those gaps.

CHAPTER THREE

3.0 MATERIALS AND METHODS

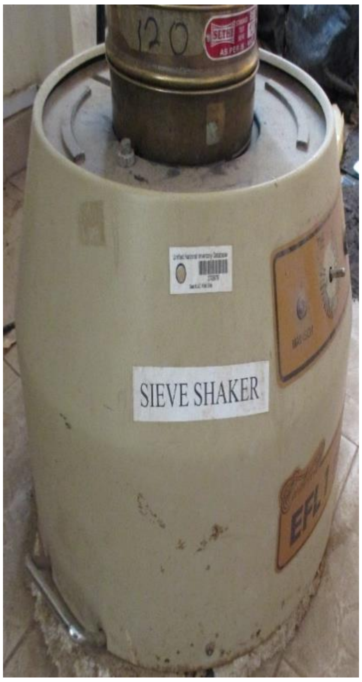
This study is aimed at the assessment of effects of climate change on groundwater resources in 3 LGA's (Lokoja, Bassa and Kotonkarfe) of Kogi State. Specifically, this chapter discussed the materials, data collection processes and methods of analysis which were used to achieve the aim of the study. For that purpose, primary and secondary data were collected from ministries, departments, agencies and educational institutions within and outside the study area. The summary of the main steps and activities involved on each chapter to achieve this thesis objectives is presented as followed in the table 3.1

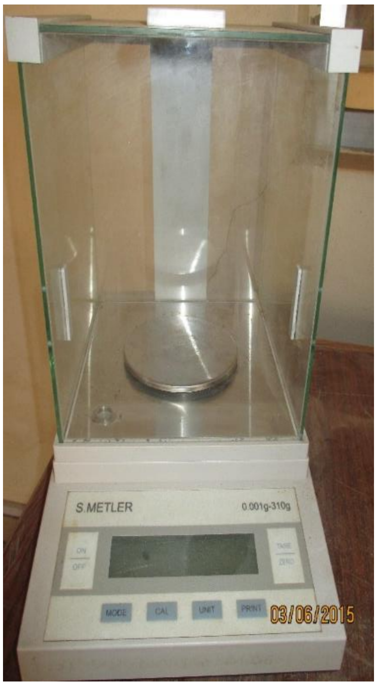
Table 3.1: Flowchart of research methodology

General steps	Activity involved	Procedures	Sources
Chap 1 and 2: ❖ State Problem ❖ State Objectives ❖ Literature Review	Review literature	Read: - reports - Articles - Thesis - Journal	-Internet -Library - Book
Chap 3:	- Search maps - Download maps - Sampling process - Climate data	-Soil sample -Temp, Rainfall, ETP, solar radiation, wind speed	Field work, Kogi State
❖ Data Collection	Modify data to model compatible format	- Temperature - Rainfall - PET - Solar radiation -Relative humidity	
	Graphs	-Data screening	
❖ Data Preparation		-Run the model	Desk work at
❖ Data Analysis	Statistical analysis		Wascal Center FUT, Minna
Chap 4: ❖ Results ❖ Discussing		- Reports results - Plots - Discuss results	
Chap 5: ❖ Conclusion ❖ Recommendations	- Finding	Answer research questions	

3.1 Materials

During the field work, the principal instruments which were used to collect relevant information to the thesis objectives include GPS, digital camera, shovel, polythene bags and questionnaires. The GPS was used to obtain the coordinates of wells, boreholes, soil samples location and other relevant coordinates such as roads, water bodies, villages, land cover and land use types. Digital camera was used to capture pictures considered relevant to the study. The shovel and plastic sachets were used respectively for digging and collecting soil samples. Questionnaires were used to collect inhabitants' perceptions or feelings about climate change and its effects on domestic water in general, especially on groundwater. Laboratory analysis of soils samples conducted in Hydrogeology Laboratory (Geology Department), FUT Minna, Nigeria was mainly sieve analysis using sieves (Plate 3.1) of different size (A), sieve shaker (B) and weighting balance (C).





(A) Sieves (B) Sieve Shaker (C) Weighting Balance

Plate III: Sieve analysis materials

Desk work engaged the use of software such as ArcGIS 10.1, SPSS 20, and Office 2013 for data preparation and analysis as well as thesis report writing. Table 3.1 presents the summary of materials used during the field work.

Table 3.2: Summary of materials used during this work

N◦	Materials	Purpose
1	Global Positioning System (GPS)	Spatial position record of the selected sites for groundwater (wells) sampling
2	Digital camera	Evidence of climate change on water supply or other relevant pictures for the study
3	ArcGIS 10.1	Identification of the sampling sites
4	SPSS 20	Statistical analysis
5	Office 2013	Thesis writing

3.2 Data Collection Methods

Data collection processes include questionnaire administration, obtaining of climate data from NIMET and soil sampling and analysis procedures.

3.2.1 Questionnaire Administration

Questionnaires were used to collect people's view or feeling about climate change and its impacts on water availability for domestic needs. Ecosystem natural resources on which population life depend are strongly affected by climate change and its consequences. According to the view of Doss and Morris (2001), the perceptions of the indigenous people, the way they think and behave in relation to climate change, as well as their values and aspirations have a significant role to play in addressing climate change adverse effects. For this reason, a well-structured questionnaire easy to understand by the indigenous population was designed and it includes:

- Socio demographic information about the respondent;
- Water sources for domestic need;
- Climate change perception; and
- Climate change impact on groundwater.

A total of 50 questionnaires were prepared and only 45 of them (90%) were administered (Plate 3.2) during the field work in ten (10) villages in the study area. The localities which were randomly chosen within the study area include Banda, Felele, Lokoja (in Lokoja LGA), Shintaku, Kpata, Kpatakpale, Atakpa and Elule (in Bassa LGA) and Onumaye and Edumose (in Koton-Karfe LGA). Owing to the relatively small population size of the localities/villages, only five inhabitants were randomly selected and the questionnaires were administered to them through interpreters due to language barrier. The respondents were chosen based on their age (older than 20 years). Three (3) interpreters were employed during the questionnaire administration especially for the principal reason that many languages are spoken in the study area and to ensure a very good translation.

Plate IV: Questionnaire administration at Onumaye, Kotonkarfe LGA

3.2.2 Climate Data

Climate change evidence has been done through analysis of the most appropriate indicators (Mogheir and Ajjur, 2013); that is, rainfall and temperature data. For that purpose, daily minimum and maximum long term temperature and daily mean rainfall data were acquired from Nigerian Meteorological Agency (NiMet), Abuja. For groundwater recharge assessment purpose, other necessary meteorological data such a mean wind speed, solar radiation and relative humidity were also acquired from the same agency. The Climate data collected from NiMet are described in the Table 3.2.

Table 3.3: Climatic data Utilized

PARAMETER	PERIOD	CHARACTERISTICS
Solar radiation	1985 – 2014	Daily average solar radiation
Relative Humidity	1981 – 2010	Daily average relative humidity
Wind Speed	1975 – 2007	Monthly average wind speed
Temperature maximum	1975 – 2014	Daily average maximum temperature
Temperature minimum	1975 – 2014	Daily average minimum temperature
Rainfall	1971 – 2014	Daily rainfall*****

Source: NiMet Agency, Lokoja weather Station

3.2.3 Wells and Boreholes Data

An inventory of some hand dug wells and boreholes was taken during the field work and the coordinates of their locations were recorded with GPS. Unfortunately, all wells and boreholes coordinates in the study area were not recorded for lack of time and fund. The inventory for this study concern wells and boreholes expressly identify by villagers as the mostly used.

3.2.4 Soil Sampling Procedure and Laboratory Analysis

Water storage rate in aquifer is governed by porosity and permeability of soil materials through which water flows (Chilton and Seiler, 2006). Odong (2007) affirm that hydraulic conductivity estimation using grain size distribution characteristics was the less expensive method developed to assess the transmitting properties of soil media. In this view, soil samples were collected during the field work. The same localities selected for the questionnaire administration were the collection sites for soil sample collection, generally not too far from wells or borehole identified by village dwellers as the ones mostly used by the villagers. Three (3) samples were collected for each location respectively at 0 cm, 50 cm and 100 cm to assess water flow characteristic for the first meter under the soil surface. The soil was dug (Appendix C) using a shovel and collected in clean polythene bags and properly sealed. Each sample was labelled using the local name and the level at which the soil was collected using a permanent marker. The sample site or location coordinate was determined using a GPS. Laboratory analysis of soil sample were conducted through dry sieve analysis test. This test describes particles size distribution in a soil sample by grouping particles into separate ranges of sieves. Particles between each range of sieve were weighed and use to determine the relative proportion retained. The samples were initially spread in the laboratory (Plate IV) to dry up at ambient temperature during 24 hours to avoid alteration in material particles size and sample contamination from others soil material.

Plate V: Soil samples spread in the Laboratory

Then, an initial weight (250 g) samples were separated according to particles size using series of sieves (Appendix C) with progressively smaller openings. The big size particles were retained at the top and gradually the finest particles were retained down. Sieves number and their openings are described in Table 3.3.

Table 3.4: Sieves opening used for soil analysis

Sieve Number	Equivalent opening (mm)
10	2
20	0.841
44	0.354
60	0.25
80	0.177
100	0.149
120	0.125
Pan	Pan

Results from the dry sieve analysis are summarize in Appendix D and used to plot semi logarithmic graph using Excel 2013 (Appendix E). Hazen (1892) formula was used to compute Hydraulic Conductivity (K).

3.3 Data Analysis Methods

In order to answer the research questions, all the data collected were analyzed and discussed according to the specific objectives of this work:

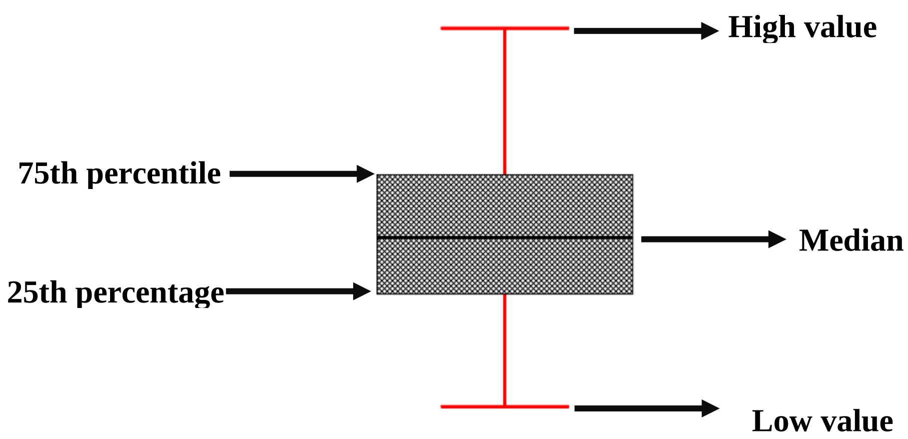
- ❖ Population perception about climate change and its effects on groundwater availability;
- ❖ Evidence of climate change through past climate data analysis;
- ❖ Monthly and annual groundwater recharge estimation.

3.3.1 Climate Perception

The best ways to assess climate change or fluctuation impact on population life is to make direct enquiries. To do that, a questionnaire was prepared and administered to people living in the study area (Appendix I). Questions were organized by section to make the understanding and computation easier. Responses for each question were used to calculate a percentage of answers and then bar charts were plotted for each question. Data from the questionnaire were analyzed using excel 2013.

3.3.2 Evidence of Climate Change

Daily climate data obtained from NIMET were algebraically averaged to get monthly mean values for each year over the study period using excel. In order to conduct a serious statistical analysis, rainfall and temperature data were subjected to normal distribution test (descriptive statistics and the measures of dispersion) in SPSS 20 software through box plots and bar plots. Box plot is a graphic way which helps to visualize the distribution characteristics of a data by showing high and low values, median value, 25 and 75 percentiles of data values range in ascending order.



A trend analysis was conducted to investigate climate parameters (rainfall and temperature) behavior over the past years. Trend analysis was examined using Microsoft excel 2013 through time series and bar charts plots for rainfall and temperature (minimum and maximum) and then generated the trend line and its equation. The trend line displayed the direction of change.

To estimate the inter-annual change in past using the data collected, Standardized Precipitation Index was computed with excel 2013. Standardized Precipitation Index (SPI) is a measure of distance, in standard units, between a data value and its mean. SPI is a tool which was developed by McKee *et al.* (1993) primarily for defining and monitoring drought. It allows the determination of drought events frequency at a given time scale (temporal resolution) of interest for any rainfall station with historical data. It can also be used to determine periods of anomalously wet events at a particular time scale for any location in the world that has a precipitation record. The following formula was defined by McKee *et al*., 1993 for standardized precipitation index:

$$SPI = \frac{X_i - X_m}{s}$$

Where: Xi is the cumulative rainfall for year i; X_m and S are respectively the mean and the standard deviation of annual rainfall observed that series.

The result of SPI computation was plotted with respect to years and was interpreted using the SPI table 3.4 below (WMO, 2012).

Table 3.5: SPI classes (WMO, 2012)

SPI Values	Classes
2.0 +	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

3.3.3 Recharge Estimation

Recharge rate measurement with accuracy is one of most difficult and indispensable parameters in water management process. As shown in literature review, a larger number of methods exist to estimate annual recharge. Water balance method was used for recharge assessment in this study and it equation is as follow:

$$\mathbf{P = I + R + PET}$$

Where: **P**= Precipitation/Rainfall;

I= Infiltration (recharge or water storage into the soil);

R= Runoff;

PET= Potential Evapotranspiration.

If the soil moisture and base flow are assumed constant, the above equation can be written as:

$$\mathbf{I = P - (R + PET)}$$

From this formula, aquifer recharge depends on climate condition.

a) Precipitation (P)

Daily rainfall data collected from NiMet were added to obtain monthly values and used to estimate the amount of rainfall which flows to aquifers per month.

ii) Runoff (R)

Surface runoff is define as water, from rain, snowmelt, or other sources, that flows over the land surface, it represents one of the major component of the water cycle. Runoff that occurs on surfaces before reaching a channel is also called overland flow. The calculation of runoff is conducted using Ayoade (1975) formula based on relationship between rainfall and runoff. Value of runoff is estimated by multiplying the precipitation (P) by runoff coefficient (Rc) where Rc= 23.64% **(**Ayoade, 1975; Ayoade, 2010; Oke et al, 2013).

$$\mathbf{R = P \times R_c}$$

iii) Potential evapotranspiration (PET)

Potential evapotranspiration is the amount of water that would be evaporated under an optimal set of conditions, which is an unlimited supply of water (Bakumdukize et al 2011). A lot of methods in litterature can be used for evapotranspiration estimation such as FAO Penman-Montheith (Allen *et al.*, 1998; Blaney-Criddle, Thorntwhite model equation. In the case of Nigeria, Blaney-Morin-Nigeria (BMN) potential evapotranspiration model has been developed to fit the country's climate condition. Duru (1984), proposed a modified BMN equation because of wide variabilities observed in relative humidity over the country. For that reason, relative humidity should be taken as a crucial parameter in any model for evapotranspiration in Nigeria. In this study, evapotranspiration (PET) was determined using the modified equation by Duru (1984). The BMN model is currently the only PET model specifically developed for the Nigerian condition and it is widely used in the country (Duru, 1984; Dike, 2005; Edoga and Suzzy, 2008; Odofin et al ,2011). This equation is expressed as follow:

$$PET = r_f * \frac{(0.45T + 8)(520 - R^{1.31})}{100}$$

Where: **PET**=Potential evapotranspiration (mmday^{-1}); r_f = is radiation ratio which is calculated as the ratio of maximum possible radiation to the annual maximum; T = mean daily temperature in (°C) obtained by averaging the daily maximum and minimum temperatures; R= mean daily relative humidity in (%) obtained by summing the daily means of relative humidity at 09 h 00 m and 15 h 00 m GMT.

All the parameters needed for recharge estimation were computed using excel 2013 at monthly time scale and then averaged for annual values. Descriptive statistic, bar plots, time series and Kendall's tau b correlation were used to interpret results from recharge estimation. Descriptive statistic include Minimum, Maximum, Mean, Median and Standard Deviation determination. Time series allow a visual behavior of annual recharge over the study period. Kendall's Correlation was used to assess the degree of the relationship among parameters used for recharge estimation.

3.3.4 Soil Analysis

In order to appraise the natural ease with which water flows through the porous medium and recharge aquifers, dry soil sieve analysis was conducted. Groundwater storage and flow depend on grain size organization and granular porous media (Chilton and seiler, 2006). According to the same author, hydraulic conductivity in the laboratory, is a measure of the ease with which water flows through the sand contained in the cylinder experiment or through the various materials that form aquifers and aquicludes. Many researchers have studied this relationship between grain size and hydraulic conductivity and several formulae were proposed based on experimental work. Kozeny (1927) suggested a formula which was improved by Carman (1937, 1956) to become the Kozeny-Carman equation. Other attempts were made by Hazen (1892), Alyamani and Sen (1993). The results from sieve analysis were used to estimate Hydraulic Conductivity (K) by empirical method using the Hazen formula (Hazen 1892). Hazen expressed hydraulic Conductivity (or permeability) as function of square of 10th percentile grain size diameter (d_{10}).

$$k = C_h * d_{10}^2 \quad \text{(Hazen, 1892)}$$

Where: $\mathbf{C_h}$ is empirical constant set as **0.0117** in this thesis because of soil texture type in the study area.

Hazen empirical is generally accepted and depend only on particle size for which 10% are finer (d_{10}) that justify it used. Simple Statistical tools were used for interpretation of data from laboratory analysis with IBM SPSS statistics 20 software.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

To achieve the objectives of this thesis, the data collected were analyzed following procedures described in the preceding chapter (chapter three). Chapter four presents the results from the data analyzed and discusses the findings. The results discussion includes the results from questionnaires administered to inhabitants in the study area on their perception of climate change and its potential impact on groundwater. It also presents climate change evidence through historical data (rainfall, minimum and maximum) analysis. Additionally, hydraulic conductivity from soil analysis is presented and discussed.

4.1 Climate Perception in the Study Area and it Impact on Groundwater

Respondents were asked about their personal perceptions on climate pattern over the past years and how it affects groundwater quantity and quality. Results of the questionnaire analysis are presented as bar charts of the percentage of responses.

4.1.1 Socio-Demographic Information about Respondent

The socio demographic information of the respondents is presented in Figure 4.1. Majority of respondents (91.1%) were male while 8.9% were female. Women in the study area declined responding to the questions because of religion reason. They do not talk to other men directly without approval from the head of the family. Moreover, some women refused to answers the questions because for them, the husbands' responses are theirs too. 42.4% of respondent's age were from 41 to 60; between 61 to 80 years (22.2%), while

6.7% of respondents were older than 80 years. The youngest of respondent were between 21 to 40 years with a percentage of 28.9%. Questionnaires were administered to the more experienced and matured population because they are better at distinguishing climate change from simply inter-annual variation of weather. Most of respondents were old enough to be able to talk about climate change.

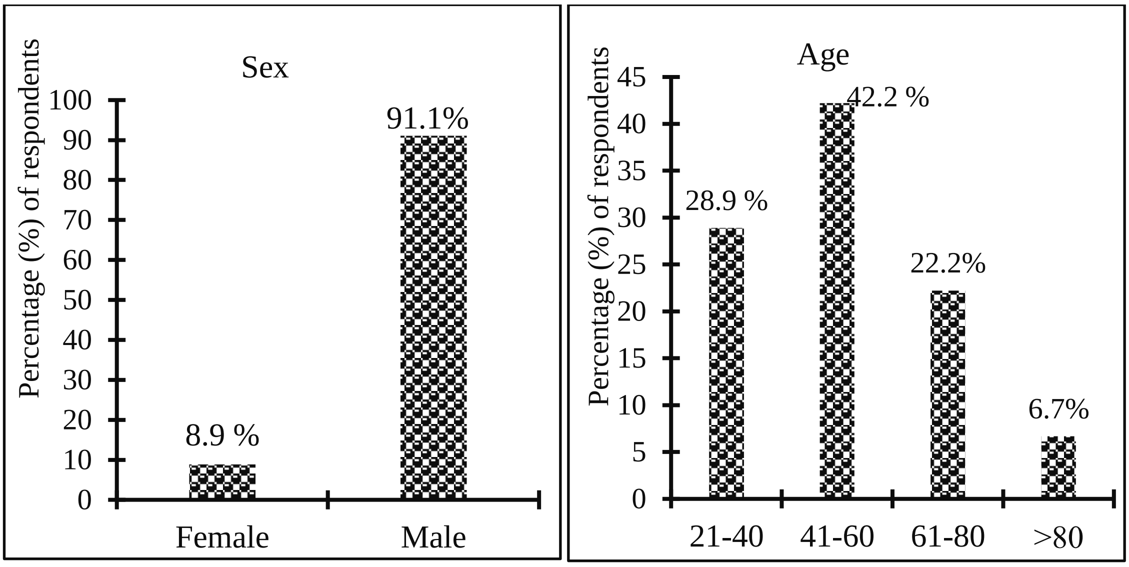


Figure 4.1: Sex and age of respondents

Considering respondents level of education and whether they are village native or not, Figure 4.2 gave more details. Maximum of respondents were natives of the study area (86.7%) while 13.3 were strangers with long period spent in the village. Respondent's educational level improves their understanding of questions related to climate change. 22.22% of inhabitants interviewed who are mostly farmers and fishermen did not go through any formal education process. 15.6%, 35.6% and 26.7% of respondents attained primary, secondary and tertiary levels of education respectively.

