THE HYDROPHYSICO-CHEMICAL AND BACTERIOLOGICAL STUDIES OF GOMBE AREA (SHEET 152 NE), NORTH-EASTERN NIGERIA

BY

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MSC/SCI/00182/2006-2007

THESIS SUBMITTED TO THE POST GRADUATE SCHOOL AHMADU BELLO UNIVERSITY, ZARIA; IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DECREE OF MASTER OF SCIENCE IN GEOLOGY

DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

AHMAD BELLO UNIVERSITY

ZARIA

NOVEMBER, 2011

CERTIFICATION

This work titled "Hydrophysio-chemical and bacteriological studies of Gombe sheet 152 NE" by Maryam Tafida has met the requirements for the award of degree of Masters of Science in Geology of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge.

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DECLARATION

I Maryam Tafida, with registration number M.Sc/Scie/00182/2006-2007 declare that this thesis is a product of my own research work and has not been previously presented for the award of higher degree at any other institution. And information derived from published and unpublished work has been duly acknowledged.

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Maryam Tafida Date

DEDICATION

This project is dedicated to my late father Alhaji Tafida Gadzama, May the exalted, the merciful (Allah) grant him aljannah.

ACKNOWLEDGEMENT

I wish to acknowledge my supervisors Dr. S. A. Alagbe and Dr. U. A Danbatta for their guidance during the course of my research. The contributions of Alhaji Aliyu Kamara, Arabi Suleiman, Usman Abubakar, Umar B. Ahmed, Rabiu M.B and all my lecturers in the Department of Geology, Ahmadu Bello University, Zaria will remain fresh in my memory, may Allah reward you with the best of His rewards.

The kind support of my mother Hajiya Amina Bello and my family can never be over emphasized, may God Almighty reward them infinitely.

ABSTRACT

Groundwater sampled from 20 hand dug wells of Gombe sheet 152 NE for the purpose of evaluating its quality for different uses, were obtained within the area bounded by latitude 11º09' to 11º 27' and longitude 10º15' to 10º 27' covering about 732.26 km^2 . Gombe sheet 152 NE falls within the upper Benue trough and stratigraphically made up of five different formations namely; Bima Sandstone, Yolde , Pindiga, Gombe Sandstone and the Kerri-Kerri Formations. Desk study which involved review of literatures and map, field studies such as reconnaissance survey, data gathering from the different agencies and laboratory studies by the federal ministry of Agriculture and water resources, Gombe regional water quality laboratory where qualitative and quantitative analysis was carried out using Atomic Absorption Spectrometry (AAS) and Flame photometry. RockWare Aq•QA spreadsheet for water analysis was utilized in the evaluation stage.

Three water types were determined from the study area and these include CaCl, Ca-HCO3 and NaCl. Total carbonate ranges from 27.393 mg/L to 239.27 mg/L and salinity hazard ranges from low (<250 µohm/cm) to medium (250 – 270 µohm/cm). No detrimental effects are expected on crop for waters with low salinity, while for medium salinity waters detrimental effects are expected only on crop that are sensitive to salinity. Dissolved solids ranges from <200 mg/L and 200 – 500 mg/L, Sodium Absorption Ratio (SAR), Exchangeable Sodium Ratio (ESR) and Magnesium Hazard (MH) ranges from 0.832 – 4.13, 0.292 – 3.968 and 0.086 – 82 respectively. The variation in the chemical composition of groundwater in the study area may be due to leaching of terrestrial salts mostly within the Gombe formation, extensive use of fertilizers and ion exchange between soil's minerals and water, the examined groundwater quality is fairly suitable for domestic and agricultural uses. Pattern of groundwater elevation in the study area shows flow of groundwater vis a vis the concentration of physic-chemical and bacteriological parameters.

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CHAPTER ONE

1. INTRODUCTION

Water is essential to life and the largest available source of fresh water lies underground. As a result of its availability, different techniques for investigating the occurrence and movement of groundwater resources have been developed. Thus, knowledge of groundwater which was once veiled in mystery has now grown rapidly in recent decade (Todd, 1980; Schoeneich, 2002). Today, even with the discovery of vast amount of groundwater, there is a concern about groundwater depletion and contamination. There is therefore a strong need to understand, protect and manage the groundwater resources of an area wisely.

Nearly all rural dwellers depend mainly on groundwater for their domestic supplies, which is an extensive reliance on diminishing resources. On average water is being removed from the ground several rates higher than it is being replenished (Rex and Robert, 1993). The presence, depth of occurrence and quality of groundwater resources are often difficult to imagine and understand. Although the general principles that determine the occurrence and characteristic of groundwater are well known, there is need to understand and document these with respect to Gombe sheet 152 NE, because of the extensive reliance of the people living in the area on the groundwater resources.

Hydrophysico-chemical and bacteriological study of the area is of great interest, whose availability and quality are directly influenced by the properties of the geological formations within which it occurs. In the study area the physical and chemical nature of the formations vary from area to area creating a wide range of water yield and quality properties. The variation in quality could be as a result of change in hydrochemical anomaly between the rocks of the different areas and the water flowing through them or may be due to many human activities going on in the area. These, together or individual could pose health hazards to the water consumers living in the area and variation in yield as a result as a result as variation of variation in aquifer characteristics.