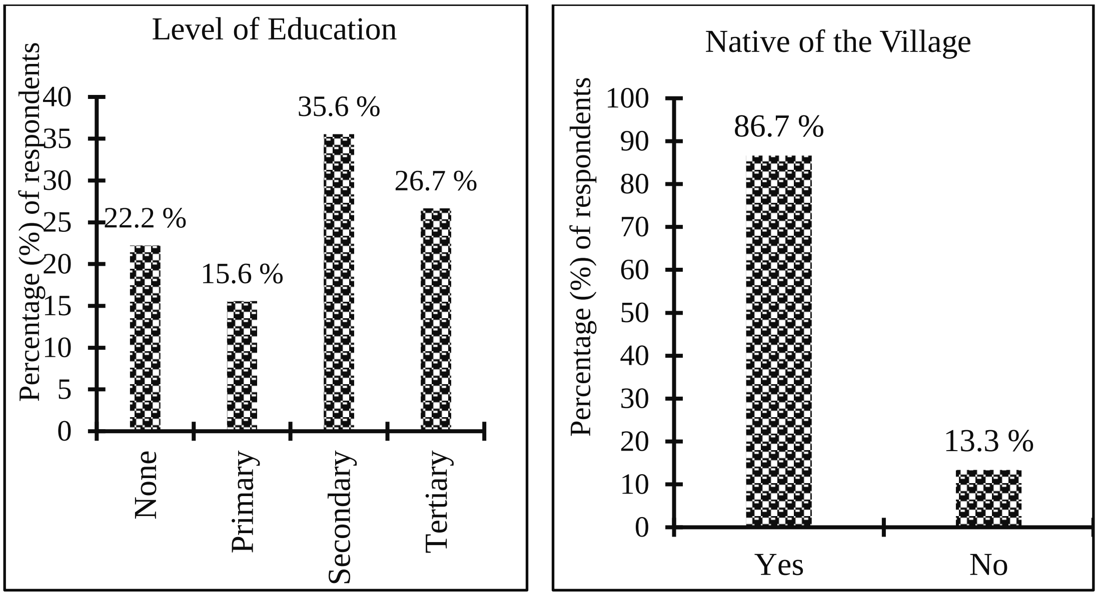


Figure 4.2 Respondents level of education and nativity

4.1.2 Water Sources for Domestic Need

Water sources for domestic need is predominantly Wells, Boreholes and Rivers (Niger, Benue, Mimi). Majority of respondents (77.8 %) affirm the use of all the sources available either in the same time or according to season of the year (Figure 4.3). This is the case concerning population in localities of Felele, Lokoja, Banda, and Elule. Only few respondents (22.2%) affirm that the unique source of water throughout the year is rivers. For example, at Shintaku, Onumaye and Edumose, because of the location of their villages (between rivers), according to them, there is no need to dig wells or borehole since water for domestic and agriculture need is available all the time. The choice of the place for the villages was based on the proximity to rivers. Hand dug wells and boreholes are used by inhabitants far away from the rivers with respective percentages of 20% and 24.4%. Most of inhabitants of the study area representing 55.6 % use only water from rivers. Those using hand dug wells or boreholes, during a shortage period (dry season) revert to rivers or water vendors.

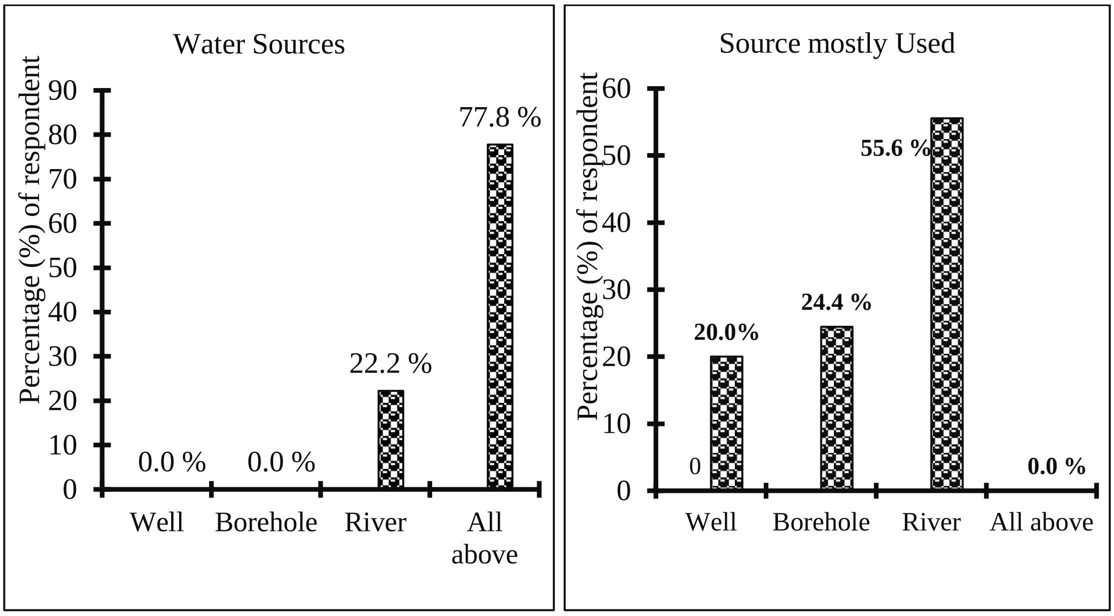


Figure 4.3: Domestic Water for population daily needs

Water in the study area is used for domestic purpose and also for agriculture (irrigation) according 97.8% of respondents view (Figure 4.4). Distance of Water sources from dwelling places rarely exceeds 1 km (86.7%); 11.1% of respondents affirm that water source is between 1 to 2 km from their households; water sources location greater than 2km were about 2.2%.

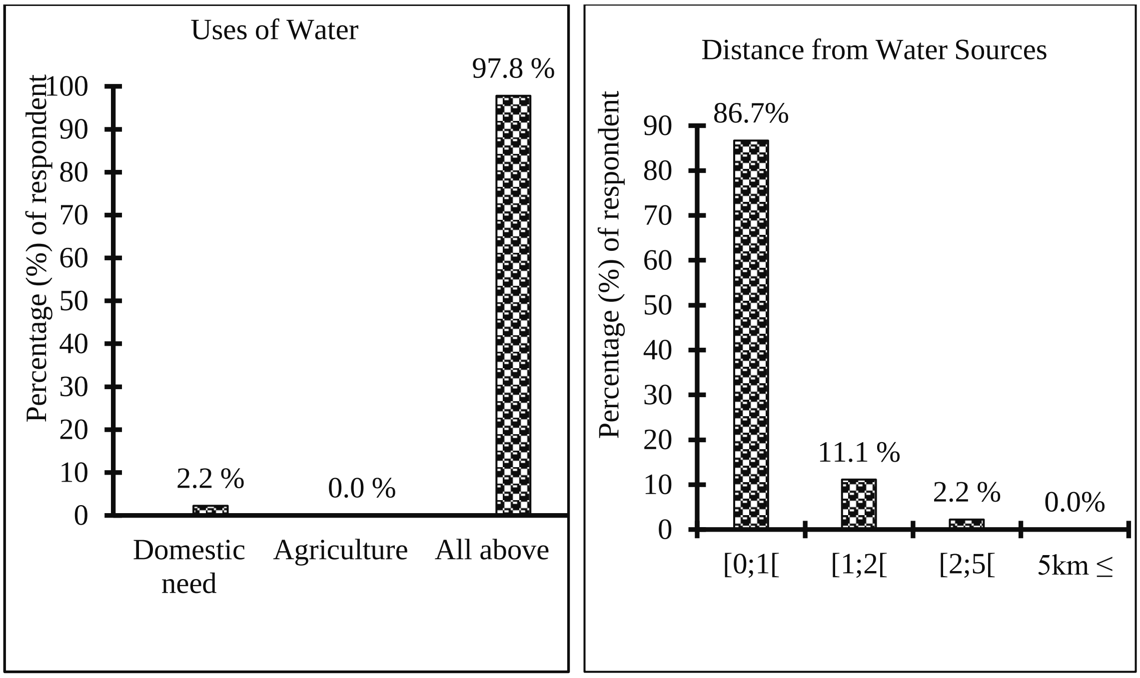


Figure 4.4: Uses and distance of water sources from habitation

The respondents largely (71.1%) believe that water is enough for their need throughout the year but some still rely on water vendors (40%) especially during the dry season (Figure 4.5).

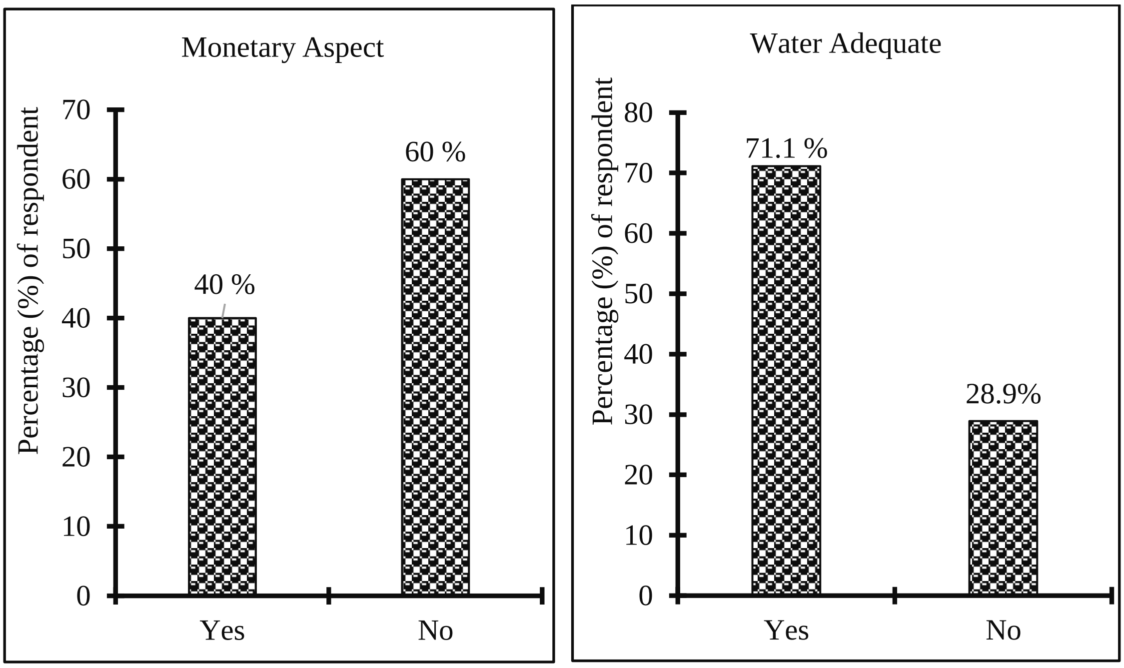


Figure 4.5: Water adequate and monetary Aspect of the availability for population use

4.1.3 Respondents' Perception about Change in Climate Condition

The study reveals that 44.4% of the respondents (Figure 4.6) have the view that rainfall intensity has become low over the years; 6.7% believe that the amount of rainfall per year has increased; while 15.6% are of the opinion that it has neither increased nor decreased over the years. 31.1% have observed observe fluctuation in the rainfall pattern while 2.2% are not sure of any change. Most of respondents (64.4%) observe that the raining season onset is now later than previous years while 17.8% affirm fluctuation in the start of raining season. Some of the respondents (13.3%) think that the raining season starts earlier than before and very few (4.4%) of them perceive no change on rainfall onset date.

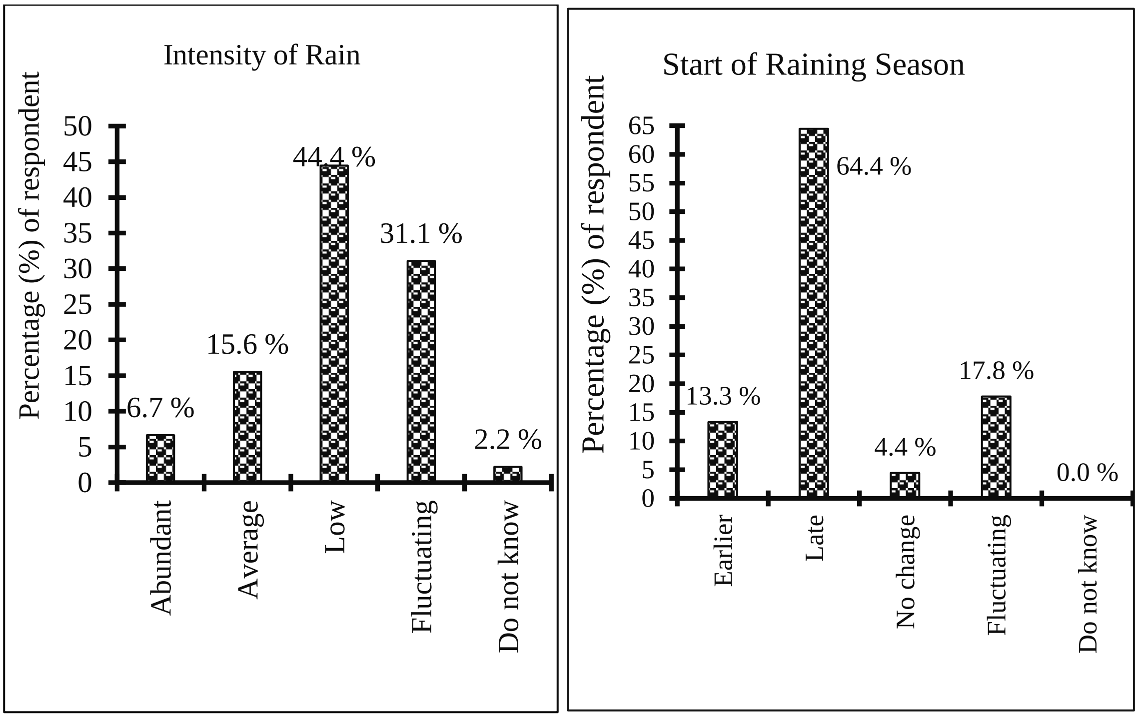


Figure 4.6: Rainfall amount and start period in the study area

Majority of the respondents (64.4%) are of the view that rainfall cessation is now late when compared to preceding periods, 13.3%, 17.8% and 4.4% respectively believe that the rain ceases earlier than before, there are fluctuations in the cessation dates, and there is no change in cessation dates when compared to past years (Figure 4.7). Majority of the respondents (86.7%) describe intensity of sun as very hot, some of them (4.4%) believe the atmosphere is hot while some of the respondents believe that the intensity of sun has not changed over time. Also 4.4% of respondents say they do not know.

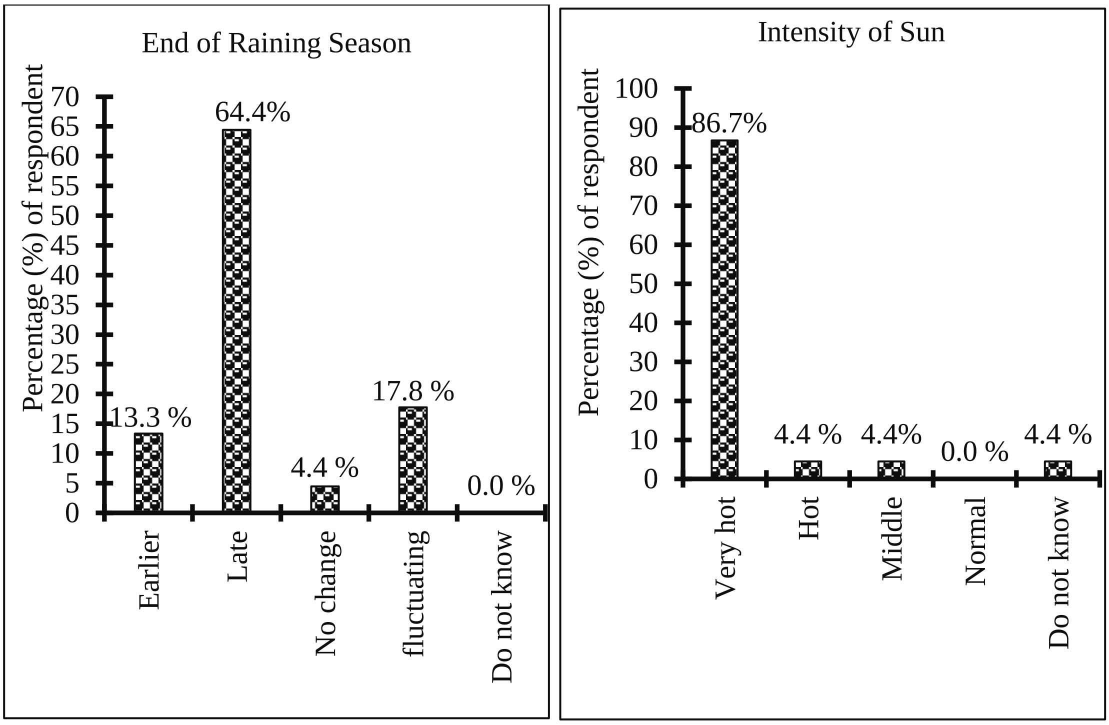


Figure 4.7: End of raining season behavior and sun intensity perception

Majority (86.7%) of respondents agree that they have faced drought conditions in the past years while 8.9% disagree with occurrence of drought in their localities (Figure 4.8). Among respondents, 4.4% do not know or cannot remember the occurrence of any drought situation. No one seem however to seemed to remember when the drought occurred. 33.3% believe that the drought was experienced in the past 2 years, while another 33.3% of the respondents could not remember. 15.6%, 6.7% and 11.1% of the respondents believe that there was occurrence of flooding in the last past 4, 6 and 8 years respectively.

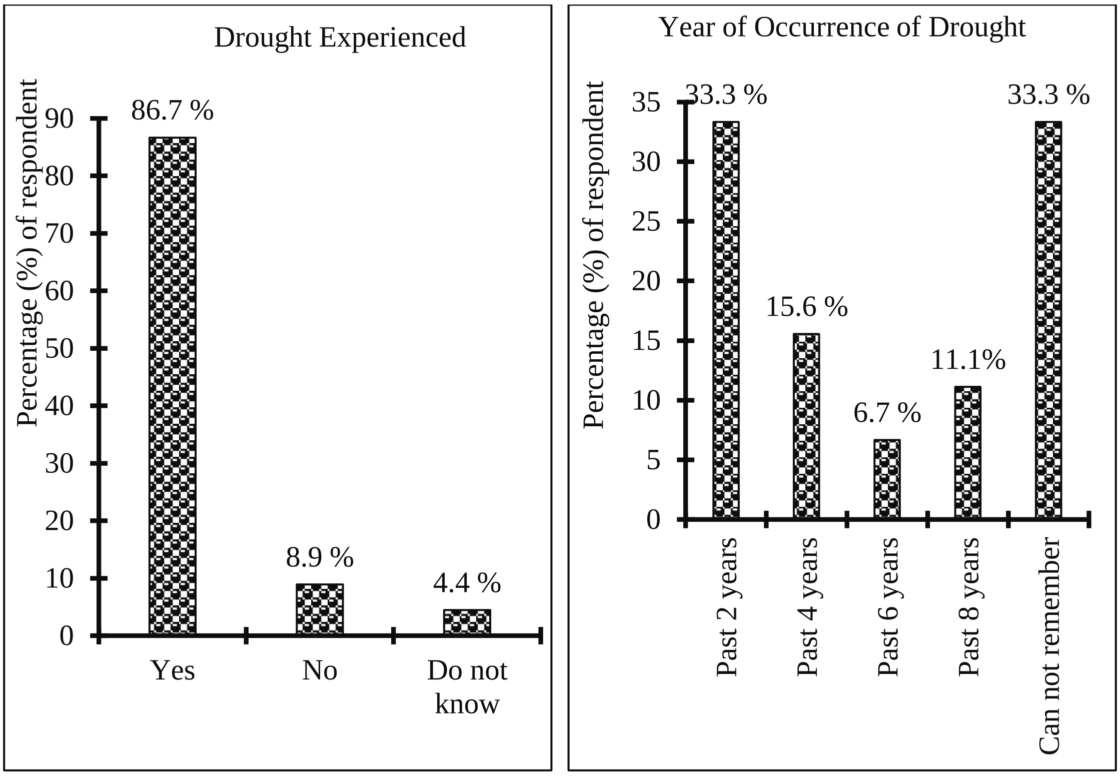


Figure 4.8: Occurrence of drought

On flooding, 91.1% of respondents agree that there was occurrence of flooding in their villages out of which 66.7% of them expressed that the last flood event took place in the last 4 years. Some respondents agree that the last flooding event was 2 years ago (28.9%) while 4.4% cannot remember the period of the last flooding event (Figure 4.9).

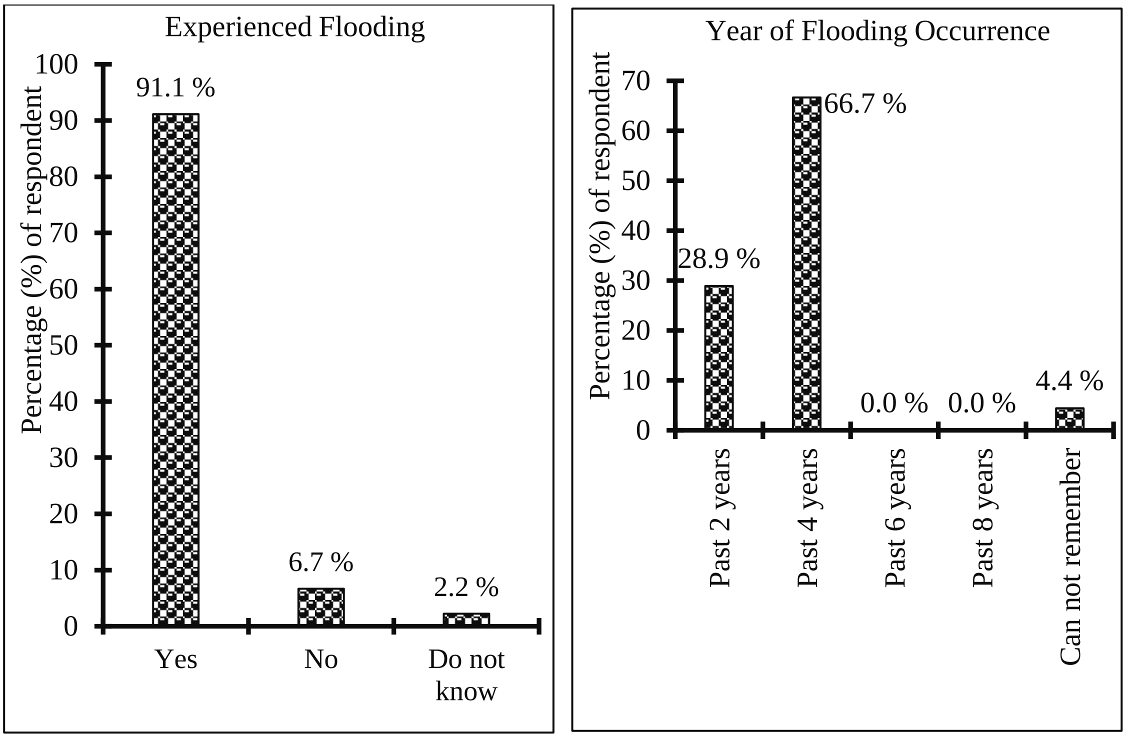


Figure 4.9: Occurrence of flooding event

Only few persons (20%) seem to be well informed about climate change (Figure 4.10) while majority (80%) demonstrated their ignorance of the phenomenon. However, in spite of the inadequate or total lack of information about the climate change phenomenon, the expressions of most of the respondents (95.6%) indicate that they believe that the climate is changing. 2.2% of respondents do not believe in climate change while, 2.2% of the respondents whom do not know if climate is changing or not.

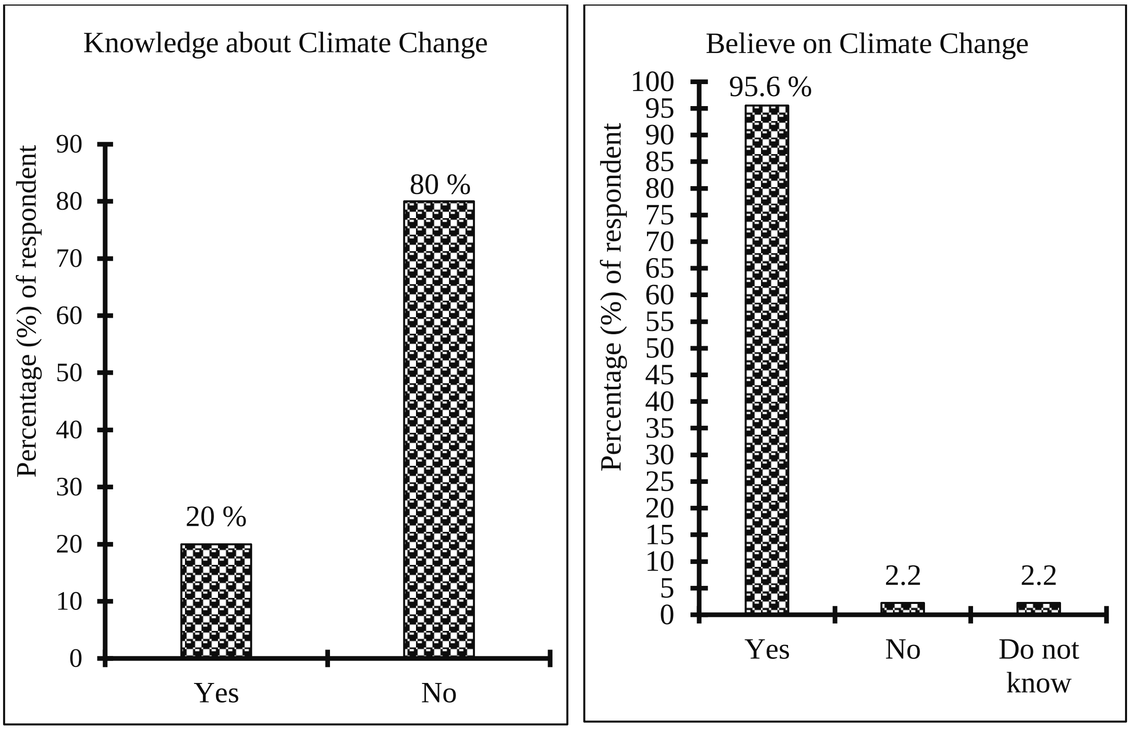


Figure 4.10: Knowledge and belief on climate change

4.1.4 Perception of Climate Effect on Groundwater

Respondents were asked whether the changes in climate on which majority of them believe have effect on water availability for their need and especially if this change affects groundwater. Almost all of respondents (98%) believe it has effects on water availability while 62% believe it impacts on groundwater availability. 22% disagree that change has any effect on groundwater, while 16% do not know whether it has effects (Figure 4.11).

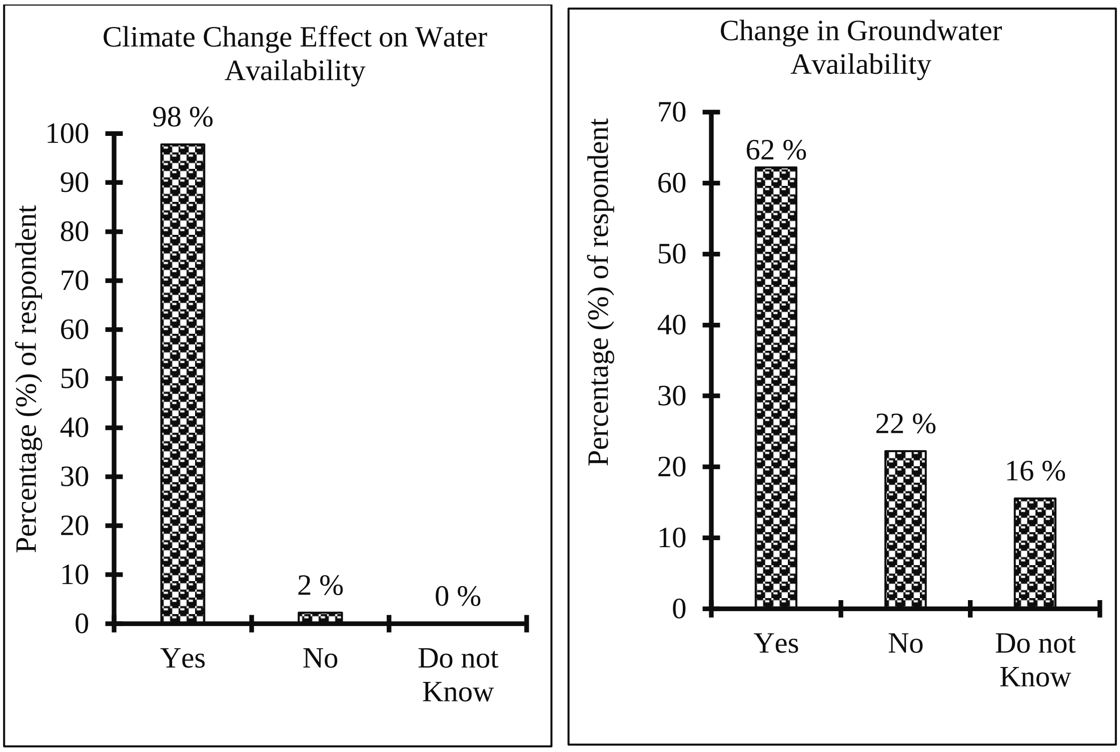


Figure 4.11: Climate and water relationship

Perceptions of effect of climate change on groundwater (Figure 4.12) are expressed as increase of water in wells during the raining season (73%) and drastic decrease during the dry season (67%). 29% of respondents do not know if water increases during the dry season in wells or not while 4% affirm increase of water in their wells during the dry season. 2% of respondents are of the view that there is no change in water level in their well during the dry season, while 24% percent of the respondents expressed that they have no idea.

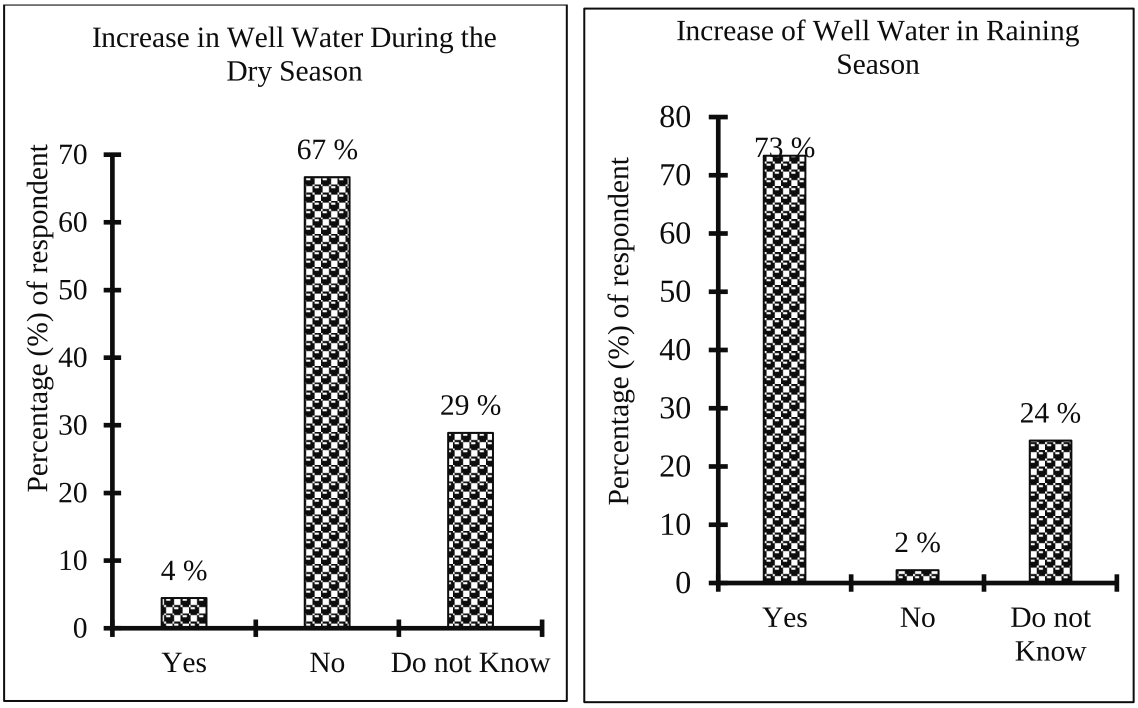


Figure 4.12: water level in wells during rain and dry season

During the dry season some wells dry up as affirmed by 51% of respondents. About 20% of the respondents disagree that their well dry up at that period, while some inhabitants do not know whether water dries up in well during the dry season (29%). Change in groundwater taste is confirmed by 42% of respondents while 33% disagree and 24% do not know (Figure 4.13).

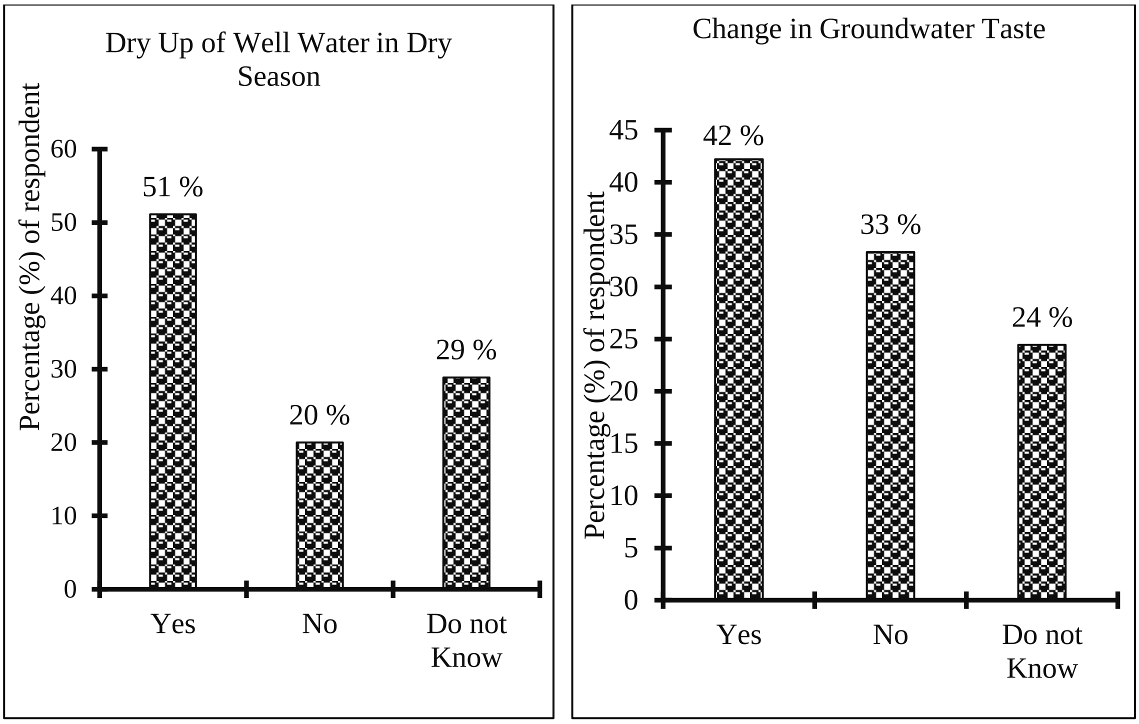


Figure 4.13: Water level in dry season in wells and change in groundwater taste

Over years, 38% of the respondents believe there is change in wells or boreholes water color and 40% disagree with this belief while 22% do not know. Most respondents (53%) are of the view that there is no change in groundwater odor, 22% affirm the change, while 24% do not know if there is change in odor (Figure 4.14).

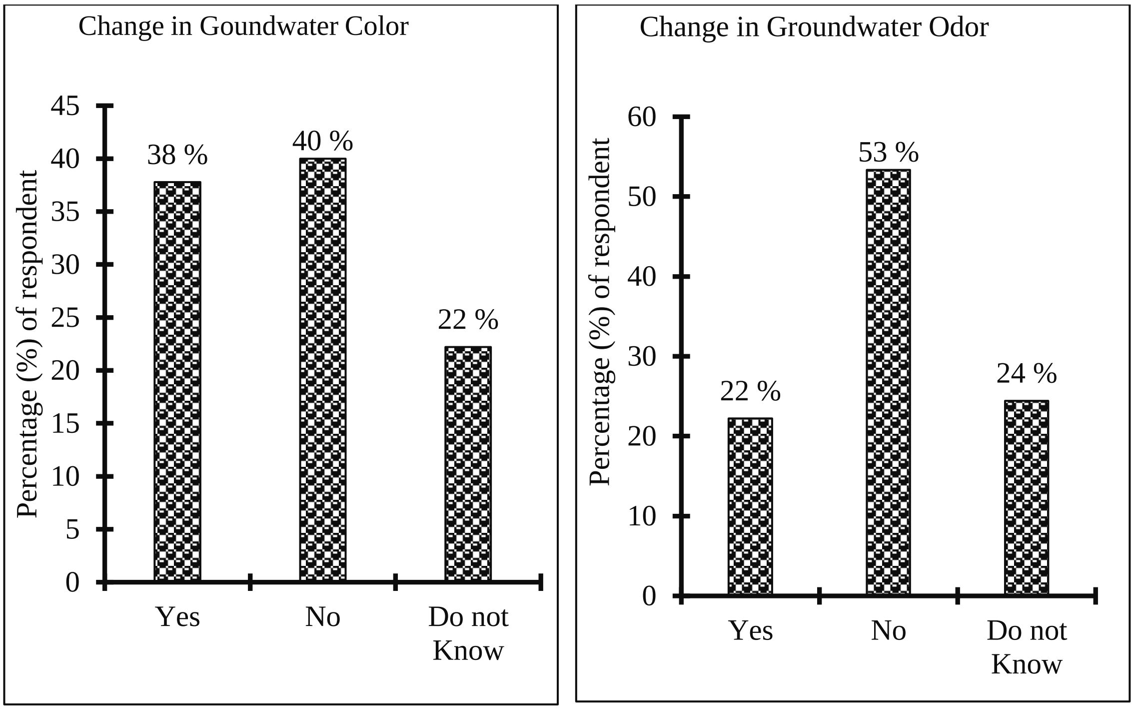


Figure 4.14: Change in groundwater color and odor over the years

About 13% of the respondents are of the view that the changes observed in groundwater taste, color and odor occur in rainy season, 33% of them think the changes are observed during the dry season, while 53% of respondents do not know at which period those changes occur. Groundwater shortage during the year is believed to last between 0 to 2 months (4.4%), 2 to 4 months (28.9%), 4 to 6 months (35.6%), greater than 6 months (4.4%), while 26.7% of respondents do not know the duration of occurrence of the shortage. Most of the respondents (73%) agree that groundwater shortage occurs in dry season, 4% think this shortage is in rainy season, while 22% do not know (Figure 4.15).

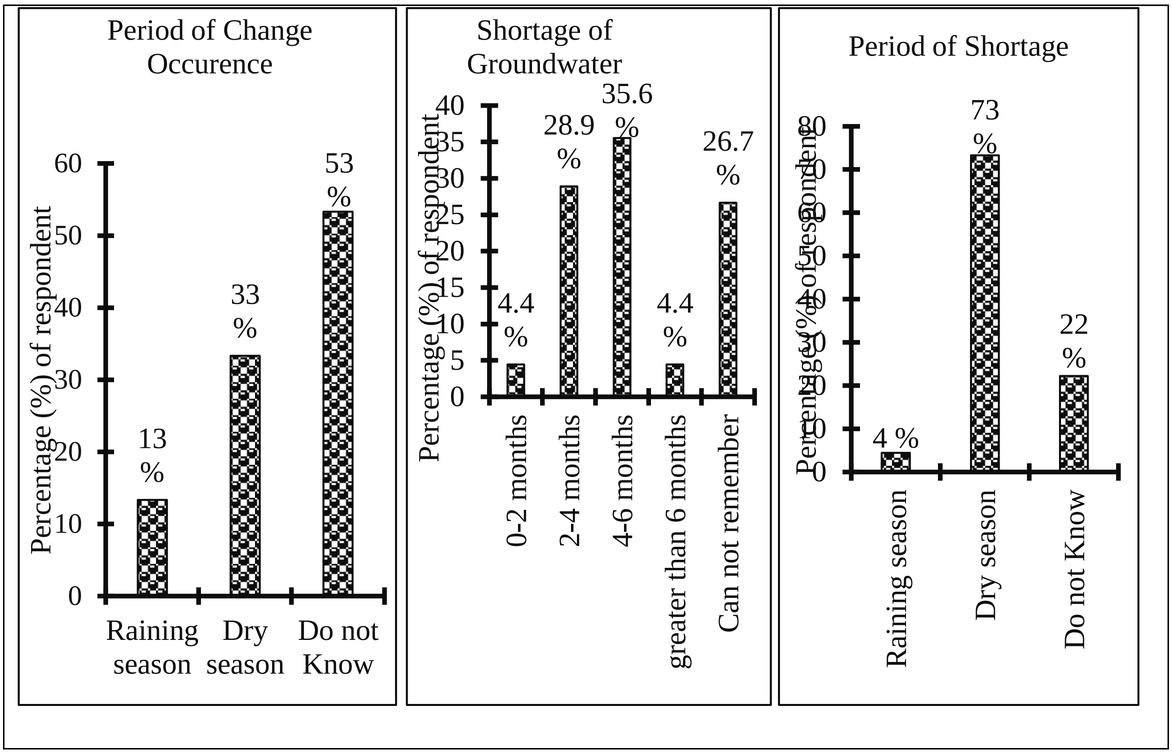


Figure 4.15: Period of change on groundwater availability

4.2 Signal of Climate Change

Climate data (rainfall, minimum and maximum temperature) were analyzed with the aim of detecting any significant change over the past years. Results are presented as graphs or tables in this section.

4.2.1 Rainfall Data Analysis

Daily rainfall data collected from NiMet was algebraically summed to get monthly rainfall for each year. Graphic visualization of monthly distribution of rainfall data over the study period was displayed using box plot. Figure 4.16 show high fluctuation of monthly rainfall amount within each month. The months of July and August received more rainfall than other months over years while the months of January, February March, November and December received less rainfall than others. Since aquifer recharge occurs mainly from rainfall, this variation of rainfall amount implied that recharge is likely to take place within half of the year between April to October.

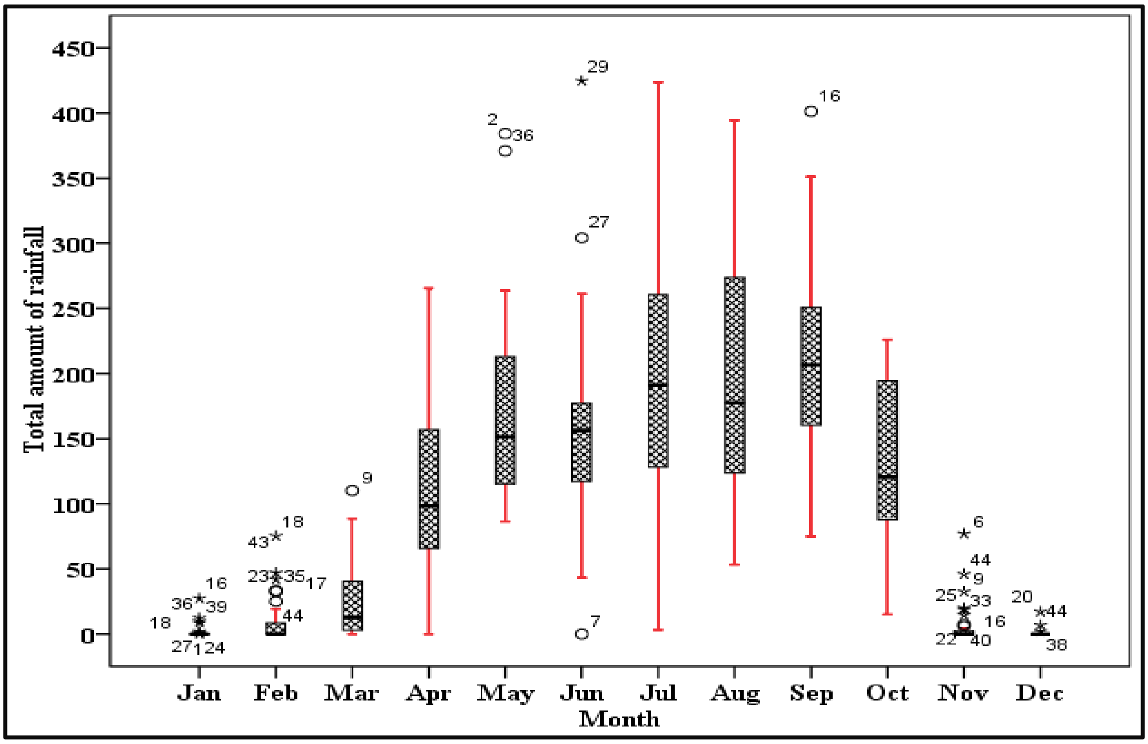


Figure 4.16: Rainfall monthly distribution over 1971-2014 using box plot

Monthly rainfall data were subdivided into decades and the mean value calculated for each decade. Histogram plot was used to compare mean values of decades. The graph (Figure 4.17) shows a bimodal distribution of rainfall. The dry season occurs between November and March with a mean rainfall lower than 50mm. The raining season starts in April and ends in October. From the graph, the raining season occurs 7 months in the year while the dry season occurs during 5 months. The months of July, August and September receive more rain than other months in the raining season (greater than 150mm per months).