The characteristics of the groundwater resources of the study area Gombe sheet 152 NE, its quality determined by both natural and artificial factors, exploitation and management provide a conceptual view of the procedure and problems involved in the utilization of these resources. Whether groundwater is one word or two the water does not care and must be studied in an interdisplinary base so as to understand all the implications and complications involved.

There is therefore a serious need to upgrade the knowledge of the hydrophysico-chemistry and bacteriological study of Gombe sheet 152 NE, so that better and well informed decision can be made about groundwater protection, management and use in the area.

1.2 Aim

The aim of this study is to determine the hydrophysico-chemical and bacteriological quality of groundwater of Gombe, sheet 152 NE.

1.3 Significance

This research will attempt to present the hydrophysico-chemistry and bacteriological study of the area. The findings will be of value to public health practitioners, who will be fully aware of the disease characteristics related to groundwater resources of the study area, so that exclusive update will be called for from the health practitioners on how to go about treating the ailment. The study will be of value to Gombe State Water Board ensuring that places of good water quantity and quality are exploited for consumption. The research will be of significance to the inhabitants of the area as places favourable for groundwater consumption will be demarcated and developed, while water from hazardous should be treated.

1.4 Location, Extent and Accessibility

The study area lie within Gombe sheet 36 (Figure 1) and includes parts of Gombe town, Akko; Yemaltu Deba and Kwami Local Government Areas. It is located within the Upper Benue Trough (Figure 2) bounded by latitudes 11°01'33" to 11°30′00"N and longitudes 10°15'00" to 10°30.00"E covering an area of about 732.26 km^2 (Figure 3). The study area is easily accessible in the dry season through numerous foot paths, minor road; dry stream channels and a few rural road

networks constructed over the past decades. During the wet season accessibility is hindered by the presence of farmlands, waterlogged nature of some sedimentary formations; the overflowing nature of some streams and perennial streams.

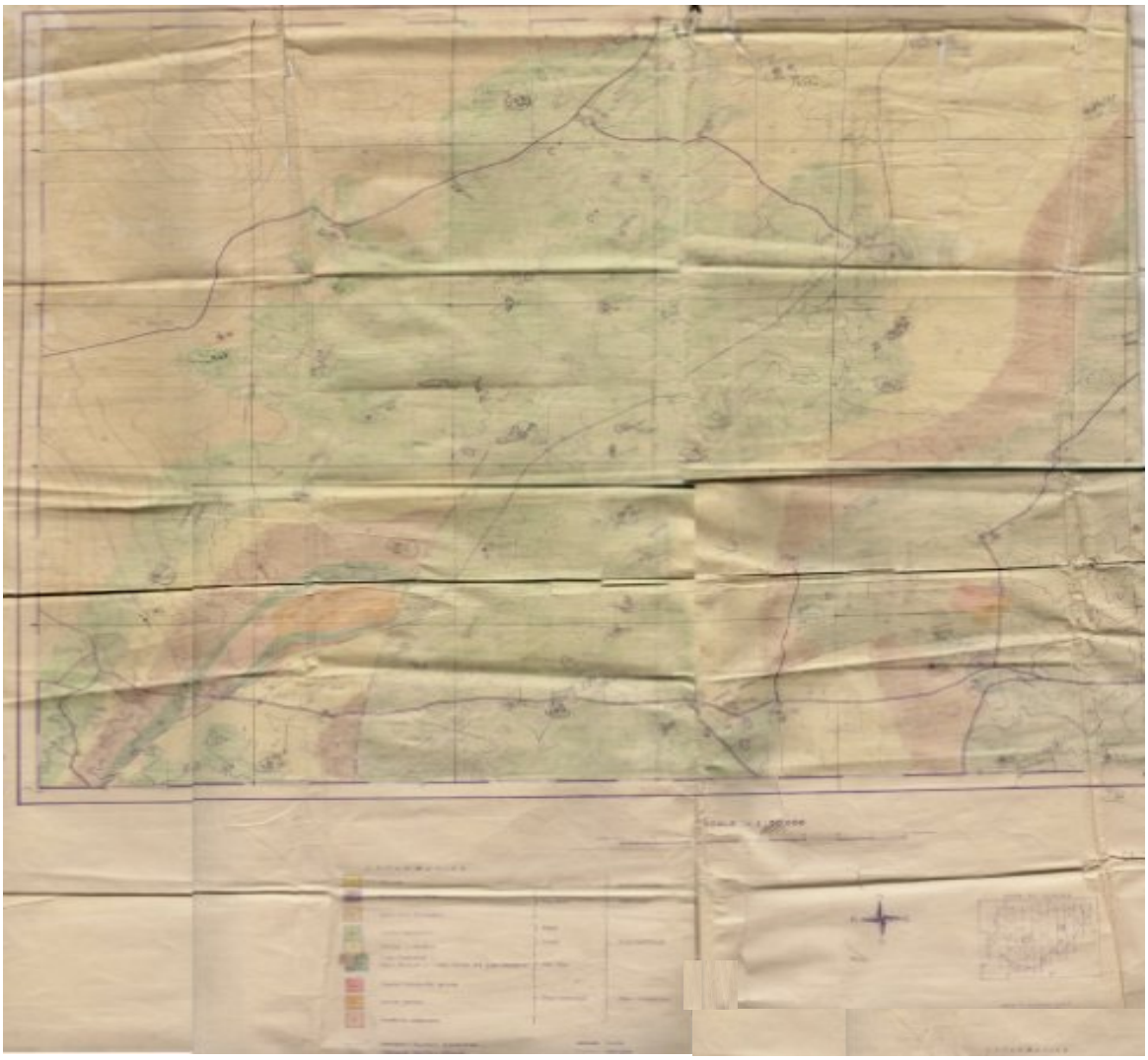


Figure 1: Location, Topography and Fact Map of the Study Area

1.5 Topography and Drainage

The study area was designed partly by the striking landform, the Gombe and Liji Hills to the north of Gombe town, which are characterised by high relief and steep flanks (**Figure 3**).The slopes between the eastern summit of plateau and the Gombe Hill were dissected by numerous water courses which originate from the eastern edge of the plateau and running west to east. The