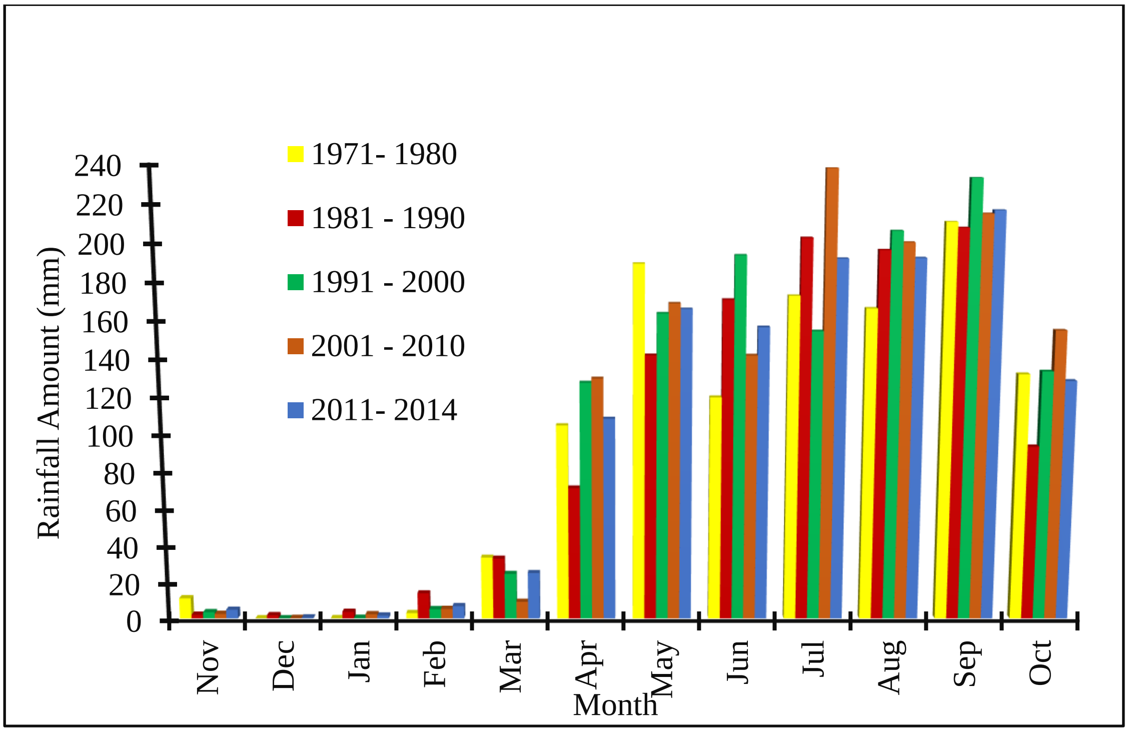


Figure 4.17: Comparison of mean monthly rainfall over the decades

Monthly value of rainfall were then added to obtain annual amount of rainfall. Descriptive statistic (Table 4.1) was performed and reveals that over the period of 1971-2014, minimum and maximum annual rainfall was 771.70 mm (1977) and 1767.10 mm (1999) respectively. The mean value was 1205.17mm with standard deviation of 236.71 mm and 1188.90 mm was the median value.

Table 4.1: descriptive statistic of annual rainfall from 1977 to 2014

Descriptive Statistic	Annual rainfall
Mean	1205.17
Median	1188.90
Standard Deviation	236.71
Minimum	771.70
Maximum	1767.10

Time series analysis was conducted to assess rainfall behavior over the years (Figure 4.18). The rainfall pattern is shown to be highly variable with general tendency is of increase in rainfall amount over years.

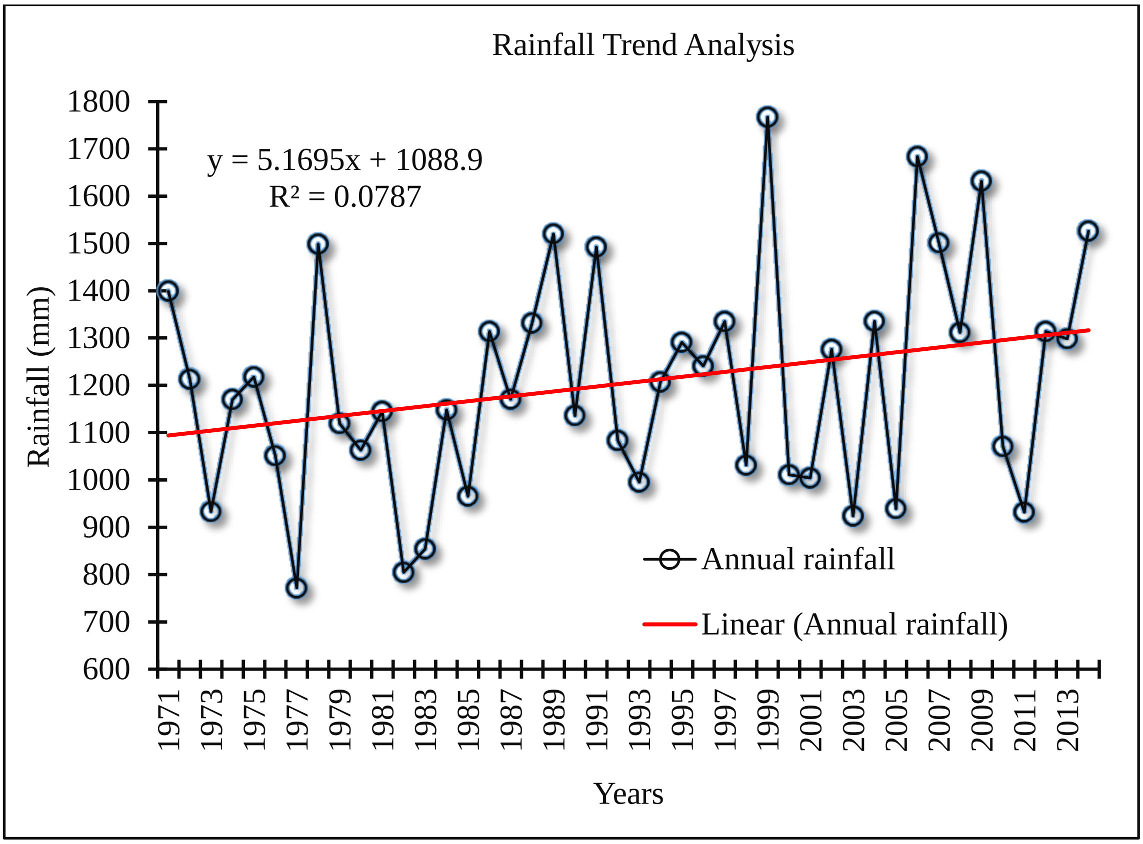


Figure 4.18 Time series analysis of mean annual rainfall (1971-2014)

Standardized Precipitation Index (SPI) for each year was computed from annual mean precipitation (McKee et al 1993) to compare annual rainfall within the study period. Results were interpreted based on the World Meteorological Organization (2012) key classifications as follow:

SPI value greater than 2……………. classed as……………...Extremely wet;

SPI value between 1.5 to 1.99 ………………………………..Very wet;

SPI value between 1.0 to 1.49…………………………………Moderately wet;

SPI value between -.99 to .99 …………………………………Near normal;

SPI value between -1.5 to -1.99………………………………..Severely dry;

SPI value less than -2…………………………………………..Extremely dry

Figure 4.19 indicates that years 1999 and 2006 receive more rainfall than other years (extremely wet) while 1977 and 1982 were classified as severely dry. Most other years have SPI values between -0.99 to 0.99. In other words they are classified as near normal.

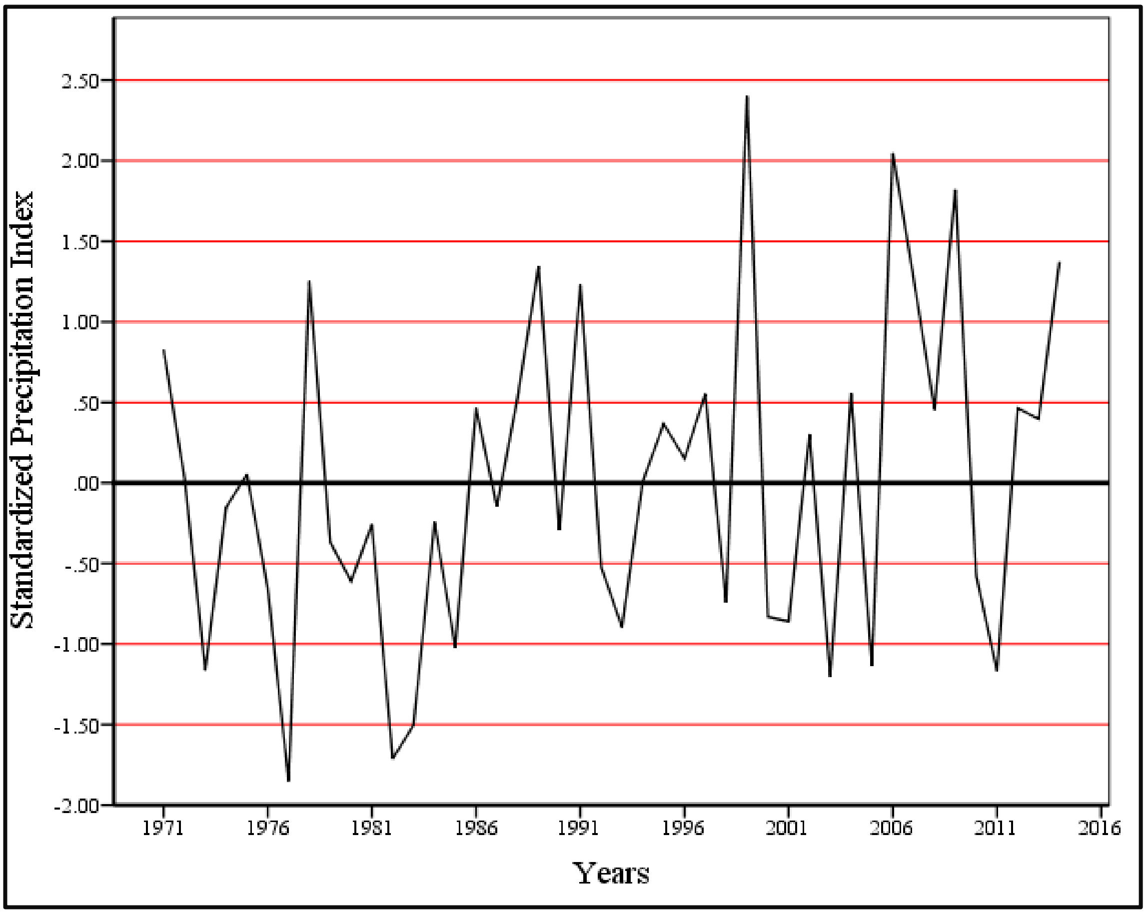


Figure 4.19: Standardized Precipitation Index of mean annual rainfall

Annual rainfall amount was also compute per decade in order to understand it behavior from one decade compare to another. The rainfall amount per decade (Figure 4.20) is between 1143.64mm for the first decade (1971-1980) to 1267.45 for the period 2011-2014. Bar chart plot displays a general increase from one decade to the following.

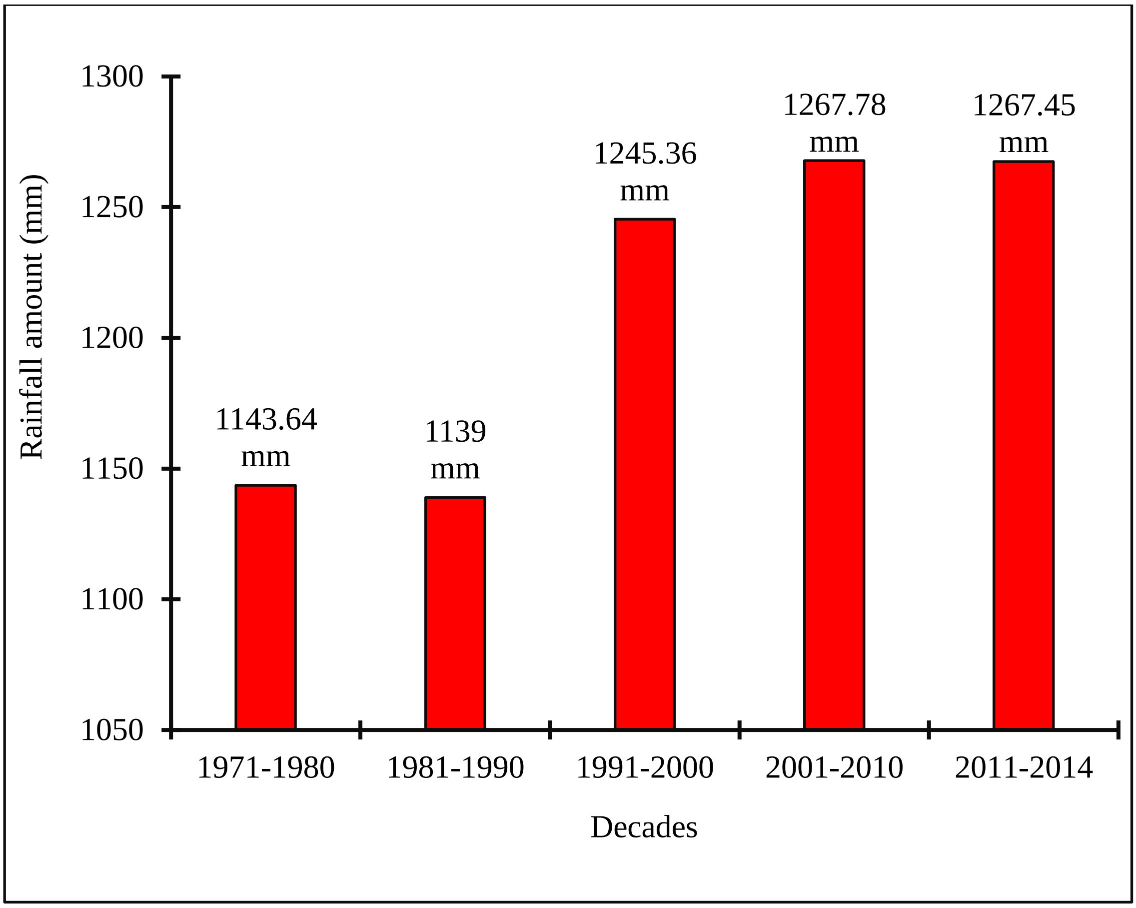


Figure 4.20: Rainfall amount per decade

4.2.2 Temperature Data Analysis

Same procedures were used to describe minimum and maximum temperature in the study area with the purpose of identifying significant change in their comportment over time. These procedures include box plots, bar charts, time series analysis like in the case of rainfall data analysis.

i. Minimum Temperature Data Analysis

Minimum temperature analysis shows monthly value between 22.5^0C and 26^0C except for January and December where the lowest value of minimum temperature were recorded (Figure 4.21).

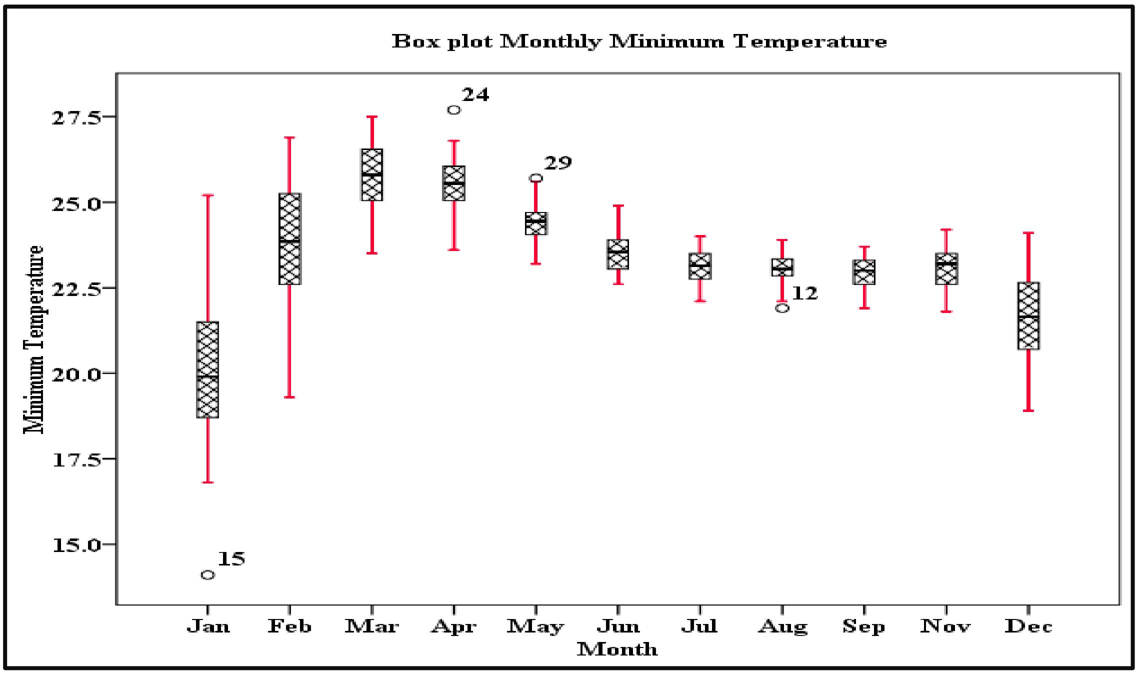


Figure 4.21: Monthly distribution of minimum temperature (1975- 2014)

Time series plot of minimum temperature (Figure 4.22) displays a continuous rise over years with fluctuations from year to year. The lowest value of 21.4^{0}C was recorded in 1989 and highest value of 24.2^{0}C in 2010. The straight line equation is $y = 0.0325x - 41.78$ with R^2 of 0.4127.

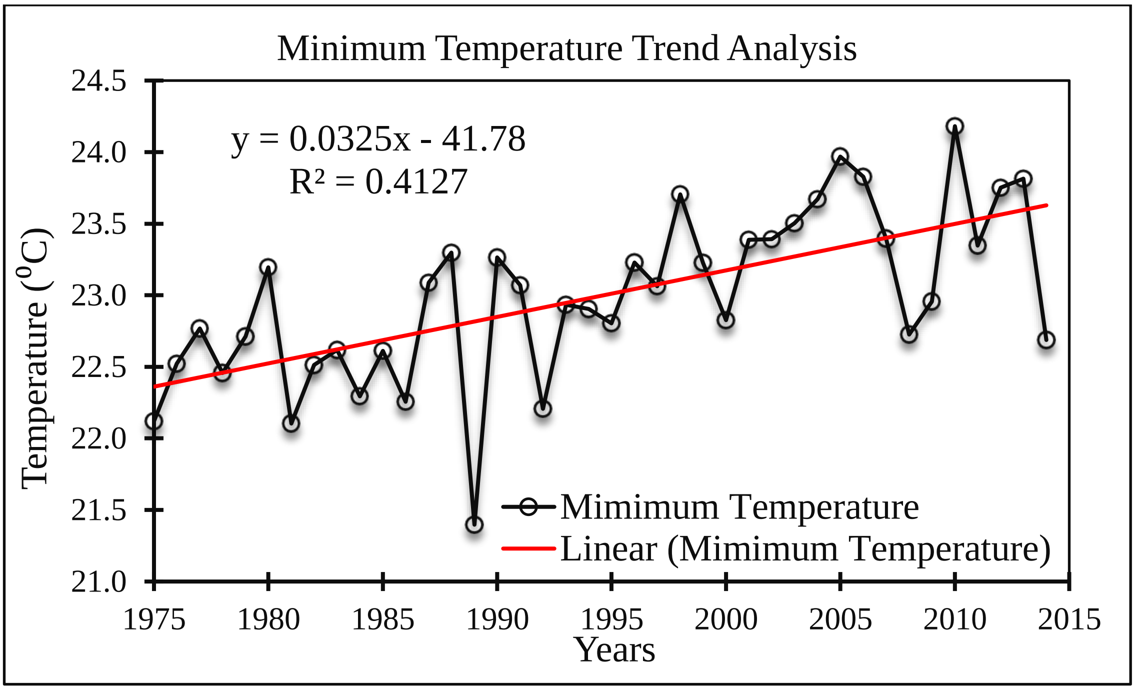


Figure 4.22: Time series of Minimum Temperature

Decadal mean minimum temperatures were computed in order to assess it behavior. Table 4.1 indicate 22.2 ^{0}C for the first decade (1975-1984), 22.7^{0}C for the second decade (1985-1994), 23.3^{0}C for the third decade (1995-2004) and the last decade (2005-2014) have a mean minimum temperature of 23.5^{0}C. The upward trend from time series analysis is confirmed through decadal mean comparison. This rise in mean minimum temperature is more visible in Figure 4.23.

Table 4.2: Decadal Mean Minimum Temperature

Years	Decade N◦	Mean Minimum Temperature ^{o}C
1975-1984	1	22.5
1985-1994	2	22.7
1995-2004	3	23.3
2005-2014	4	23.5

Bar chart plot in Figure 4.12 enables visualization of the increase in mean minimum temperature.

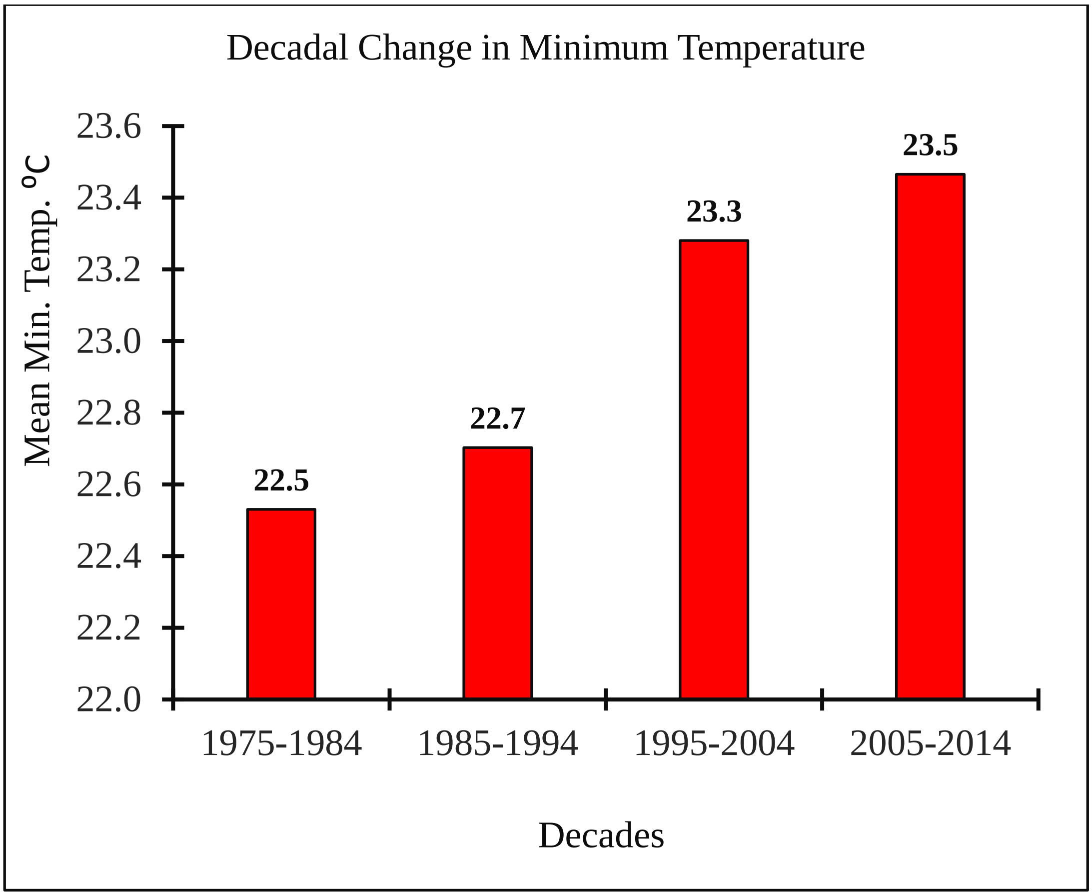


Figure 4.23 Bar chart of decadal Minimum Temperature

In order to quantify this change in mean minimum temperature, simple differences were used. Decadal difference show general increase from one decade to the following with a mean increase of 0.5^{o}C (Table 4.2).

Table 4.3: Decadal difference of Mean Minimum Temperature

Decade	Difference
2nd Deca. -1st Deca.	0.2
3rd Deca. - 2rd Deca.	0.6
4th Deca - 3rd Deca	0.2
4th Deca. -1st Deca.	0.9
Mean	0.5

ii. Maximum Temperature Data Analysis

Distribution of maximum temperature per month during the study period (1975-2014) is shown through box plot (Figure 4.24). Maximum temperature is highly variable within each month of years. The high values of maximum temperature are observed between December and April corresponding to the dry season. The lowest values of maximum temperature are then measured between May and November corresponding to the raining season.

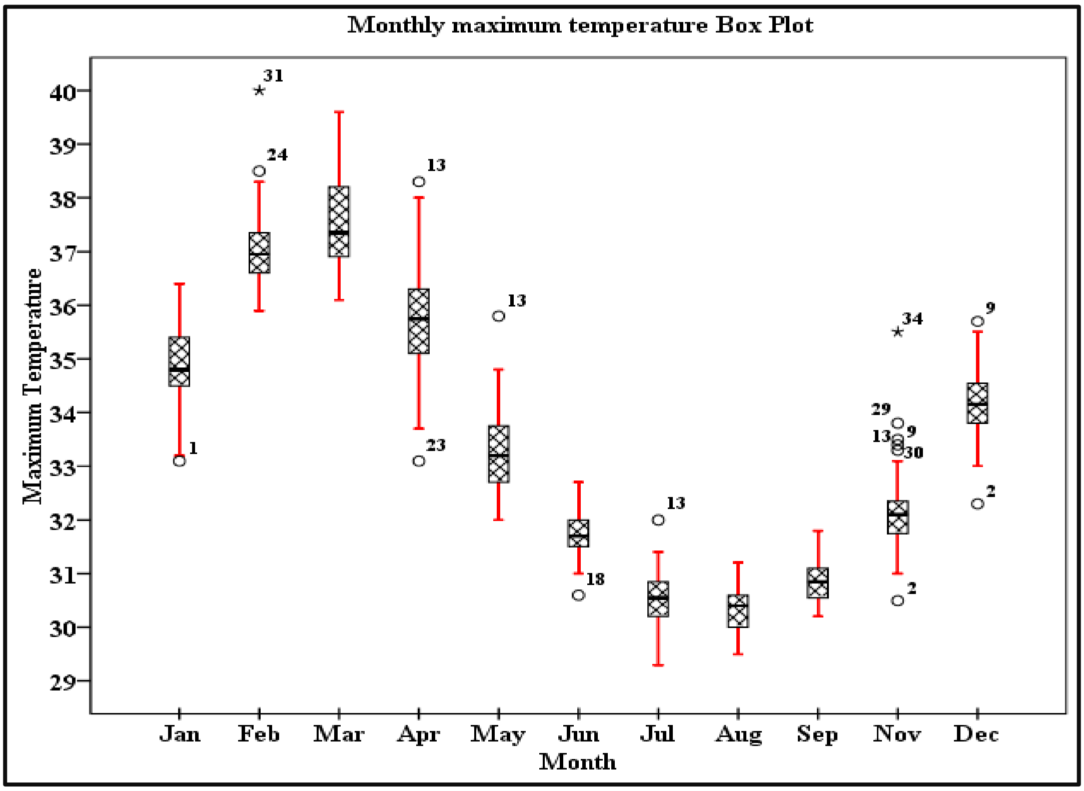


Figure 4.24: Monthly Distribution of Maximum temperature over the study period

Time series analysis carried out using trend line (Figure 4.25) allows for discernment of whether there is increase or decrease in general trend in maximum temperature at Lokoja station. The upward trend observed yields a straight line equation of **y** =

0.0135x + 6.6829 for the 40 years data. This confirms the continuous increase in maximum temperature as observed with minimum temperature data set.

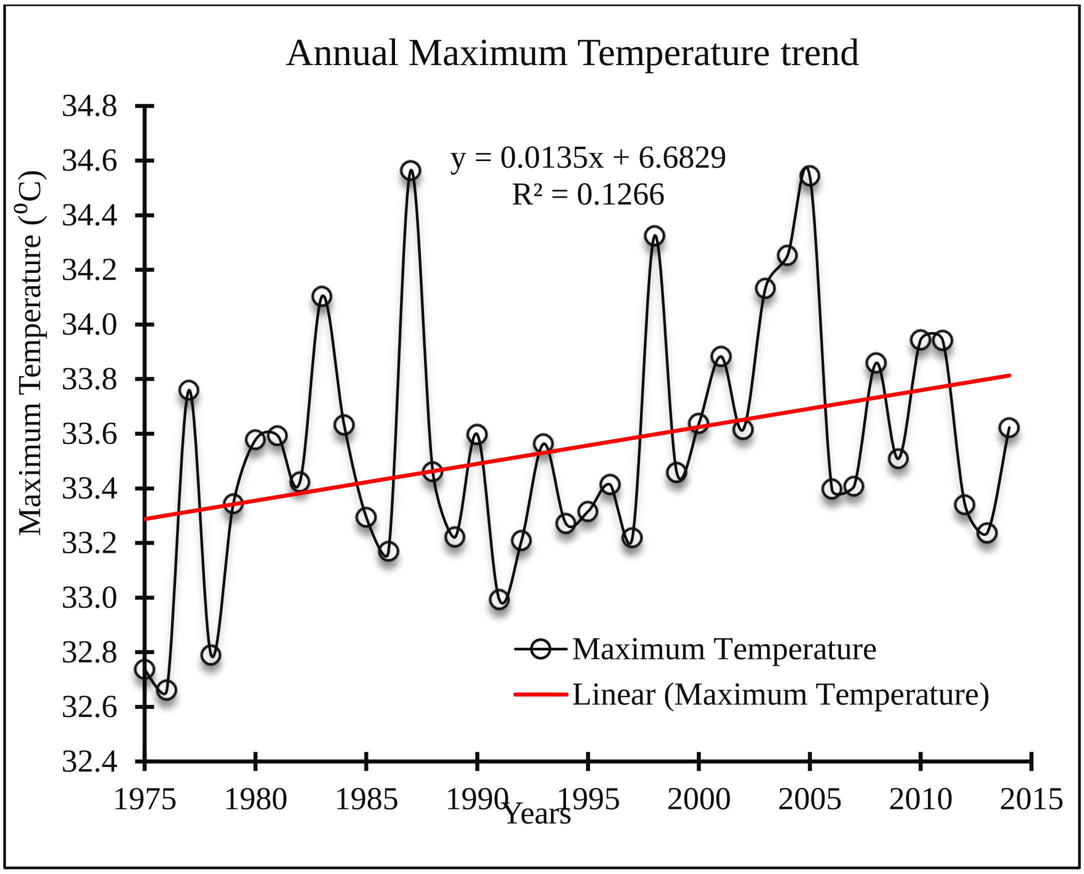


Figure 4.25: Time series of Maximum Temperature

Decadal mean maximum temperature (Table 4.3) were also computed and shows the same mean for the first and second decade about 33.4^{0}C. Same mean for the third and fourth decades about 33.7^{0}C was also found.

Table 4.4 Decadal Mean Maximum Temperature

Years	Decade N◦	Mean Minimum Temperature ^{0}C
1975-1984	1	33.4
1985-1994	2	33.4
1995-2004	3	33.7
2005-2014	4	33.7

Decadal mean maximum temperature computed was used to plot bar chart (Figure 4.26). Changes in maximum temperature was observe after the second decade.

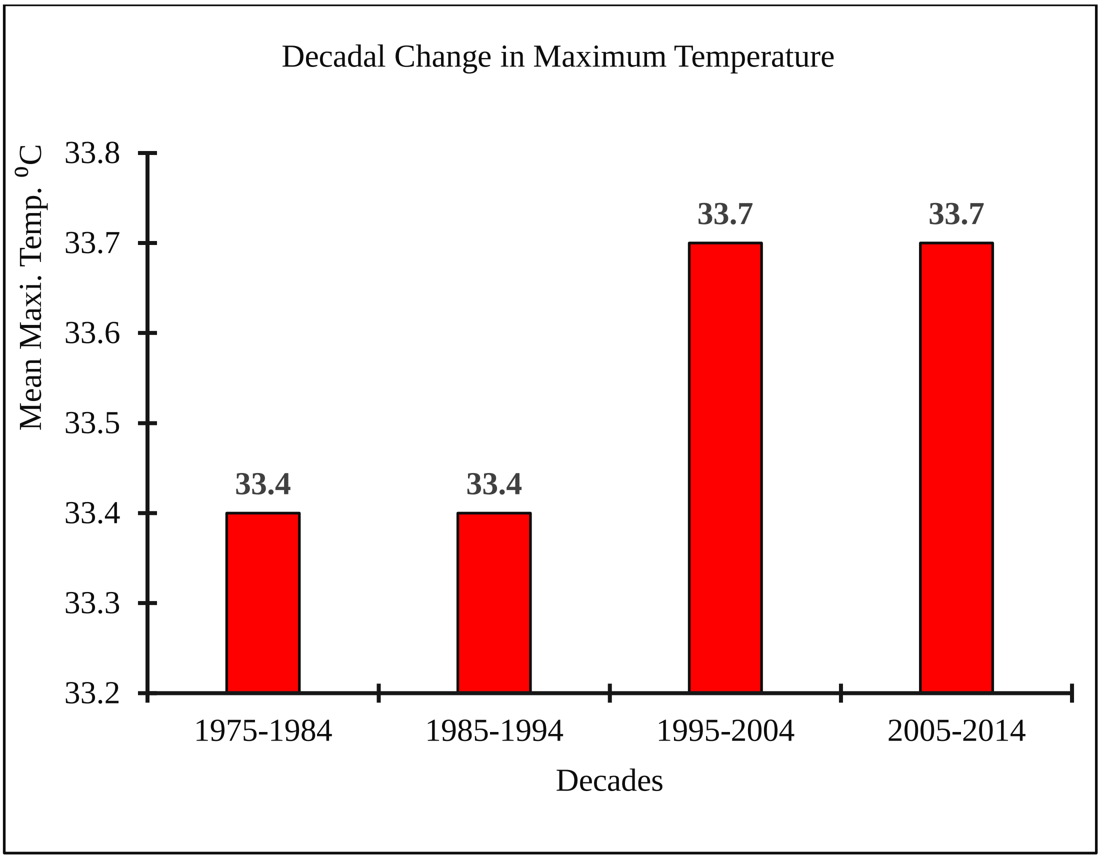


Figure 4.26: Decadal change in mean maximum temperature

4.3 Groundwater recharge

Climate change evidence described in precedent sections may affect groundwater in terms of quantity and quality, according to inhabitants in the study area. The effect of climate change on groundwater was analyzed through recharge estimation. Aquifer recharge estimation in this study was computed using the proposed methodology (water balance equation). Individual parameters such as runoff, evapotranspiration and mean temperature were computed using data collected from NiMet over the period 1985 to 2010. This period 1985 to 2010, correspond to the period on which data needed to compute aquifer recharge was available for each parameter. For each parameter, monthly value were compute and then used for monthly recharge estimation. Table 4.4 present the monthly recharge for each year of the study period. The period from November to April was characterized by no infiltration or trace amount of water flow to aquifer recharge. Indeed, this period correspond to the dry season where there is no rain or the rain amount is no enough to fill soil porous media.

High values of monthly recharge were observed within the period from May to October during the rainy season. In other word, it is the period on which rain water is enough to overcome lost from evapotranspiration and runoff.

Table 4.5: Monthly recharge value (1985-2010)

Years	January	February	March	April	May	June	July	August	September	October	November	December
1985	0	0	0	0	0	36.07	9.07	0	129.46	0	0	0
1986	0	0	0	0	12.96	44.35	44.06	0	224.51	0	0	0
1987	0	0	0	0	0	7.23	43.19	179.29	60.11	0	0	0
1988	0	0	0	0	0	93.74	238.49	3.07	23.12	0	0	0
1989	0	0	0	0	54.27	27.95	143.86	134.54	91.99	63.32	0	0
1990	0	0	0	0	0	33.48	67.91	128.84	41.74	0	0	0
1991	0	0	0	0	78.68	65.26	69.32	145.68	103.71	0	0	0
1992	0	0	0	0	67.46	18.99	8.81	22.59	89.07	0	0	0
1993	0	0	0	0	29.92	0	0	0	57.33	0	0	0
1994	0	0	0	0	23.27	0.48	33.00	154.09	22.50	0	0	0
1995	0	0	0	0	0	0	144.70	74.04	0	35.96	0	0
1996	0	0	0	0	0	0	30.17	95.72	150.35	0	0	0
1997	0	0	0	2.09	0	133.80	0	0	162.62	46.24	0	0
1998	0	0	0	0	0	71.04	38.32	0	65.70	0	0	0
1999	0	0	0	0	39.93	223.46	66.85	167.73	94.01	53.66	0	0
2000	0	0	0	0	0	14.84	0	53.63	57.69	0	0	0
2001	0	0	0	0	0	0	63.13	34.51	121.52	0	0	0
2002	0	0	0	0	0	0	133.24	123.15	46.22	0	0	0
2003	0	0	0	0	0	35.67	114.24	0	4.85	0	0	0
2004	0	0	0	0	65.40	26.93	76.21	0	84.88	21.17	0	0
2005	0	0	0	0	0	27.87	0	0	0	19.01	0	0
2006	0	0	0	0	201.14	0	176.39	205.21	158.24	50.70	0	0
2007	0	0	0	7.10	126.17	38.64	123.40	117.33	122.31	97.54	0	0
2008	0	0	0	0	21.79	40.36	118.36	131.64	40.47	0	0	0
2009	0	0	0	39.76	0	61.89	132.53	150.82	100.38	46.98	0	0
2010	0	0	0	0	0	8.79	104.88	18.39	19.81	28.76	0	0

Source: Author, 2015

Monthly values were added to get the mean amount of water which recharge aquifers from 1985 to 2010 and then used for bar chart plot (Figure 4.27). This figure shows that within the year, aquifer recharge start properly in May and end in October whereas, high values of recharge occurs during 3 months in the year (July, August and September).

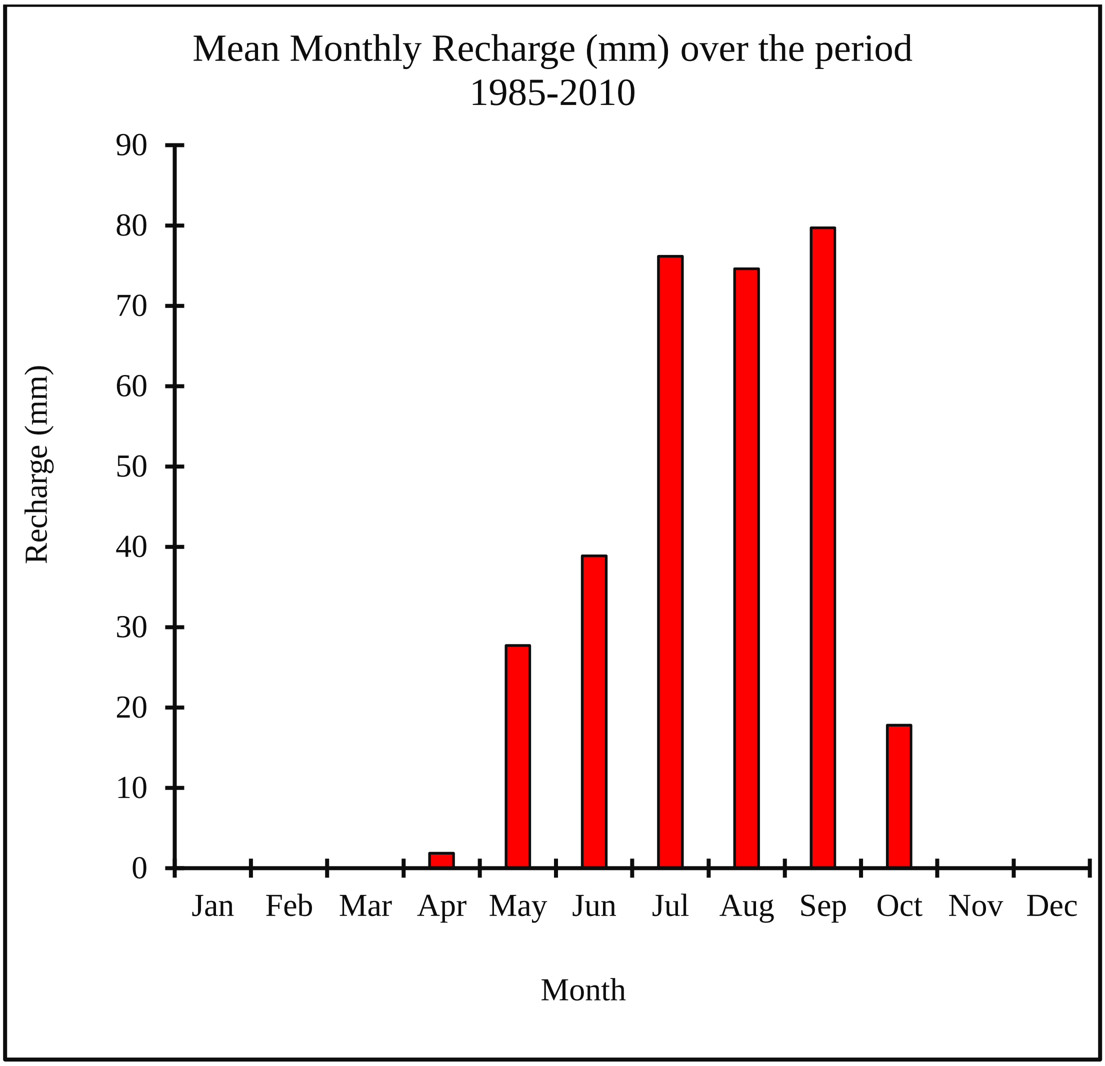


Figure 4.27: Mean Monthly aquifer recharge

Annual recharge was calculated by adding monthly values for each years and the result is presented in Table 4.6.

Table 4.6: Annual recharge values (1985-2010)

Year	Rainfall (mm)	PET (mm)	Recharge (mm)
1985	965.7	1596.59	174.60
1986	1314.1	1518.86	325.88
1987	1170.8	1637.61	289.82
1988	1331.4	1754.32	358.42
1989	1520.1	1937.81	515.92
1990	1136.3	1689.72	271.96
1991	1492.7	1789.88	462.63
1992	1083.1	1938.56	206.93
1993	995.6	1907.84	87.25
1994	1207	1843.98	233.33
1995	1291.1	1809.61	254.70
1996	1240.7	1803.93	276.24
1997	1334.6	1818.52	344.74
1998	1031	1973.63	175.06
1999	1767.1	1822.63	645.62
2000	1010.7	1936.13	126.16
2001	1003.8	1961.65	219.16
2002	1276	1884.66	302.60
2003	923.6	2017.88	154.76
2004	1335.4	1925.09	274.59
2005	939.4	1930.50	46.88
2006	1684.1	1119.33	791.67
2007	1501.4	1145.84	632.49
2008	1311.5	1700.85	352.63
2009	1631.5	1664.99	532.37
2010	1071.1	1640.14	180.63

Descriptive statistic of annual rainfall, PET and annual recharge over the period of 26 years (1985-2010) is presented in Table 4.6.

Annual rainfall was characterized by minimum and maximum value of 923.6 mm (2003) and 1767.1 mm (1999) respectively with 1258.35 mm for the median. The mean value was 1252.68 mm while standard deviation was 238.58 mm.

Minimum and maximum value were 1119.33 mm (2006) and 2017.88 mm (2003) for the PET with 1814.07 mm as median value. The mean value was 1760.41 mm/year whereas standard deviation was 226.28 mm.

Annual recharge value were between 46.88 mm (2005) and 791.67 mm (2006) with a mean value of 915.93 mm. Standard deviation value was 183.66 mm while median was characterized by 917.44 mm/years.

Table 4.7: Descriptive statistic of annual recharge

Descriptive Statistic	Rainfall (mm)	PET (mm)	Recharge (mm)
Mean	1252.68	1760.41	316.81
Median	1258.35	1814.07	275.41
Standard Deviation	238.58	226.28	182.25
Minimum	923.60	1119.33	46.88
Maximum	1767.10	2017.88	791.67

Time series of annual recharge present fluctuations from one year to another with a slight upward trend (Figure 4.28). The trend equation is $y = 4.4888x + 1192.1$ $R^2 = 0.0207$. The coefficient of determination (R^2) value indicates that there is a weak relationship between annual recharge and year. In other word, the recharge is not dependent on year. Figure 4.28 also reveals that recharge is not dependent on year but follow rainfall trend.