plateau comprises three water sheds, two major and a minor one. The meandering eastern arm separates the water courses that run eastward down Gombe slope from those which run northward, these two are tributaries of the Gongola River which is the main river that drains the study area. The central eastern to western limb separates the water course of the south.

1.6 Climate

The study area experiences a two season climate, rainy and dry seasons. The rainy season lasts from April to November with temperature ranging from 23.32ºC in January to 31.91ºC in April, with an annual average of 27.62ºC and an annual rainfall rainfall of 129.68 to 138.91 in 2004 and 2007 respectively (Gombe Meteorological Station, NIMET, 2007).

1.7 Scope

The scope of this research is to study the hydrophysico-chemical and bacteriological study of the Gombe sheet 152 NE.

1.8 Previous work

Offodile (2002) studied the groundwater resources management in Nigeria with emphasis on the potential of the formations covering the Upper Benue Trough within which the study area falls. In the hydrogeology of the Gombe sub-catchment, Benue Valley, Nigeria, Iyioriobhe *et al*, (2003) found out that Gombe Formation with its percentage of silts is slightly permeable, while the Pindiga Formation and Yolde Formation are essentially aquiclude, although the latter has scattered water bearing horizons. Chemical analysis of groundwater in the sub-catchment indicates good quality despite the difference in depth of sampling. Furthermore, two groups of water emerged; these include sodium bicarbonate rich and sodium bicarbonate deficient. Also result of isotope hydrology suggests that sodium deficient type of water has similar characteristics to the water from the middle zone aquifer of the Chad Basin and deep aquifer of the Sokoto Basin. Iyioriobhe *et al.*

(2003) concluded that Bima Sandstone is thus the best aquifer in the Gombe sub-catchment. Carter *et al.,* (1963) studied the geology of parts of Adamawa, Bauchi and Borno Provinces in the north-eastern Nigeria. They discovered that the varied lithology of the Cretaceous strata and the structure imposed on these sediments produced pressure water condition on the groundwater. The generalised Cretaceous succession is that of a thick sequence of arenaceous beds overlain by shale which form aquiclude. At Gombe town boreholes have obtained water from pressure wells of the Yolde Formation, the aquiclude being the shale of the Pindiga Formation.

Correlations of vertical electrical sounding curves with lithologies and hydrochemical analysis from boreholes in the north-eastern part of Gombe Town by Arabi (2006) suggests that the lithologic units penetrated are laterite, clay, shale, sandstone and sandy clays. The sandy clay and sandstone units are the aquifer zones with resistivity range of 28 to 84 ohm-m for clay to 40 to 5010 ohm-m for sandstone, and 967-1008 ohm-m for sandy clay. The others are 2069-9607 ohm-m for calcareous and laterite units, 17456 ohm-m for compacted sands. He deduced that average pH value is 7.02 with an average conductivity of 72.16 μS/cm. He also concluded that the hydraulic head of the study area ranges between 200 m and 219 m above mean sea level and a static water level of 5.15 m to 124 m with borehole depth ranging between 38 m to112 m and turbidity of 1 to 31 NTU.

CHAPTER TWO

2. General Geology of the Study Area

The Basement Complex upon which the Benue Trough is lying consists of migmatite-gneiss complex, which has been extensively intruded by the granitic and charnokitic rocks of Pan-African age. The migmatite-gneiss complex is composed predominantly of migmatite and banded gneisses. Relics of metasedimentary and metavolcanic rocks are widely distributed in the migmatite-gneiss complex and they form part of the succession (Ajibade *et al.,* 1989).The Biotite granite forms the inlier of the Gombe Hill and a portion of it was seen in the southern part of the study area. The basaltic plugs were also seen scattered around quite a few part of the study area (**Figure 2**) while in the southern part they intruded the older sedimentary rock (Bima Sandstone Formation) of the area.

2.1 Benue Trough

The Benue Trough within which the formations of the study area situated is an elongated linear NE-SW trending rift structure and has a length of approximately 800 km opening into the Gulf of Guinea, where the Cainozoic Niger Delta has built upon oceanic crust (Avbovbo, 1980). The trough was recognised as an aulacogen that developed as a result of the Lower Cretaceous Continental rifting and opening of the Atlantic Ocean (Olade, 1975). Proximally, the Benue Trough bifurcates into an E-W trending Yola Arm and the N-S trending Gongola Basin (Zaborski, 1998).

The Benue Trough (**Figure 2**) is conventionally subdivided into a 'Lower Benue Trough', 'Middle Benue Trough' and an 'Upper Benue Trough within which the study area falls. The Benue Trough was terminated by a Late Santonian episode of compressional folding. Subsequent sedimentation centred in the basin developed on the north-western flank of the resultant deformed sediments (Zaborski, 1998).

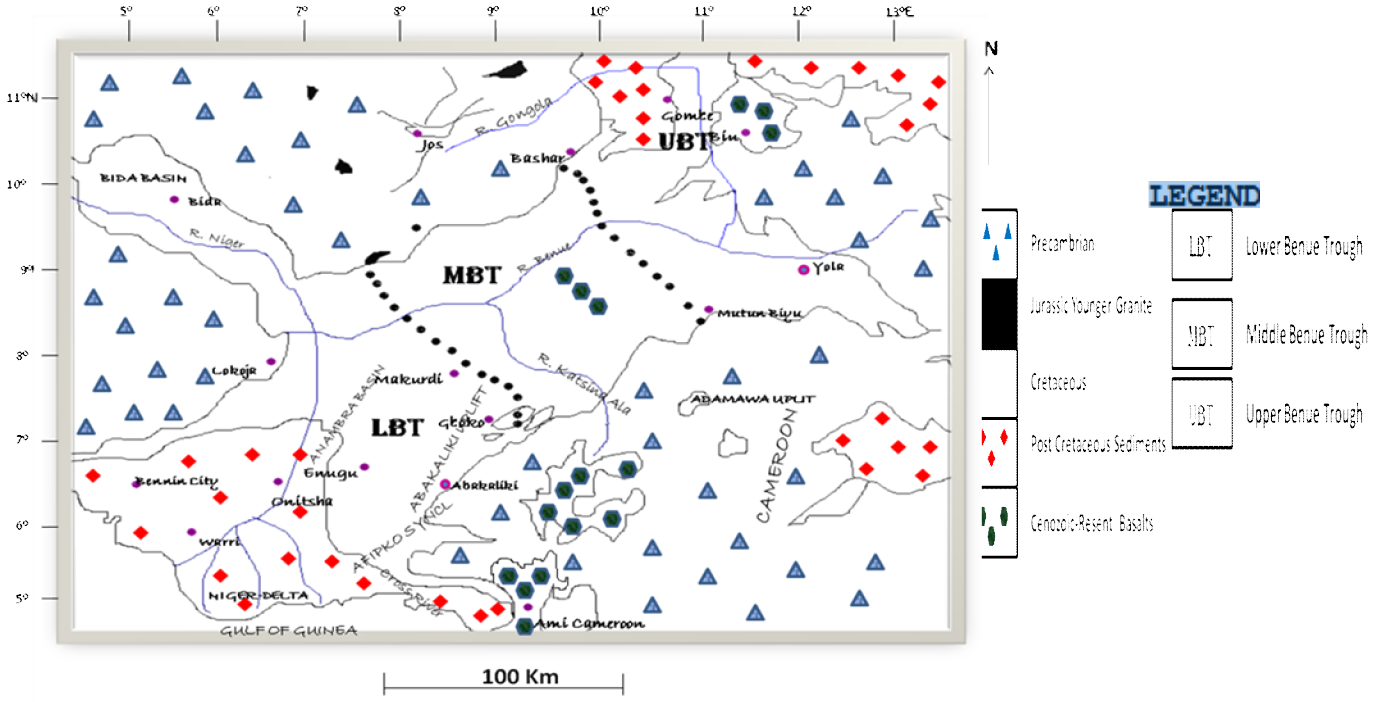


Figure 2: Outline geological map of the Benue Trough and adjacent area (Modified after Zaborski, 1998).

2.1.1. Stratigraphy of the Benue Trough

The stratigraphy of the Benue Trough is made up of five different formations with sub-groupings, starting with the oldest to the youngest are: the Basement Complex, Bima Sandstone Formation, Yolde Formation, Pindiga Formation, Gombe Formation and the Kerri-Kerri Formation (**Figure 3**).