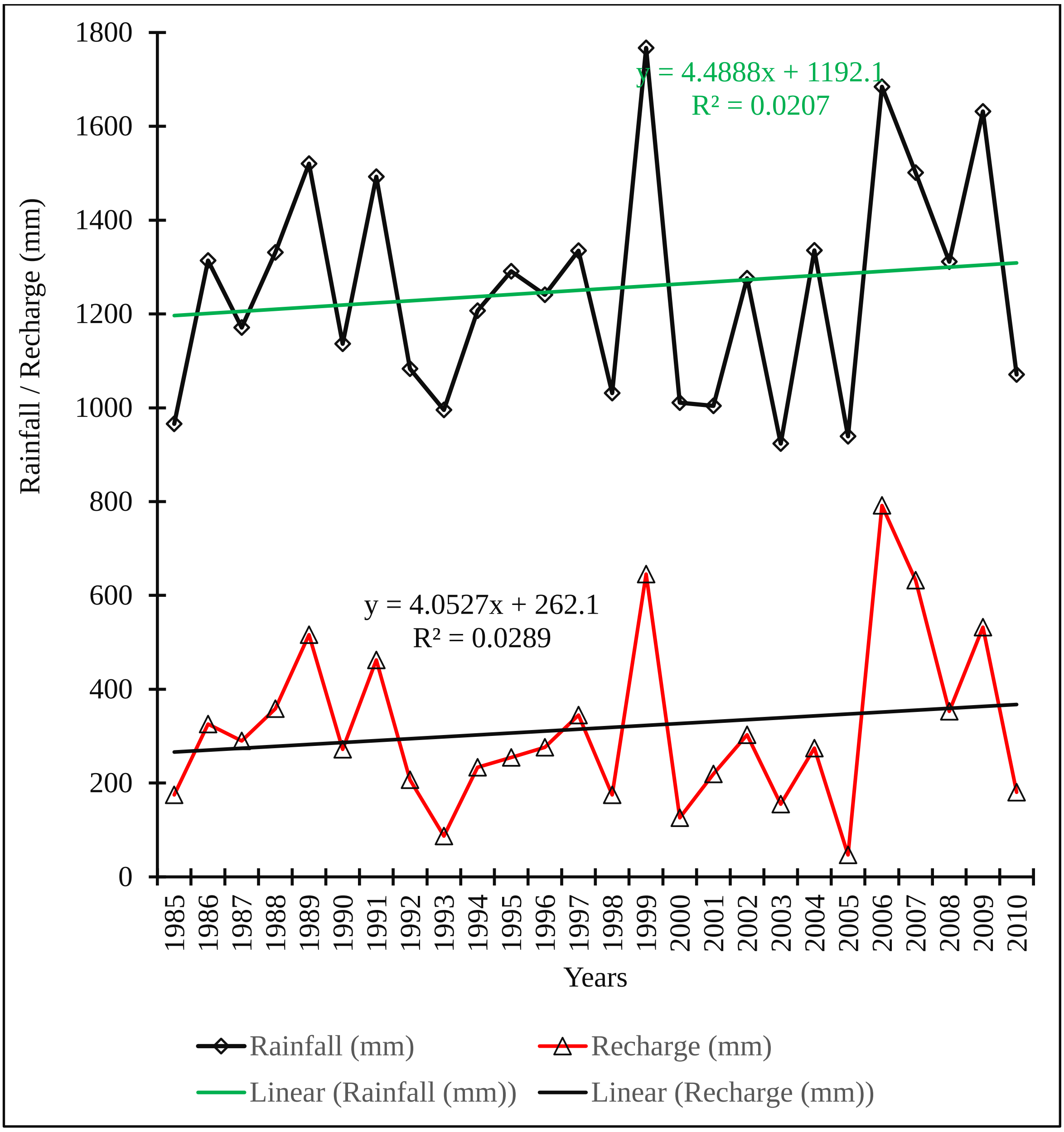


Figure 4.28: Annual rainfall and recharge fluctuation

Bar plot were used to check the visual relationship between rainfall and recharge for the study period. Figure 4.27 shows that annual recharge computed follow the same trend with the corresponding annual rainfall. This may justify the assertion that groundwater recharge is related to the amount of rainfall in the year.

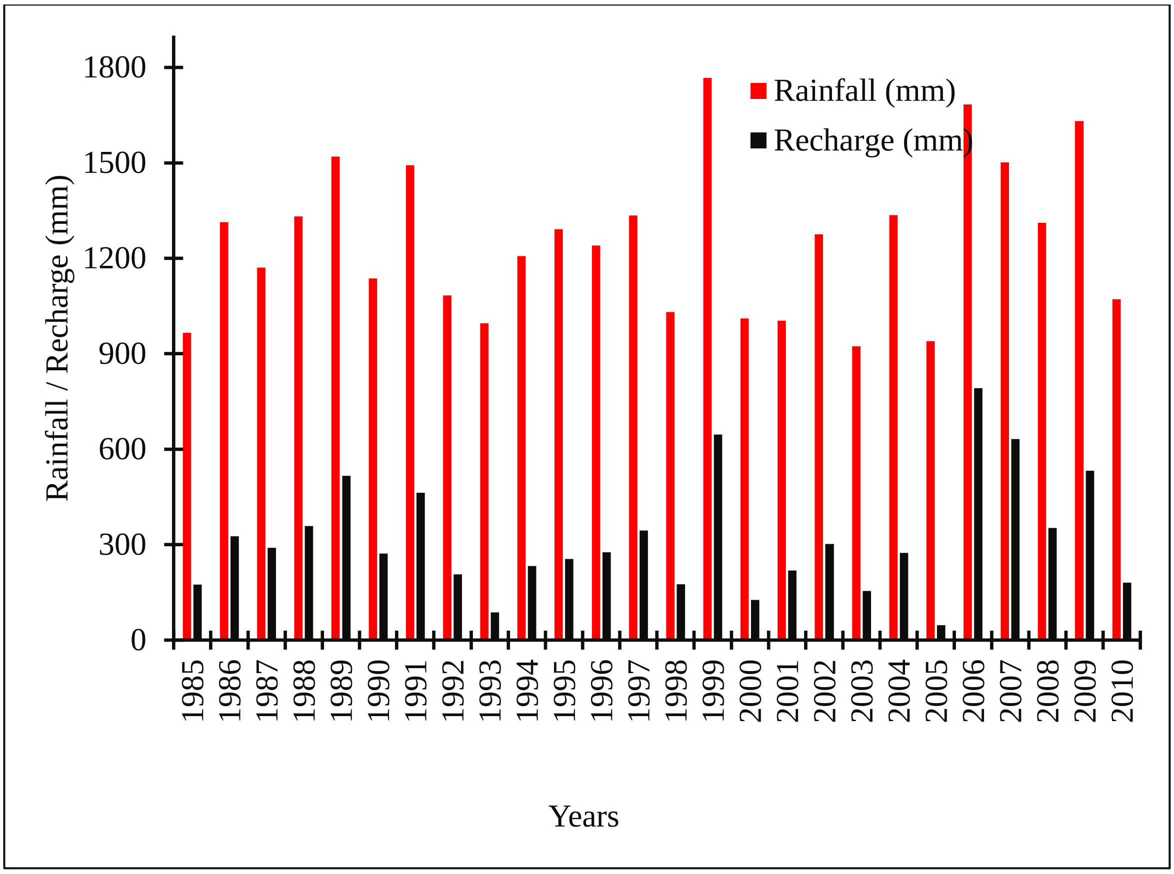


Figure 4.29: Visual relationship between annual rainfall and annual recharge

To evaluate the strength and relationship between parameters used for recharge estimation, Kendall's tau b correlation test was conducted in SPSS software. Table 4.7 presents the result of correlation test and reveal a very strong positive correlation of 0.982 with a significance level of 0.01 between annual rainfall and annual recharge. Similar results was found by Oke *et al.*, (2014) within Ona River basin, southwest Nigeria, using soil moisture balance and water table fluctuation. The same Table 4.6 shows a negative correlation (-0.102) between PET and annual rainfall also negative (-0.12) correlation between annual recharge and PET. Since runoff was calculated as percentage of annual rainfall, the evidence of relationship was not taken account in the computation of Kendall correlation.

Table 4.8: Kendall's tau b correlation among water balance parameter

Correlation	Recharge	Rainfall	PET
Recharge	1		
Rainfall	0.938	1	
PET	-0.641	-0.473	1

Based on the strong relationship (Kendall's correlation) between annual rainfall and annual recharge, regression analysis were run with Excel 2013. The regression analysis (Figure 4.28) also shows a positive relation with the equation of:

Recharge (mm) = 0.7162 *Rainfall - 580.34

The coefficient of determination value (R^2) = 0.879 express that annual recharge can be predicted using this equation provided that annual rainfall is known. R^2 precise that 87.9 % of the predicted value (groundwater recharge) will be explain by the independent variable (annual rainfall).

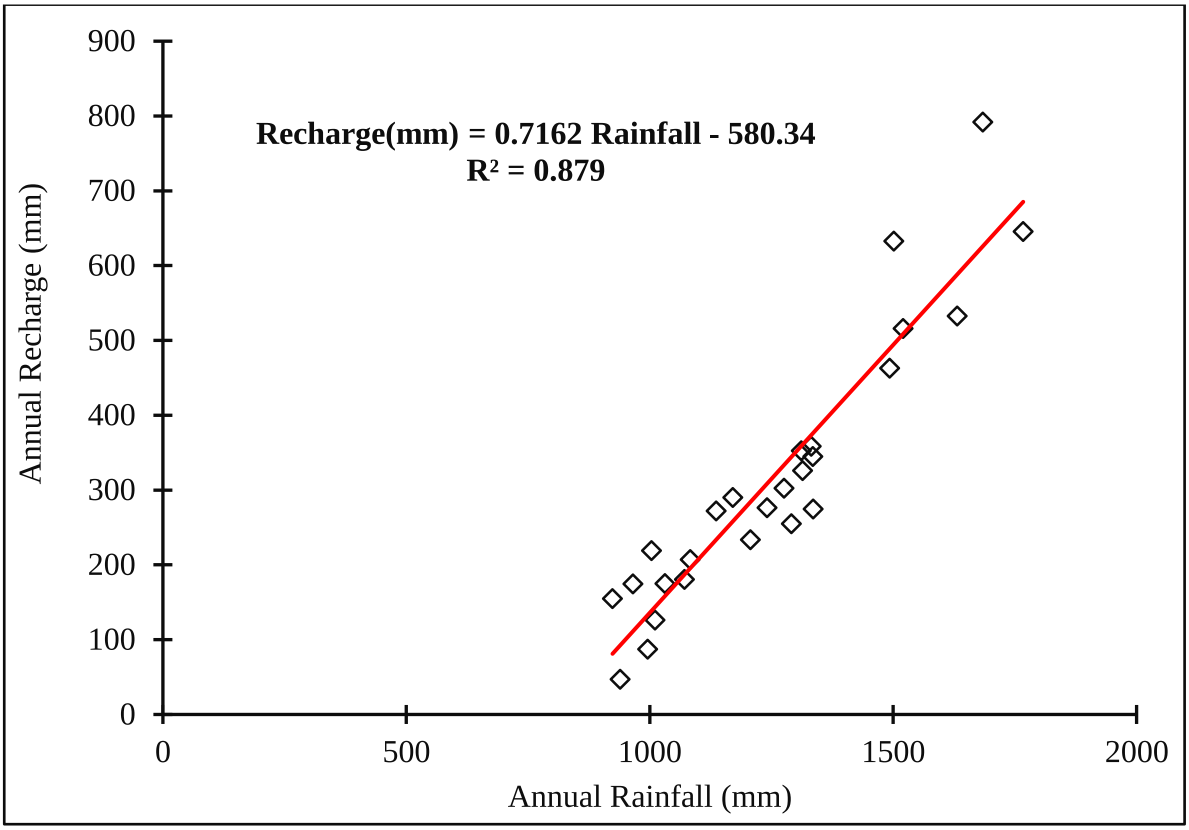


Figure 4.30: Regression analysis of recharge and rainfall

4.4 Sieve Analysis Results

In order to assess soil hydraulic characteristics, soil sampled from the study area was sieved to determine the particles size distribution at 0cm, 50cm 100cm depths. From this sieve results (Appendix E), percentage particles passing in each sieve were computed and plotted against sieve size using semi-logarithmic plot in Excel 2013. Appendix F are graphs determining the 10% diameter (**D_{10}**) for each sample at each level (0cm. 50cm and 100cm). D_{10} represent sieve size (opening) at which 10% of particles pass through the sieves. Hazen (1892) empirical formula was computed to estimate Hydraulic Conductivity (K) at each level using D_{10} values. Hydraulic Conductivity (K) result is established in Table 4.9.

Table 4.9: Hydraulic Conductivity (K)

Villages	Level (cm)	C	D_{10} (mm)	K (mm/day)	Mean K (mm/day)	K (mm/year)
Lokoja	0	0.0117	0.165	3.19E-04	3.49E-04	452.05
	50	0.0117	0.18	3.79E-04		
Felele	0	0.0117	0.149	2.60E-04	3.26E-04	422.05
	50	0.0117	0.18	3.79E-04		
	100	0.0117	0.17	3.38E-04		
Edumose	0	0.0117	0.06	4.21E-05	2.27E-05	29.44
	50	0.0117	0.025	7.31E-06		
	100	0.0117	0.04	1.87E-05		
Onumaye	0	0.0117	0.04	1.87E-05	5.69E-05	73.79
	50	0.0117	0.07	5.73E-05		
	100	0.0117	0.09	9.48E-05		
Shintaku	0	0.0117	0.045	2.37E-05	4.85E-05	62.91
	50	0.0117	0.086	8.65E-05		
	100	0.0117	0.055	3.54E-05		
Banda	0	0.0117	0.035	1.43E-05	3.36E-05	43.59
	50	0.0117	0.05	2.93E-05		
	100	0.0117	0.07	5.73E-05		
Kpata	0	0.0117	0.12	1.68E-04	2.22E-04	287.60
	50	0.0117	0.13	1.98E-04		
	100	0.0117	0.16	3.00E-04		
Kpatapkale	0	0.0117	0.15	2.63E-04	2.05E-04	265.48
	50	0.0117	0.125	1.83E-04		
	100	0.0117	0.12	1.68E-04		
Atapka	0	0.0117	0.18	3.79E-04	3.73E-04	482.82
	50	0.0117	0.185	4.00E-04		
	100	0.0117	0.17	3.38E-04		
Elule	0	0.0117	0.09	9.48E-05	1.97E-04	255.75
	50	0.0117	0.13	1.98E-04		
	100	0.0117	0.16	3.00E-04		

Source: Author, 2015

Table 4.10 give a summary descriptive statistic of hydraulic conductivity in the study area. From this table, hydraulic conductivity is between 8.178E-02 mm/day and 1.341mm/day with a mean value of 6.599E-01mm/day while standard deviation value is 4.918E-01mm/day.

Table 4.10. Descriptive statistic of Hydraulic conductivity

Descriptive statistic	Mean	Median	Standard Deviation	Minimum	Maximum
K (mm/day)	0.65986	0.72394	0.49176	0.08178	1.34117

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMANDATIONS

5.1 Conclusion

This study was conducted to understand climate change effects on groundwater resources in Kogi State through analysis of questionnaires, past climatic data, recharge estimation and soil samples analysis.

Questionnaires administered reveal that all respondents were old enough to be able to give their feelings about climate change (older than 20 years) and the level of education of most of them facilitate their understanding of climate change. The greater part of respondents was male (91.1%) and native of the study area (86.7%). Water sources for inhabitants need were found to be under climate change threat (rivers, hand dug well, and boreholes). Majority of view affirm that the rainfall is becoming low (44.4%) and rainfall season start late than before (64.4%). Sun intensity is described to be very hot (86.7%). The past years witnessed drought and a severe flooding (2012). 80% of respondents do not have knowledge on climate change but they belief strongly (95.6%) that climate is changing and it affects groundwater availability and quality aspect (taste, colour and odour).

Historical climate data analysis reveals unequal repartition in rainfall within each month over the study period. The trend line of time series analysis with rainfall data shows a general increase over the study period. This is corroborated by decadal rainfall bar chart which depict increase from one decade to another. Minimum temperature behavior is shown to increase at a rate of 0.5^{o}C per decade and maximum temperature at a rate of 0.1^{o}C per decade.

5.2 Recommendation

Climate Change impact on human life in Kogi State has been less unstudied. This work interest was climate change effects groundwater and has been conducted with some limitations which may be necessary to fill by some feature study. Findings also give some ideas for more explorations of climate influence on groundwater such as:

a) This study was carried out only on 3 LGAs because of lack of time and fund which constitute a serious limitation, therefore it may be more interesting and more useful for the State water management agency or decision makers, if the study can be extended to the whole state.

b) More details on groundwater recharge process should be conducted using other methods such as GIS based models which will allow to extend the study area to the whole state. In this study, runoff and evapotranspiration were estimated with empirical methods known to overestimate those parameters. In the case of runoff, it was determined using Ayaode (1975) formula which used only rainfall and runoff coefficient. Further detailed researches are needed to take account the nature of soil, water content of the soil, land used and land cover in runoff calculation.

c.) Since climate change affects groundwater quality, the lack of historical information about groundwater quality were a limitation in this study, water managers should monitor groundwater quality aspect so that urgent measures can be taken in case of drastic change in climate conditions.

REFERENCES

Adelena, S.M.A, Olasehinde, P.I. & Bale, R.B. (2008). An Overview of the Geology and Hydrogeology of Nigeria. Applied Groundwater Studies in Africa. International Association of Hydrogeologists, (13), 171-197.

Aizebeokhai P. A. (2011). Potential Impacts of Climate Change and Variability on Groundwater Resources in Nigeria. *African Journal of Environment Sciences and Technology, 5(10),* 760-768

Alaci D. S. A, Jiya S. N. & Omata M. I. (2013). Dimensions of Water Accessibility in Eastern Kogi State of Nigeria. *Herald International Research Journals, (2),* 105 – 113

Alyamani, M. S., & Sen, Z. (1993). Determination of Hydraulic Conductivity from Grain-Size Distribution Curves. *Ground Water,* (31), 551-555.

Allen GR, Pereira LS, Raes D & Smith M. (1998) Crop Evapotranspiration (Guidelines for Computing requirements). FAO Irrigation and Drainage Paper No56, 333

Allen, D. M., Mackie, D. C. & Wei, M. (2004). Groundwater and Climate Change: A Sensitivity Analysis for the Grand Forks Aquifer, Southern British Columbia. *Hydrogeology Journal*, 12, 270–290.

Audu, E.B. (2012). An Analytical View of Temperature in Lokoja, Kogi State, Nigeria. *International Journal of Science and Technology, 2, (12),* 856-859

Ayoade JO (1975). Water Resources and their Development in Nigeria. Hydrological Sciences, XX, (4), 581-591

Ayoade JO (2010). Water Resources and their Development in Nigeria. Hydrological Sciences Bulletin, 20(4), 581-59.

Bakundukize C, Camp M.V. & Walraevens K. (2011) Estimation of Groundwater Recharge in Bugesera Region (Burundi) Using Soil Moisture Budget Approach. Geologica Belgica, 85-102.

Bates B C, Kundzewicz Z W, Wu S &Palutikof J P (ed) 2008 Climate change and water Technical Paper VI of the Intergovernmental Panel on Climate Change (Geneva: IPCC Secretariat), 210.

Belkhiri L, Boudoukha A, Mouni L & Mouni L (2010). Application of Multivariate Statistical Methods for Characterization of Groundwater- A case Study: Ain Azel Plain, Algeria. *African Journal of Environment Sciences and Technology, 4(8)* 526-534.

BGR (2008). Groundwater and Climate Change: Challenges and Possibilities. Groundwater Resources and Management German Federal Ministry for Economic Cooperation and Development (BMZ) p.20

BNRCC (2011) National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN). Prepared for the Federal Ministry of Environment Special Climate Change Unit p.101. Available electronically at: http://www.nestinteractive.org/publications.php. (Consulted 16/10/2015)

Bokar H., Mariko A., Bamba F., Diallo D., Kamagaté B., Dao A. & al. (2012). Impact of Climate Variability on Groundwater Resources in Kolondieba Catchment Basin, Sudanese Climate Zone in Mali. *International Journal of Engineering Research and Application (IJERA), 2*, 1201-1210.

Boufekane A. & Saighi O. (2013). Assessment of Groundwater Pollution by Nitrates Using Intrinsic Vulnerability Methods: A Case Study of the Nil Valley Groundwater (Jijel, North-East Algeria). *African. Journal of Environment Science and Technology, 7 (10)*, 949-960.

Bovolo C.I., Parkin G & Sophocleous M (2009). Groundwater Resources, Climate and Vulnerability. Envir. Res. Lett.: Impact Factor: 4.09 DOI: 10.1088/1748-326/4/3/035001

Carman, P. C. 1937. Fluid Flow through Granular Beds. Trans.Inst.Chem. Eng., 15,150.

Carman, P.C. 1956. Flow of Gases through Porous Media. Butterworths Scientific Publications, London.

Chilton J. & Seiler K.-P. (2006). Groundwater Occurrence and Hydrogeological Environments *in* World Health Organization: Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources. Published by IWA Publishing, London, UK.

Craiz and Heinz (2009). Shallow Groundwater Temperature Response to Climate Change and Urbanization. *Journal of Hydrology*, 601-612.

Dike F.I. (2005). Blaney-Morin-Nigeria (BMN) Evapotranspiration Model. (a Technical Note). *Nigerian Journal of Technology, 24, 2*,101-104.

Doss C, Morris M (2001). How does Gender Affect the Adoption of Agricultural Innovations? The Case of Improved Maize Technology in Ghana. Agricultural Economics, 25, 27–39.

Duru, J .O. (1984). Blaney-Morin-Nigeria. Evapotranspiration Model. *Journal of Hydrology,* 70, 71-83. (In Dike, 2005).

Edoga R.N. and Suzzy A.B.U.(2008). Effect of Temperature Changes on Evapotranspiration in Minna, Niger State. *Journal Engineering and Applied Sciences, 3*, 482-486.

Flint, A. L., L. E. Flint, E. M. Kwicklis, J. T. Fabryka-Martin & G. S. Bodvarsson (2002). Estimating Recharge at Yucca Mountain, Nevada, USA: Comparison of Methods, *Hydrogeology Journal*, *10*, 180– 204. DOI 10.1007/s10040-01-0169-1

FME (2009). Nigeria and Climate Change: Road to Cop15‘Achieving the Best Outcome for Nigeria’ Federal Government of Nigeria p.84.

Green T. R., Taniguchi M., Kooi H., Gurdak J.J., Hiscock K.M., Treidel H. al (2011) Beneath the Surface of Global Change: Impacts of Climate Change on Groundwater. *Journal of Hydrology,* 405, 532–560

Hazen A (1892). Some Physical Properties of Sand and Gravels. Massachusetts State Board of Health, 24th Annual Report (in Ishaku *et al.,* 2011).

Holman IP (2006). Climate Change Impacts on Groundwater Recharge: Uncertainty, Shortcomings, and the Way Forward. *Hydrogeology Journal.,* 14(5), 637-647.