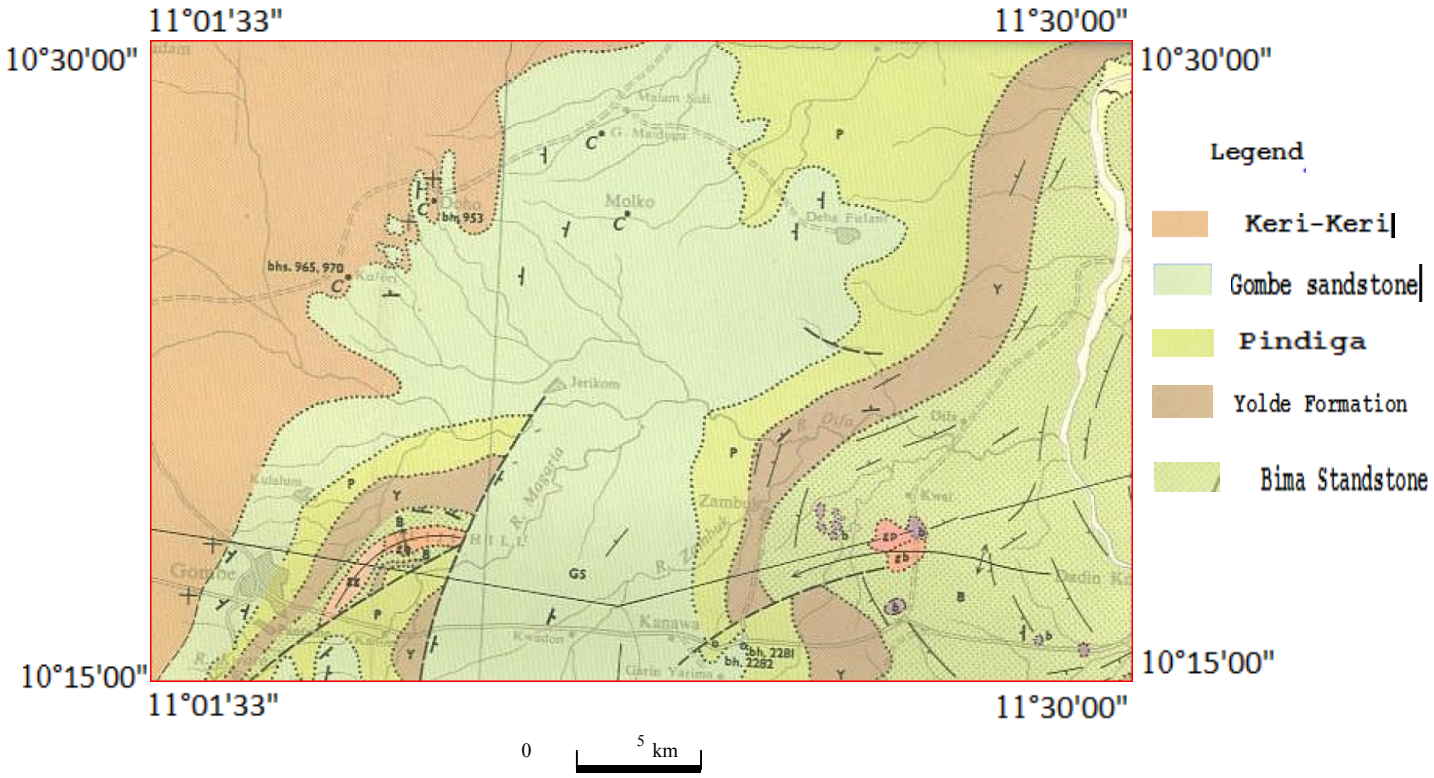


Figure 3: Geological map of the study **(**after Carter *et al*, 1960)

2.1.1.1.1 The Lower Cretaceous Series

2.1.1.1.1. Bima Sandstone Formation

This is the most important of all the sedimentary units in the Gongola Basin, forming the base of the Cretaceous system (Benkhelil, 1986). The Continental Bima Group comprises of oldest sediments in the Upper Benue Trough overlying the crystalline basement rocks (**Figure 3**). The Bima Sandstone is divided into three which include the 'Upper Bima Sandstone' (B3) a fairly homogenous fine to coarse-grained sandstone, characterised by tabular cross-bedding with an average thickness estimated at 500 m and a maximum thickness of about 1500 m. The 'Middle Bima Sandstone'(B2) a widely distributed, fairly uniform unit consisting of fining upward circle, characterised by trough and tabular cross-bedding with thickness of between 100 and 500 metres. The Lower Bima Sandstone is a highly variable unit with an overall thickness of over 1500 m separated by regional uncomformity from the younger beds. The sediment consists of mainly

poorly sorted and angular arkoses, granulestone; pebbles and boulder conglomerate. Fresh fragments of acidic rocks are also common; these lithofacies are found in the study area.

2.1.1.1.2 The Yolde Formation

The Yolde Formation is a variable sequence of sandstone and shales, which overlies the Bima Sandstone. Yolde Formation corresponds to the passage between the continental Bima Group and the upper marine levels (Benkhelil, 1986). For this reason it was named 'passage beds' (Falconer, 1911) or the 'transition beds' (Barber et al., 1953; Reyment, 1965).

2.1.1.1.3 The Pindiga Formation

The Pindiga Formation is a sequence of black marine shale, limestone and a number of interbedded sands which overlies the Yolde Formation (Carter *et al.*, 1963).These rocks outcrops in some parts of the study area**.** The Pindiga Formation consists of five members which include the Fika, Dambulwa, Deba Fulani, Gulani and Kanawa members (Zaborski, 1997)**.**

2.1.1.1.4 The Gombe Sandstone Formation

The Gombe Formation comprises of flat lying alternating thinly bedded, fine to medium grained friable ferruginous sandstones, sand, silty micaceous shales, mudstones and some coal beds (Offodile, 2002). This formation is deltaic and estuarine deposit. The sandstone forms sufficient aquifers and adequate yields can be obtained from them (Carter *et a*l.*,* 1963; Offodile, 2002)

2.1.1.2 The Post Cretaceous Rocks

2.1.1.2.1 The Kerri-Kerri Formation

This Tertiary sedimentary rock consists of a continental sequence of flat lying grit, sandstones and clay (Carter *et al.*, 1963).

2.1 General Hydrogeology of the Study Area

2.1.1 Bima Sandstone

The lithological sequences of the Bima Sandstone forms a comparatively poor aquifer. Well yields are often small as a result of low permeability of the sediments which may contain much interstitial clay derived from the weathering of feldspars. The Bima Sandstone is also highly crystalline and cemented. Under this condition it presents the hydrogeological characteristics of the basement (Offodile, 2002). Secondary permeability is only developed by means of fracturing and weathering. This sandstone groundwater occurs mostly under water table condition, sometime the clay beds confines this aquifer.

Yields in the Bima Sandstones are unpredictable, ranging from two litres per second to eight litres per second. An average of one to five litres has been recorded depending on the hydrogeological environment (Offodile, 2002). The Bima Sandstone is found covering the south-eastern part of the study area including places like Gwani, Difa, Kwali and also found encircling the Gombe Hill in the study area.

2.1.2 The Yolde Formation

The Yolde Formation sandstone member including sometimes fractured limestone beds form the aquifer in this formation. This formation is more water bearing than the Bima Sandstone, as the sandstone and limestone are more permeable (Offodile, 2002). Variation in the permeability of these strata coupled with structures imposed on these beds produce pressure water conditions. The Yolde Formation is overlain by the shale of Pindiga Formation which provides the seal producing pressure wells such as the case in Kwadon of in study area. Groundwater is also found in unconfined aquifer within the Yolde Formation of the area and borehole is situated entirely within the Yolde Formation where the pressure seals are intra-formation aquicludes (Carter *et al.,* 1963).

2.2.3 Pindiga Formation

The interbedded sand of the Pindiga Formation forms pressure aquifer within it (Offodile, 2002). The aquifer of the Pindiga Formation appears limited in extent (Thompson, 1958). In Gombe Town this formation has given yields of less than 4,500 litres per hour (1.2 litres per second)However, in some cases argillaceous materials dominate and are in considerable percentage, this reduces the permeability considerably. In Gombe Town a borehole of 900 m was drilled through the Gombe Sandstone Formation, but failed to encounter any water bearing horizon. The Gombe Sandstone covers most part of the study area as seen in (**Figure 3**).

2.2.4 The Keri-Keri Formation

High yield can usually be obtained from wells in Kerri-Kerri Formation where the water table is shallow. Unfortunately most of the areas covered by this formation have water table at great depth and wells are very deep (Carter *et al.,* 1963). This is the case in Doho and Kolori in the north western part of the study area. The opinion that these poor aquiferous characteristics are due to permeability is contradicting considering the texture and porosity of the sand in the Kerri-Kerri Formation (Du-Preeze, 1963). Instead it is more tenable to contend that the highly permeable nature of the sand probably makes it possible for the infiltrating water to run through the aquifer very easily and rapidly to a very low level (Offodile, 2002).

Clay lenses within the Kerri-Kerri Formation sometimes give rise to perched aquifer. These are important in areas where groundwater is the main source of water supply in most areas underlain by the Formation (Carter *et al.,* 1963).

CHAPTER THREE

3. METHODOLOGY

The research activities consisted of desk, field and laboratory studies of water sampled from the study area which was carried out the regional water quality laboratory Gombe . These were done in both rainy and dry seasons using field, laboratory equipment and software for analysis.

3.1. Desk Study

The desk studies involved review of related literatures on hydrogeochemistry and bacteriology, Geology, Hydrology and hydrogeology. Collection and examination of topographical (scale 1:50,000) and Geological maps of the study area and superimposing the geological map on the topographical map on same scale to obtain a single map to work with. Compilation of hydrophysico- chemical parameters of borehole water samples for comparison with that from hand dug wells of the study area.

3.2 Field Study

This study was achieved through reconnaissance visit to the study area which included site specific evaluation and getting acquainted with the people of the area to have easy access to their wells. The collection of hydrologic, geologic and geographic data from related agencies served as an input to the research work. Climatological data were obtained from the Nigerian Meteorological station Gombe for analysis.

Rainy season activities included, measuring coordinates and elevation above mean sea level of identified wells, using the global positioning system (GPS) and locating them on the map. Water level measurement in hand dug wells using depth sounder was also done (**Plate 1**). While during the dry season groundwater level measurement and physical parameters analysis was carried out.



PLATE 1: Water level measurement in Kanawa village of the study area

3.1.2.1 Analysis of Physical Parameters on the Field

This involved turbidity measurement recorded in NTU, total dissolved solids (TDS) in milligram per litre (mgl^{-1}), hydrogen exponent (pH), electrical conductivity (EC) in micro Siemens per centimetre (μScm^{-1}); oxygen demand (DO_2) in milligram per litre (mg/l) and temperature (^{c}o). These parameters were measured immediately in the field at the water points.

3.1.2.1.1 Appearance

Most of the water sampled from hand dug wells of the study area appeared colourless, less turbid, contain no suspended solids, organisms; sediments, floating material and similar particulate matter detectable by the unaided eye.

3.1.2.1.2 Colour (Pt-Co)

Colour in water may result from the presence of natural metallic ions (iron and manganese), humus and peat materials.

The colour of the water sampled was determined using platinum-cobalt (Pt-Co)/filtration method. The collected water samples were filtered through a GF/B filter paper. A 10 ml filtered sample was put into a test labelled A. another test tube, B, was filled with 10 ml deionised water and retained for use as blank. For the colour measurement, a wavelength of 410 μm was selected on the photometer 5000 version. Thereafter, the photometer reading was taken against the blank. The colour calibration chart was consulted to determine the actual value of the colour measured.

3.1.2.1.3 Odour

A sensory method, the nose, was used to measure the odour of water sampled from the hand dug wells of the study area. Odour measured using objectionable if the odour deviates from being odourless and unobjectionable if the odour is acceptable. In most of the water sampled the odour is unobjectionable.

3.1.2.1.4 Taste

Taste refers only to sensational feel by the tongue called water salty, sour and sweet that result from chemical stimulation of sensory nerve ending located in the papillae of the tongue and salt palate. Flavour refers to a complex of gustatory olfactory and trigeminal sensations resulting from chemical stimulation of sensory nerve ending location in the tongue, nasal cavity and oral cavity (Andrew *et al.,* 1995).