Ifabiyi, I.P, Usman B.A.; Orire I.O.; Aledare, A. (2010) Productive Time of Women and Water Supply in Ijumu, Local Government Area, Kogi State, Nigeria. *Global Journal of Human Social Science, 10,* 45-52.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Group I, II, and III to the Fourth Assess Report of the Intergovernmental Panel on Climate Change[Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Kinzelbach W., Aeschbach W., Alberich C., Goni I.B., Beyerle U., Brunner P., Chiang W.-H., Rueedi J., and Zoellmann K. (2002) A Survey of Methods for Groundwater Recharge in Arid and Semi-arid regions. Early Warning and Assessment Report Series, UNEP/DEWA/RS.02-2. United Nations Environment Programme, Nairobi, Kenya. ISBN 92-80702131-3

Klove B., Pertti A.A, Guillaume B., Jason G., Hans K., & al (2014). Climate Change Impacts on Groundwater and Dependent Ecosystems. *Journal of Hydrology, 518,* 250–266.

Kommadath, A. (2000). Estimation of Natural Groundwater Recharge. Groundwater and Hydrogeology. http://ces.iisc.ernet.inSection 7, Paper 5. 7 pp.

Kozeny, J. (1927). Uber Kapillare Leitung Des Wassers in Boden. Sitzungsber Akad. Wiss.Wien Math.Naturwiss.Kl., Abt.2a, 136,271-306 (In Odong, 2007).

Kruseman, GP. De Ridder, NA. & Verweij, JM, (2000). Analyses and Evaluation of Pumping Test Data. International Institute of Land Reclamation and Improvement, Publication No. 29, Wageningen, 371 pp.

Kumar C.P. (2012). Climate Change and Its Impacts on Groundwater Resources. *International Journal of Environment and Science, 1,* 43-60.

Leterme B. & Mallants D. (2011). Climate and Land Use Change Impacts on Groundwater Recharge. IAHS Publ. 3XX, 201X pp1-7.

Mahmoud SA & Zekai S(2003). Determination of Hydraulic Conductivity from Complete Grain-Size Distribution Curves. Ground Water, 31, 551-555.

Mends, E. (1992). Kritische betrachting der wasserbilanz parameterund hydrologische Untersunchungen der Einzugsgebiete River abato und River Gurara (mittelnigeria). Geissener Geologische schriften 12e 47, 1-174. (In Adelene et al, 2008).

McKee, T.B., N.J. Doesken & J. Kleist, 1993: The Relationship of Drought Frequency and Duration to Time Scale. In: Proceedings of the Eighth Conference on Applied Climatology, Anaheim, California,17–22 January1993. Boston, American Meteorological Society, 179–184.

Misstear, B.D.R. (2000). Groundwater Recharge Assessment: a Key Component of River Basin Management National Hydrology Seminar pp51-58.

Mogheir Y. & Ajjur S., (2013). Effects of Climate Change on Groundwater Resources (Gaza Strip Case Study). *International Journal of Sustainable Envergy and Environmemt, 1* (8), 136- 149.

Morris, BL, Lawrence, ARL, Chilton, PJC, Adams B., Calow R. C. & Klinck, B A. (2003) Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management. Early Warning and Assessment Report Series, RS. 03-3. United Nations Environment Programme, Nairobi, Kenya.

NPC (2010). 2006 Population and Housing Census of the Federal Republic of Nigeria Housing Characteristics and Amenities, Priority Tables (LGA) volume II, p.393.

NPC (2010). 2006 Population and Housing Census of the Federal Republic of Nigeria Population Distribution by Sex, State, lga & Senatorial district. National Population Commission Volume III, p.64.

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria: lecture notes in earth sciences. Springer, new York, p.96-98.

Obuobie E. (2008) Estimation of Groundwater Recharge in the Context of Future Climate Change in the White Volta River Basin, West Africa. Doctoral thesis. Diese Dissertation ist auf demHochschulschriftenserver der ULB Bonn, p.165. http://hss.ulb.uni-bonn.de/diss_online elektronisch publiziert.

Obuobie E., Diekkrueger B., Agyekum W. & Agodzo S. (2012) Groundwater Level Monitoring and Recharge Estimation in the White Volta River basin of Ghana. *Journal of African Earth Science, 80-86* http://dx.doi.org/10.1016/j.jafrearsci.2012.06.005

Odofin A. J., Oladiran J. A., Oladipo J. A. & Wuya E. P. (2011). Determination of Evapotranspiration and Crop Coefficients for Bush Okra (*Corchorus olitorius*) in a Sub-humid Area of Nigeria. *African Journal of Agricultural Research, 6(17),* 3949-3953, DOI: 10.5897/AJAR10.812.

Ojo, S.B. & Ajakaije, D.E. (1989). Preliminary interpretation of gravity measurement in the middle Niger Basin Area, Nigeria. In Kogbe, C.A. (ed.) Geology of Nigeria. Rock view ignited, Jos, Nigeria, 347-358.

Oke MO, Martins O, Idowu OA & Fabiyi FD (2014). Determination of rainfall-Recharge Relationship in Ona River Basin Using Soil Moisture Balance Method. *International Journal of Water Resources and Environmental Engineering, 6(1), 1-11*

Okeola O.G. & Salami A.W.(2014). Groundwater Resources in The Nigeria's Quest for United Nation's Millennium Development Goals (MDGs) And Beyond. *Journal of Sustainable Development in Africa, 16,(4),* 57-71.

Olabode O.T., Eduvie M.O & Olaniyan I.O. (2012). Evaluation of Groundwater Resources of the Middle Niger (Bida) Basin of Nigeria; *American Journal of Environmental Engineering, 2(6),* 166-173.

Oladipo E. (2010). Towards Enhancing the Adaptive Capacity of Nigeria: a Review of the Country's State of Preparedness for Climate Change Adaptation. Heinrich Böll Foundation Nigeria, p.44.

Olasehinde P.I. (2010). The Groundwaters of Nigeria: a Solution to Sustainable National Water Needs. Inaugural Lecture Series 17. FUT, Minna, p56.

Philip. M. N. & Batalaan O. (2009). Estimating the Effects of Climate Change on Groundwater Recharge and Base Flow in the Upper Ssezibwa Catchment, Uganda. Hydrological Sciences–54(4) Special issue: Groundwater and Climate in Africa.

Rushton K. R. & Kruseman G. P. (2004). Occurrence of Groundwater, Regime and Dynamics in an International Guide for Hydrogeological Investigations Published by United Nations Educational, Scientific and Cultural Organization, pp19-41.

Rushton K.R, Eilers V.H.M. & Carter R.C (2006). Improved soil Moisture Balance Methodology for Recharge Estimation. *Journal of Hydrology, 318*, 379–399. www.elsevier.com/locate/jhydrol

Scanlon B.R., Healy R.W., Cook P.G. (2002). Choosing Appropriate Techniques for Quantifying Groundwater Recharge. *Hydrogeology Journal*, *10,* 18–39 DOI 10.1007/s10040-0010176-2.

Scibek J; Allen M D & Whitfield P. H. (2008) Quantifying the Impacts of Climate Change on Groundwater in an Unconfined Aquifer that is Strongly Influenced by Surface Water Geological Society, Lond Special Publ. 2008; v. 288; p.79-98.

Sophocleous M (2004); Groundwater Recharge and Sustainability in the High Plains Aquifer in Kansas, USA, *Hydrogeology Journal, 13,* 351–365 DOI 10.1007/s10040-004-0385-6.

Stoll S., Hendricks F. H. J., Butts M. & Kinzelbach W. (2011). Analysis of the Impact of Climate Change on Groundwater Related Hydrological Fluxes: a Multi-Model Approach Including Different Downscaling Methods. *Hydrology and Earth System Sciences, 15*,21–38.

Teklebirhan Arefaine, Dessie Nedaw, Tesfamichael Gebreyohannes (2012). Groundwater Recharge, Evapotranspiration and Surface Runoff Estimation Using WetSpass Modeling Method in Illala Catchment, Northern Ethiopia. *Momona Ethiopian Journal of Science (MEJS), 4 (2),* 96-110.

Treidel H., Martin-Bordes J.L., Gurdak J.J. (2012) Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations. International Contributions to Hydrogeology. Taylor and Francis publishing, 414p.

Wada Y., Ludovicus P. H. V. B., Reckman J.W.T. M.,Vasak S., Cheryl M. V.K.& Bierkens M.F.P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters, Vol. 37,* L20402, DOI: 10.1029/2010GL044571.

Wallace, L., Sundaram, B. Brodie, R. S., Marshall S., Dawson, S., Jaycock J., Stewart G. & Furness, L., (2012). Vulnerability Assessment of Climate Change Impacts on Groundwater Resources in Timor-Leste - Summary report. Record 2012/55. Geoscience Australia: Canberra.

WMO (2012). Standardized Precipitation Index User Guide. World Meteorological Organization WMO-No. 1090 p.24.

APPENDICES

APPENDIX A: RESEARCH QUESTIONNAIRE

Questionnaire ID: ______________________

1. Name of interviewer____
2. Date of interview: ________/ 05 /2015
3. Locality:____
4. GPS coordinate point: Lat:__________N; Long: _____________E; Alt: ______m

I-SOCIO DEMOGRAPHIC INFORMATION ABOUT THE RESPONDENT

1. Name of the respondent: ____
2. Sex of respondent: ___________ (1) Female; (2) Male:
3. Age of respondent:_______ (1) 1-20 ; (2) 21-40 ; (3) 41-60 ; (4) 60-80 ; (5) 80-100
4. Level of education: _____________

   None (2) Basic (Primary/Middle) (3) Secondary; (4) Tertiary (University)

5. Is the respondent native of the village?: _(1)Yes (2) No (If No proceed question 5)
6. How long have you been leaving in the village?_________

More than 2 years (2) More than 5 years (2) More than 10 years (3) more than 30 years

II- WATER SOURCES FOR DOMESTIC NEED

1. What are the sources of water? _______________________________________

   (1) Only Well; (2) Only Borehole; (3) Only Rivers; (4) All above

2. Which sources are mostly used? Why? ____________________________________

   (1) Only Well; (2) Only Borehole; (3) Only Rivers; (4) All above

3. What are the uses of water in the community? ________________________________

   (1) Only Domestic needs (2) Only Agriculture (3) All above

4. How accessible are the water sources?

   Distance: ______ (1) 0-1 Km (2) 1-2 Km (3) 2-5 Km (4) 5Km≤

Monetary wise: ___________ (1) Yes; (2) No

5. Is the water adequate for your daily needs over the year? _______ (1) Yes; (2) No

III- CLIMATE CHANGE PERCEPTION

1) What did you notice about the intensity of rain for the past 20 years? ____________

   (1) Abundant (2) Average (3) Low (4) Fluctuating (5) Nothing

2) What did you notice about start of raining season? ________________

(1) Earlier (2) Late (3) No change (4) Fluctuating (5) Do not know

3) What did you notice about end of raining season? ________________

(1) Earlier (2) Late (3) No change (4) Fluctuating (5) Do not know

4) How was the intensity of sun the past 20 years? ________________________

(1) Very hot (2) Hot (3) Middle (4) Normal (5) Do not know

5. Have you ever experienced drought over the past 20 years? ________

(1) Yes (2) No (3) Do not know

6. (If yes question 5) When did this drought occur? ______________

(1) Past 2 years (2) Past 4 years (3) Past 6 years (4) Past 8 years (5) Cannot remember

7. Have you ever experienced flooding over the past 20 years? _____________

(1) Yes (2) No (3) Do not know

8. (If Yes question 7) When did this flooding occur? ______

(1) Past 2 years (2) Past 4 years (3) Past 6 years (4) Past 8 years (5) Cannot remember

9. Did you have any knowledge about climate change? ____________ (1) Yes (2) No

10. Do you believe that climate is changing? ______(1) Yes (2) No (3) Do not know

IV- CLIMATE CHANGE IMPACT ON GROUNDWATER

1. If yes (question 10 previous section), do you think this changes affects the availability of water (Surface and groundwater)? ____ (1) Yes (2) No (3) Do not know

2. Have you noticed any changes in the availability of groundwater in your community over past 20 years? ___________________ (1) Yes (2) No

3. (If Yes question 2) How is this groundwater change?

	Yes	NO	Do not know
Increase in well water level during the dry season			
Increase in well water level during the raining season			
Decrease or dry up of wells water during the dry season			
Decrease or dry up of wells water during the raining season			

5) Have you noticed any changes in groundwater following parameters in your community over past 20 years?

	Yes	No	Do not know
Taste			
Color			
Odor			

6) If yes question 3, at which period that occur? ___________

(1) Rainy season (2) Dry season (3) Do not know

7) How many months in a year do you experience shortages or limited/difficult access to groundwater? ________________

(1) 0-2 months; (2) 2-4 months; (3) 4-6 months; (4) great than 6 months; (5) Do not know

7) During which period in the year that occur? ____________________

(1) Rainy season (2) Dry season (3) Do not know

ADDITIONAL INFORMATIONS

APPENDIX B: RESULTS FROM QUESTIONNAIRE ANALYSIS

I-SOCIO-DEMOGRAPHIC INFORMATION ABOUT THE RESPONDENTS

	Variables	Percentage (%) of respondent
Sex		
	Female	8.9
	Male	91.1
Age		
	21-40	28.9
	41-60	42.2
	61-80	22.2
	> 80	6.7
Level of Education		
	None	2.2
	Primary	0.0
	Secondary	97.8
	Tertiary	26.7

II -WATER SOURCES FOR DOMESTIC NEED

	Variables	Percentage of respondent
Water sources		
	Well	0 **%**
	Borehole	0 **%**
	River	22.2 **%**
	All above	77.8 **%**
	Well	20 **%**
	Borehole	24.4 **%**
	River	55.6 **%**
	All above	0 **%**
Uses of water		
	Domestic need	2.2 **%**
	Agriculture	0.0 **%**
	All above	97.8 **%**
	[0;1[	86.7**%**
	[1;2[	11.1 **%**
	[2;5[	2.2 **%**
	5km ≤	0.0 **%**
Monetary aspect		
	Yes	40.0 **%**
	No	60.0 **%**
Water adequate		
	Yes	71.1 **%**

No	28.9 **%**

III- CLIMATE CHANGE PERCEPTION

Variables		Percentage of respondent
Intensity of rain	Abundant	6.7 %
	Average	15.6 %
	Low	44.4 %
	Fluctuating	31.1 %
	Do not know	2.2 %
Start of raining season		
	Earlier	13.3 %
	Late	64.4 %
	No change	4.4 %
	Fluctuating	17.8 %
End of the raining season		
	Earlier	13.3 %
	Late	64.4 %
	No change	4.4 %
	fluctuating	17.8 %
Intensity of sun		
	Very hot	86.7 %
	Hot	4.4 %
	Middle	4.4 %
	Do not know	4.4 %
Drought Experience		
	Yes	86.7 %
	No	8.9 %
	Do not know	4.4 %
Year of Occurrence of Drought		
	Past 2 years	33.3 %
	Past 4 years	15.6 %
	Past 6 years	6.7 %
	Past 8 years	11.1 %
	Cannot remember	33.3 %
Flooding Experience		
	Yes	91.1 %
	No	6.7 %
	Do not know	2.2 %
`		
	Yes	20 %
	No	80 %
Believe on Climate Changing		
	Yes	95.6 %
	No	2.2 %
	Do not know	2.2 %

APPENDIX C: FIELD AND LABORATORY WORK PICTURES


08/05/2015

08/05/2015

08/05/2015

08/05/2015

27/05/2015

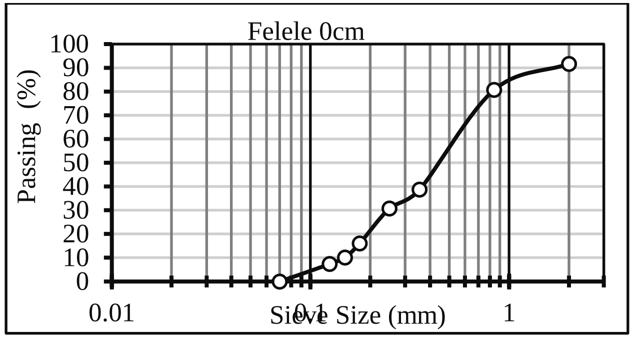
01/06/2015

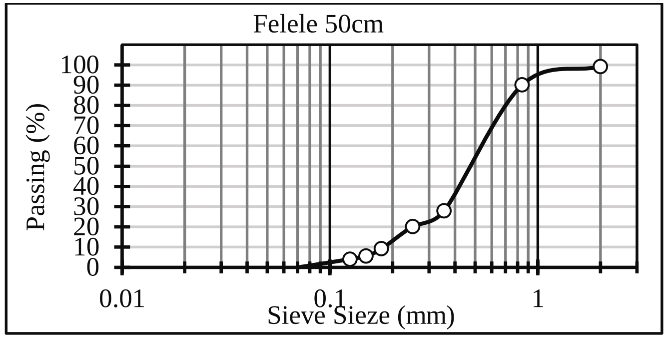
APPENDIX D: SIEVE ANALYSIS RESULTS

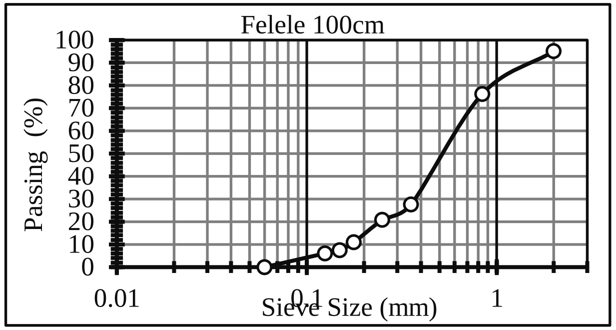
	LOKOJA			FELELE			EDUMOSE			ONUMAYE			SHINTAKU		
Initial Weight	**250**	**250**		**250**	**250**	**250**	**250**	**250.007**	**250**	**250**	**250**	**250**	**250.01**	**250**	**250**
Sieve Size	**0 cm**	**50 cm**		**0 cm**	**50 cm**	**100 cm**	**0 cm**	**50 cm**	**100 cm**	**0 cm**	**50 cm**	**100 cm**	**0 cm**	**50 cm**	**100 cm**
10	1.698	2.42		20.768	2.045	12.224	12.364	0.549	9.52	12.624	46.263	42.535	52.282	82	45.937
20	6.508	12.406		27.388	22.663	46.593	56.434	16.235	5.021	14.279	42.719	44.523	26.582	30.364	38.794
44	101.228	119.458		104.745	155.483	120.802	38.891	19.064	6.401	32.488	36.568	45.799	64.456	51.997	65.459
60	38.571	41.362		19.671	19.075	16.77	4.931	6.438	2.098	11.481	4.007	4.861	11.672	8.307	10.117
80	69.134	51.221		36.751	27.647	24.491	10.001	24.949	14.942	20.954	9.058	10.918	23.235	17.168	22.164
100	17.223	11.526		14.839	8.988	8.561	8.805	45.534	54.059	15.224	8.738	8.487	13.974	11.5	13.676
120	7.262	3.658		6.846	3.794	3.517	7.977	30.544	48.773	13.817	7.522	6.17	7.975	6.404	8.023
Pan	8.216	7.33		18.307	10.167	15.072	109.783	106.25	108.759	128.303	95.012	85.529	49.192	41.641	44.915
TOTAL	**249.84**	**249.381**	**0**	**249.315**	**249.86**	**248.03**	**249.186**	**249.563**	**249.573**	**249.17**	**249.89**	**248.82**	**249.37**	**249.381**	**249.085**

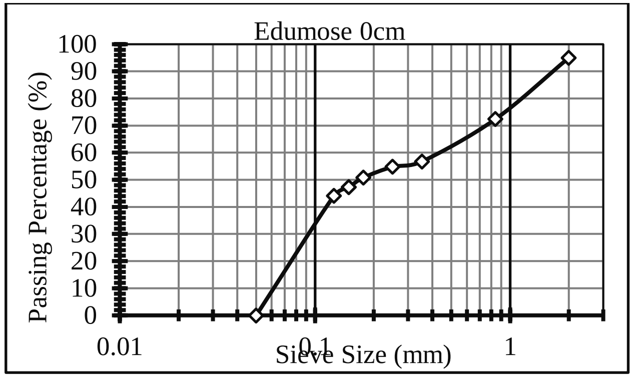
	BANDA			KPATA			KPATAPKALE			ATAPKA			ELULE		
Initial Weight	**250**	**250.007**	**250**	**250.002**	**250.002**	**250.007**	**250.014**	**250.004**	**250.001**	**250.005**	**250.004**	**250.002**	**250.009**	**250.001**	**250.003**
Sieve Size	0 cm	50 cm	100 cm	0 cm	50 cm	100 cm	0 cm	50 cm	100 cm	0 cm	50 cm	100 cm	0 cm	50 cm	100 cm
10	0.922	1.235	42.219	19.956	38.409	88.831	12.833	4.042	4.712	52.178	79.104	34.798	0.862	1.716	6.809
20	1.847	1.859	25.543	38.554	41.363	33.34	26.867	25.088	26.88	52.152	53.476	67.997	9.773	18.822	33.762
44	13.039	27.834	45.248	90.559	84.812	62.39	116.205	111.566	112.316	82.105	71.469	90.62	91.958	115.233	129.873
60	8.163	14.265	12.055	15.146	13.762	9.732	21.81	21.12	18.721	10.189	8.61	11.511	22.801	25.246	18.443
80	42.12	46.049	30.57	32.075	27.438	20.375	34.816	38.414	35.316	19.076	14.614	18.36	47.612	43.89	29.641
100	60.014	43.097	29.429	15.215	12.431	9.519	12.436	15.711	14.522	9.748	6.426	7.739	21.655	16.907	10.561
120	34.499	26.18	14.811	7.657	6.307	4.67	5.554	6.961	6.572	4.864	3.17	3.532	10.44	6.693	4.701
Pan	88.568	88.036	48.444	29.937	24.738	19.732	18.789	26.506	29.841	19.103	12.83	14.115	44.172	20.958	15.601
TOTAL	**249.172**	**248.555**	**248.32**	**249.099**	**249.26**	**248.589**	**249.31**	**249.408**	**248.88**	**249.415**	**249.699**	**248.672**	**249.273**	**249.465**	**249.391**