Water sampled taken into the mouth for sensory analysis produced flavours, although taste, odour or mouth feel predominated depending on the chemical substance present. This sensory test method using the tongue to analyse the water sampled, shows variation in taste which is unobjectionable.

3.1.2.1.5 Temperature (^{0}C)

Temperature was measured in the field using the combined TDS-temperature-conductivity meter. The temperature of the freshly sampled water in a container was taken immediately with the equipment at the thermometer mode.

3.1.2.1.6 Electrical Conductivity (µS/cm-1)

Electrical conductivity was measured at the sampling site using the electrical conductivity cell which is temperature compensated.

3.1.2.1.7 Hydrogen Ion Exponent (pH)

The pH of water is the negative common logarithm of the hydrogen ion activity (pH = - log (H^+)). It is a measure of acid-base equilibrium and usually controlled by the carbon dioxide – bicarbonate – carbonate equilibrium (Schoeneich, 2002). The pH of the groundwater samples in the study area was measured using the pH meter.

3.1.2.1.8 Total Dissolved Solid (TDS)

The total dissolved solids or mineralisation is used to describe inorganic salts and small amounts of inorganic matter present in solution (Schoeneich, 2002).The TDS of this groundwater was measured using the combined TDS-temperature-conductivity meter at the TDS mode.

3.1.2.1.9 Turbidity (NTU)

Turbidity measures the presence of suspended material such as clay, silt, and finely divided organic material (Schoeneich, 2002). Turbidity is caused by the scattering of light by suspended matter such as silt, clay and finely divided organic and inorganic matter. It was measured in the field using the Wagtech Turbidity set following standard procedure.

3.1.2.1.10 Dissolved Oxygen (DO_2)

Dissolved oxygen is the amount of oxygen present in the water sampled and it was measured using the field dissolved oxygen meter (Plate 2).



Plate 2: Recording measured values of some physical parameter in Kanawa village of the study area

3.1.3 Laboratory Study

Assessing the quality of groundwater sampled from hand dug wells in the study area is of utmost importance because of the extensive reliance of the inhabitants of the study area on these resources for domestic and agricultural purposes. This reliance becomes more acute especially during the peak of dry season when most rivers have gone dry and the few boreholes and taps rarely flow. The water samples were analysed for the major cations including sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{2+}) and magnesium (Mg^{2+}) as well as the anions which include chloride (Cl^{-}), bicarbonate (HCO_3^{-}) and sulphate (SO_4^{2-}). Some heavy metals were also studied. The reported concentration of these metals is the total concentration of metals irrespective of whether they are complex or not (Domenico and Schwartz, 1990). These analyses were carried out in the laboratories of Federal Ministry of Agriculture and Water Resources, Gombe Regional Water Quality laboratory. All the analysed water samples were taken at the peak of dry season when dilution is very minimal.

Precise laboratory analysis is necessary to quantify the degree of concentration of these elements which are toxic even in small concentration while others, when above the (Nigerian

guided level standard 1993), pose health risks to the inhabitants of the area and also to agricultural produce. The chemical parameters measured in the laboratory include the following.

3.1.3.1 Chloride (Cl)

Chloride in the water samples was determined using the Argentometric method as described in American Public Health Association (1992). 10 ml of the water sample was titrated against silver nitrate solution using potassium chromate solution as indicator until a pinkish yellow end point was achieved.



PLATE 3: Physicochemical parameters determination in the laboratory using Direct Reading (DR890), Titrimetric and Wagtech methods

3.1.3.2. Nitrate (NO_3)

The instrument used in analysing nitrate in the water samples is Nitrate /DR890 colorimeter method, using Nitra ver 5 Reagent powder pillow (RPP)/cadmium reduction and the procedure is as follows : Nitrate in the water samples was analysed by the colorimetric method using the Nitrate/DR890 colorimeter and Nitra ver 5 Reagent powder pillow(RPP)/cadmium reduction procedures (APHA,1992).

3.1.3.3 Nitrite (NO_2)

This is the unstable oxidation state of nitrogen. In soil, organic material is first decomposed to ammonia and then oxidized to nitrite and finally to nitrate. Nitrite is analysed by the Nitrite direct reading 890 method using Nitri Ver 2 reagent powder pillow (RPP) and the procedure given by the American Public Health Association (APHA, 1992).

3.1.3.4 Sulphate (SO_4)

This was determined using the sulphate direct reading method the procedure is as follows: The store program number for sulphate was entered. A sample cell was filled with 10 ml of sample, the content of one sulfa Ver 4 Reagent powder pillow (RPP) was added and capped and inverted several times to mix. After the timer beeped a second sample cell was filled with 10 ml of sample and this serves as the blank and this blank was placed and the instrument was turned to zero and within five minutes after the timer beeped the sample was placed and the reading taken.

3.1.3.5 Phosphate (PO_4)

Phosphate contained in the water sampled was measured using programme number 79, with the sample cell filled with 10 ml of sample. The content of one phos Ver 3 Reagent powder pillow (RPP) was added and another sample cell was filled with 10 ml of sample which serves as blank and set too zero and the reading was taken.

3.1.3.6 Fluoride

The fluoride salt dissolved in water originates from mineral present in rock through which the groundwater flows (Velenzuela *et al,* 2006).Excessive concentration of fluoride can cause fluorosis (Yiamouyiannis, 1993).