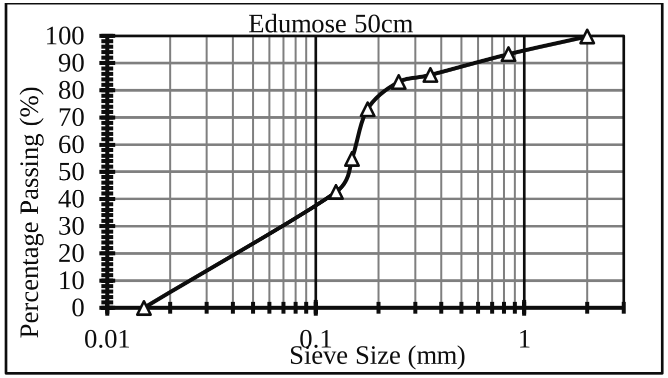
APPENDIX E: LOGARITHM PLOT OF PASSING PERCENTAGE VERSUS SIEVE SIZE

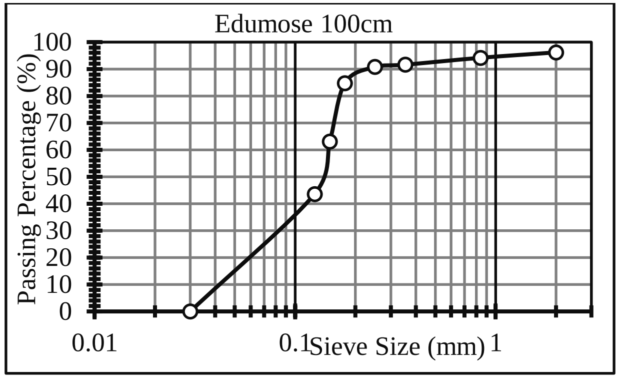


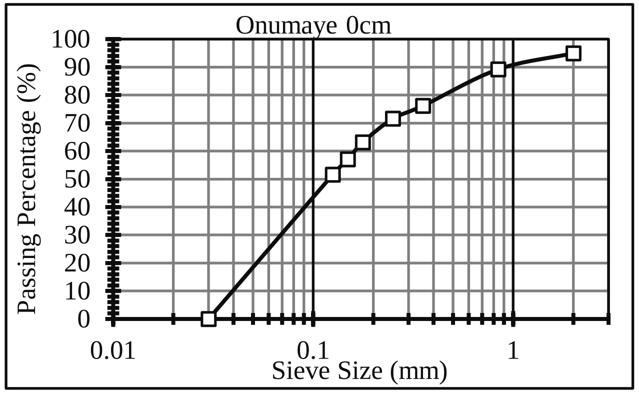


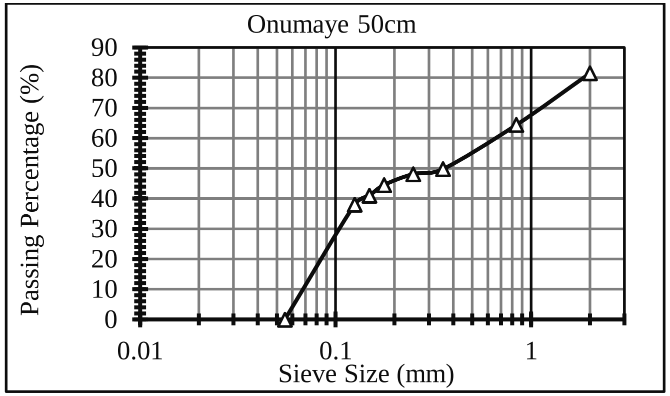


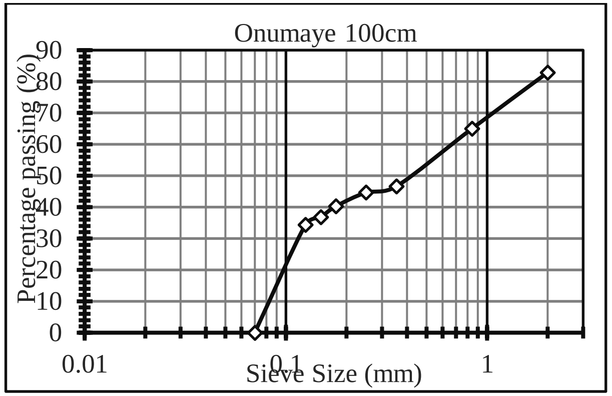


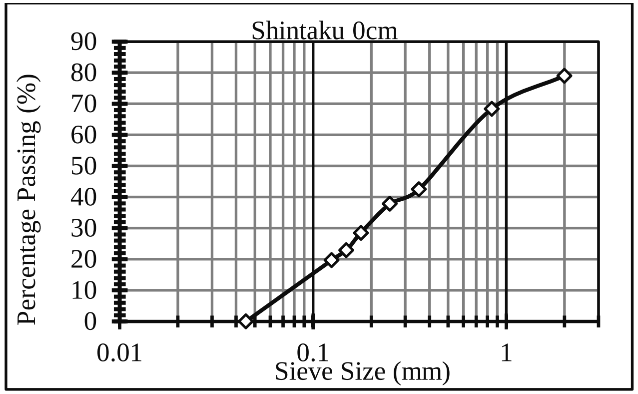


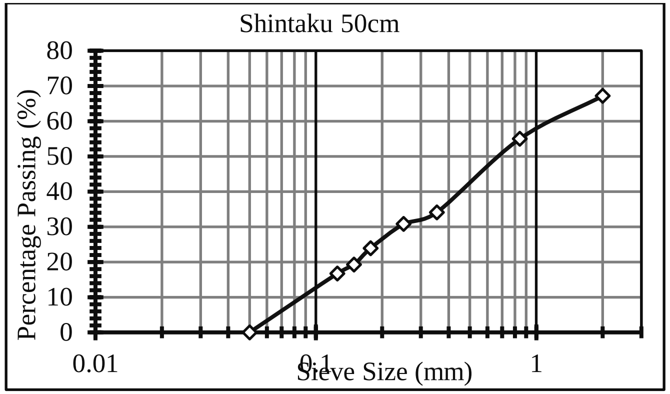


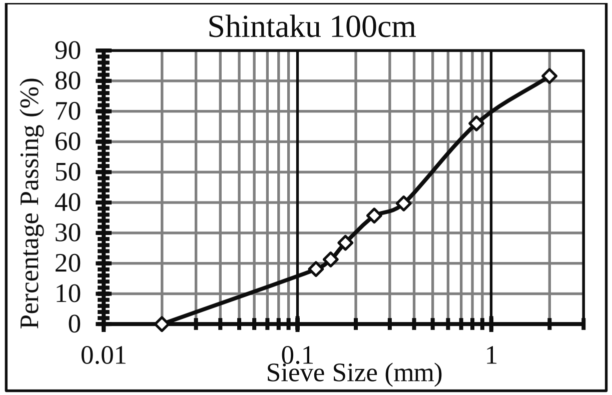


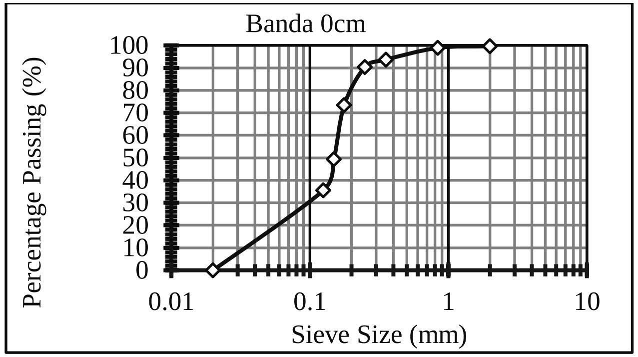


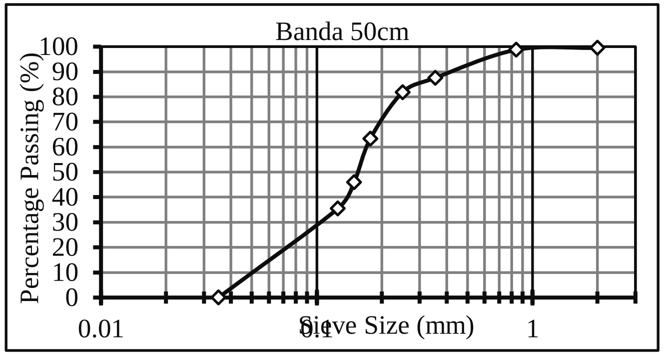


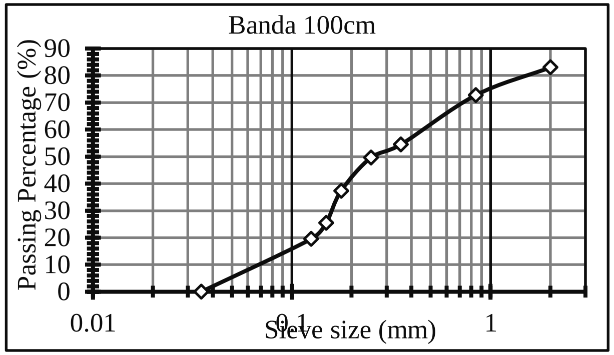

Shintaku 0cm
Percentage Passing (%)
0 10 20 30 40 50 60 70 80 90
0.01 0.1 1
Sieve Size (mm)

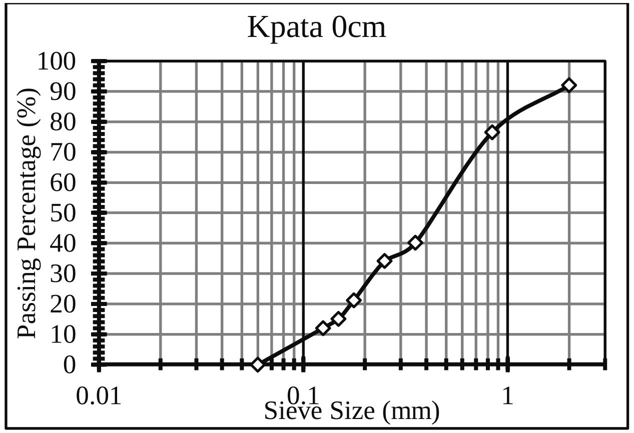

Shintaku 50cm
Percentage Passing (%)
0 10 20 30 40 50 60 70 80
0.01 0.1 1
Sieve Size (mm)

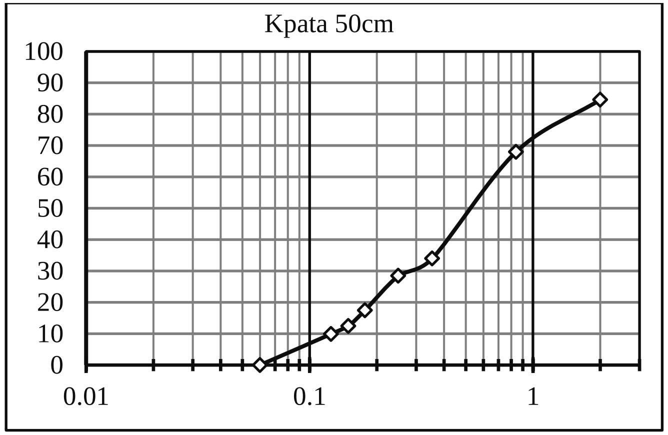

Shintaku 100cm
Percentage Passing (%)
0 10 20 30 40 50 60 70 80 90
0.01 0.1 1
Sieve Size (mm)

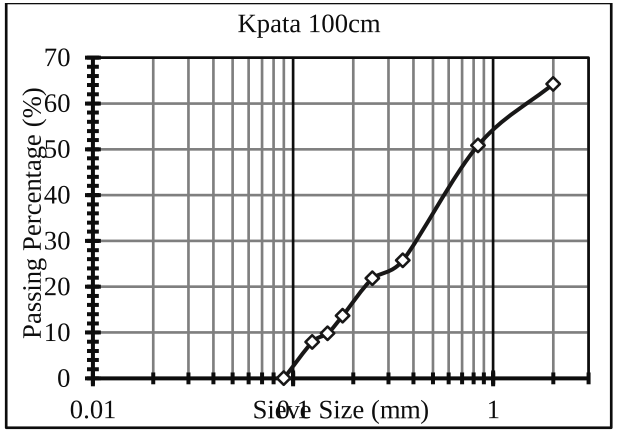

Banda 0cm
Percentage Passing (%)
0 10 20 30 40 50 60 70 80 90 100
0.01 0.1 1 10
Sieve Size (mm)

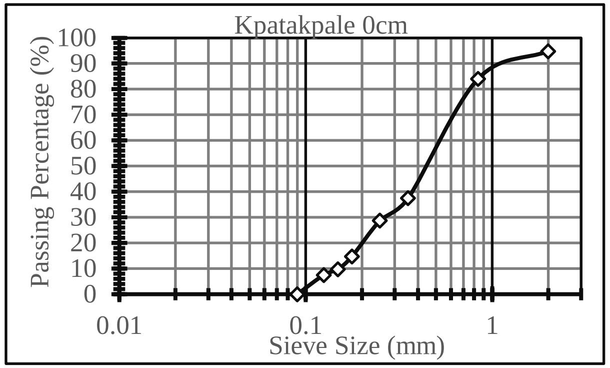

Banda 50cm
Percentage Passing (%)
0 10 20 30 40 50 60 70 80 90 100
0.01 0.1 1
Sieve Size (mm)

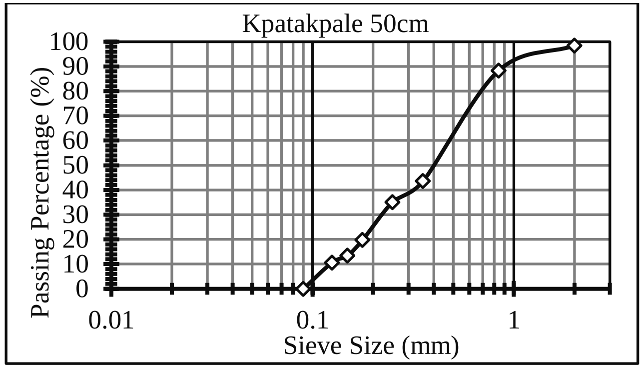

Banda 100cm
Passing Percentage (%)
0 10 20 30 40 50 60 70 80 90
0.01 0.1 1
Sieve size (mm)

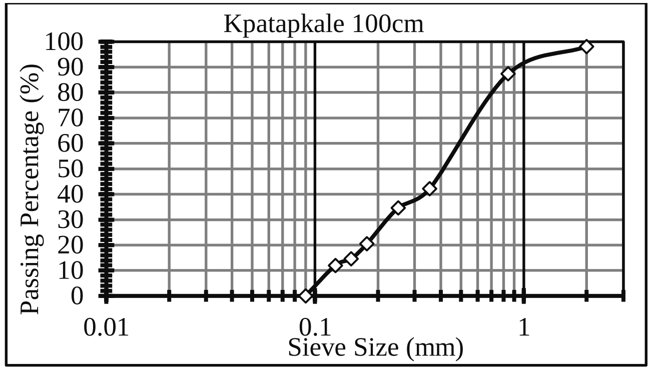

Kpata 0cm
Passing Percentage (%)
0 10 20 30 40 50 60 70 80 90 100
0.01 0.1 1
Sieve Size (mm)

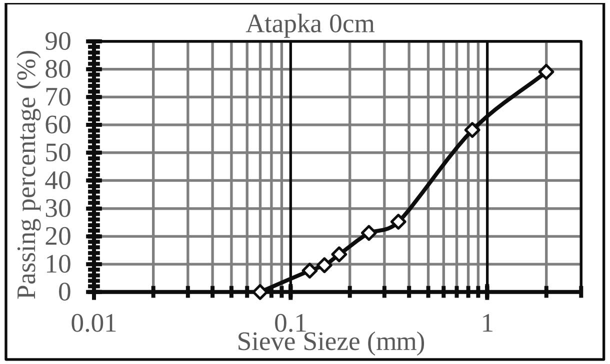

Kpata 50cm
0 10 20 30 40 50 60 70 80 90 100
0.01 0.1 1

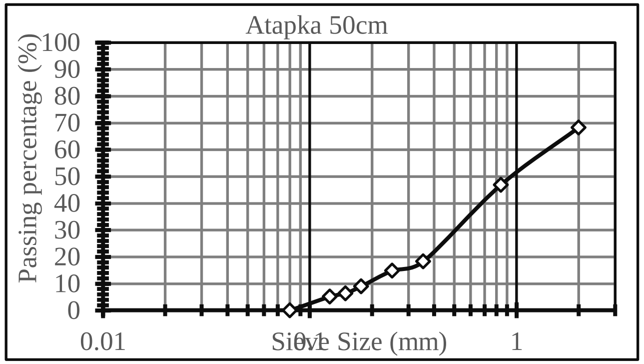

Kpata 100cm
Passing Percentage (%)
0 10 20 30 40 50 60 70
0.01 0.1 1
Sieve Size (mm)

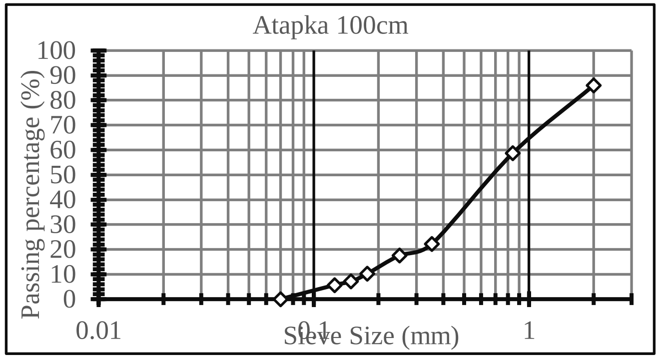

Kpatakpale 0cm
Passing Percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)

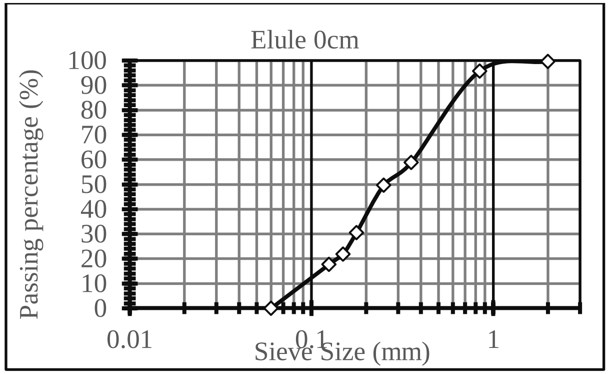

Kpatakpale 50cm
Passing Percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)

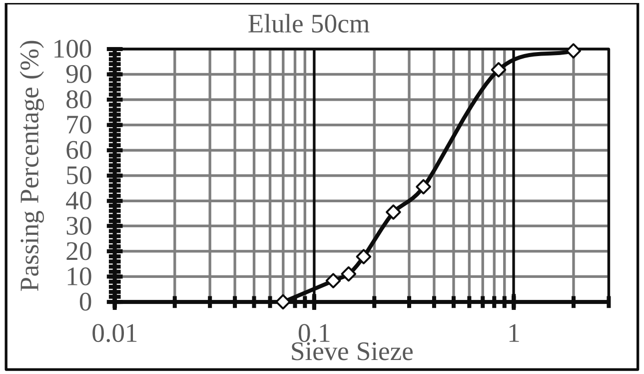

Kpatapkale 100cm
Passing Percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)

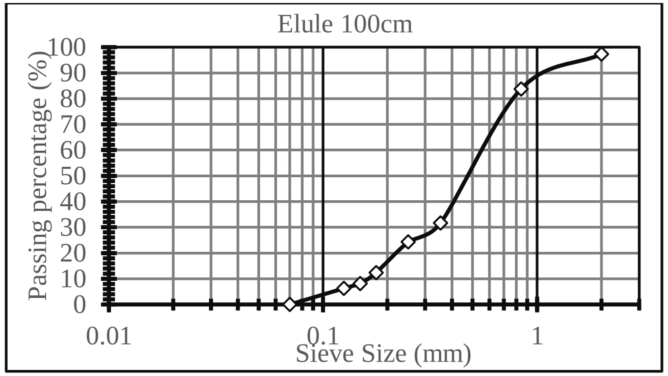

Atapka 0cm
Passing percentage (%)
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Sieze (mm)

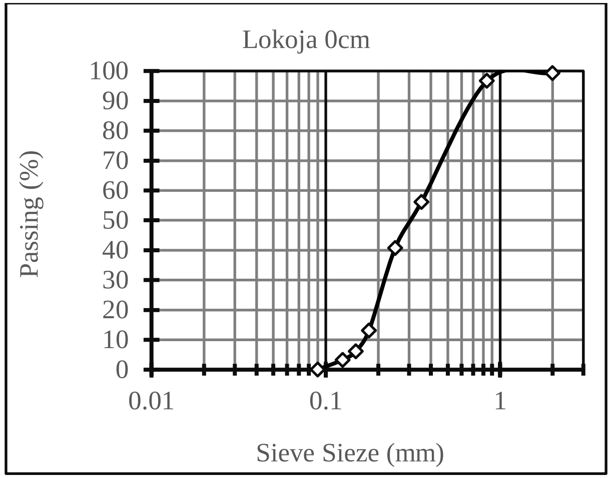

Atapka 50cm
Passing percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)

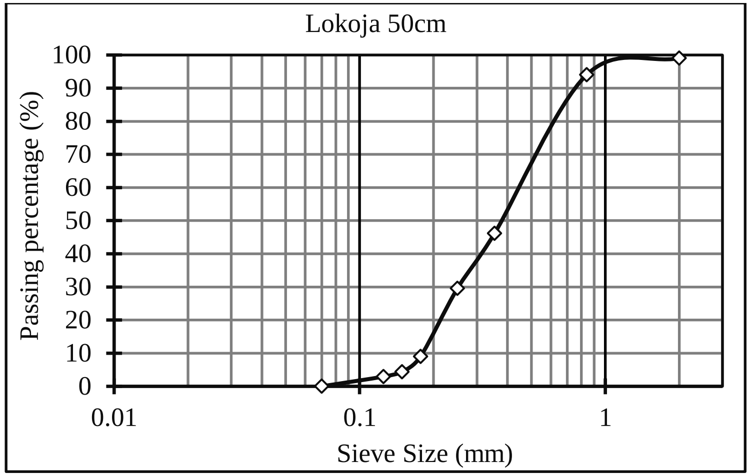

Atapka 100cm
Passing percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)


Elule 0cm
Passing percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)


Elule 50cm
Passing Percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Sieze


Elule 100cm
Passing percentage (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
Sieve Size (mm)


Lokoja 0cm
100
90
80
70
60
50
40
30
20
10
0
Passing (%)
0.01
0.1
1
Sieve Sieze (mm)


Lokoja 50cm
100
90
80
70
60
50
40
30
20
10
0
Passing percentage (%)
0.01
0.1
1
Sieve Size (mm)