Fluoride in groundwater in the hand dug wells of the study was determined using the fluoride/Direct reading 890 method using spands reagent through and the procedure is as follows: A program number 27/28 was entered.10ml sample was pipette into a dry cell and a 10 ml of de-ionized water was measured into another cell, with 2.0 ml of spands reagent was pipette to each

cell and swirled to mix. The blank was placed and the instrument was put to zero and the reading was taken.

3.1.3.7 Total Hardness (as $CaCO_3$)

Hardness results from the presence of divalent metallic cations of which calcium and magnesium are the most abundant in groundwater. It is determined using titrimetric method and it is carried out as follows:

Ammonia Buffer, Eriochrome black T and drops of Calmagite indicator were added to the sample. This was titrated against 0.02N EDTA until change of colour occurs, the titrate value was recorded and total hardness is calculated as seen below.

Ca^{2+} was determined as $CaCO_3 = \frac{Titre\,value\,x\,A\,x100}{Volume\,of\,the\,sample}$

Where A= $MgCaCO_3$, equivalent to 1.00 ml of EDTA titrant = 0.02N EDTA

3.1.3.8 Calcium (Ca^{2+}) and Magnesium (Mg^{2+})

Calcium was determined as calcium carbonate using the titremetric method of water sample analysis. The procedure is as follows: Calcium and Magnesium: Total Ca and Mg were analysed by the complexometric method using ethylene diamine tetra-acetic acid (EDTA) and in the presence of eriochrome Black-T indicator. Calcium alone was then determined in the presence of magnesium by titrating another 50 ml aliquot of water sample using muroxide as indicator. Magnesium is now determined by the difference between the first and second titrations.

3.1.3.9 Aluminium

Aluminium is found in natural water in form of aluminium salts and levels are reported to be increasing particularly in areas affected by acid rain (Wagtech, WE30210 photometer 5000).This was measured using Ascorbic acid method. Below is the procedure. The procedure is as follows one aluminium 1 tablet was crushed, dissolved and added to the water sample and another 2 tablets of aluminium was crushed and added to mix gently. This was passed through a wavelength of 570 µm on the photometer and aluminium calibration chart was consulted.

3.1.3.10 Iron (Total)

This was determined in groundwater sampled from the hand dug wells of the study area through the Direct Reading colorimetric method using ferro Ver reagent powder pillow and the procedure is as follows: The program number 33 was entered for iron, clean sample cell was filled with 10 ml of sample as a blank and the instrument was put to zero. Another sample cell was filled with 10ml of sample and a content of one ferro Ver iron reagent powder pillow was added and inverted to dissolve and these were timed to react.

3.1.3.11 Manganese (Mn)

In most cases where manganese salts occur naturally in water, the Wagtech Manganese test provides an extreme sensitive method of measuring low concentrations of manganese for the assessment of natural water. The test measures total manganese over the range 0-0.030 mg/l, using crushed and dissolved one manganese number 1 tablet and later manganese number 2 which were added to the water sample and a wavelength 640 µm on photometer was passed through, manganese calibration chart was then consulted.

3.1.3.12 Ammonia (NH_4)

(Wagtech WE30210 photometer 5000). Wagtech Ammonia test is based on indophenols method and the procedure was taken one ammonia number 1 tablet and ammonia number two tablet which were crushed and mixed to dissolve. This was passed through a wavelength of 640 µm on the photometer and ammonia calibration chart was consulted.

3.1.3.13 Sodium (Na^+)

Sodium ranks 11 in the periodic table and is present in most natural water. Relative concentrations may be found in brine and hard water softened by the sodium exchange process (Andrew *et al.,* 1995). The sodium present in groundwater sample can be determined using the flame emission photometric method and the procedure is as follows: The sodium present in groundwater sample was determined using the flame emission photometric method. A blank was

prepared and sodium calibration standards in stepped amount in the range of 0-1 were prepared. The emission was measured at 589 µm and the operation was repeated with both calibration standards and samples enough to secure a reliable average reading for each solution. After this, a calibration curve was constructed from the sodium standard. Thereafter, the concentration of sodium in the water sample was read from the calibration curve.

3.1.3.14 Potassium (K^+)

Trace amount of potassium was determined by flame photometer at a wavelength of 766.5 nm and the procedure is as follows: A blank was prepared and potassium calibration standard in stepped amount in the range of 0-10 was prepared, with emission measured at 766.5 µm. This operation was repeated with both calibration and samples enough to secure a reliable average reading for each solution and concentration of potassium from water sample was determined from the calibration curve.



PLATE 4: Determination of sodium (Na+) and potassium (K+) using Flame Photometer

3.1.3.15 Chromium (Cr^{6+})

Chromium salts are used extensively in industrial processes for corrosion control. Although this study area is mainly rural and agrarian, studying chromium becomes necessary because of its importance.

Chromium may exist in water supply both in hexavalent and trivalent states though the trivalent form rarely occurs in potable water (Andrew *et al.,* 1995). This was only interested in the hexavalent state and the procedure only measured the hexavalent chromium (Cr^{6+}). Therefore to determine total chromium all the chromium were converted to hexavalent state by oxidation with potassium permanganate using Colorimetric method, and the procedure is as follows: A calibration curve was prepared by plotting corrected absorbance values against micrograms chromium in 102 ml final volume and the water sample was treated by filtration to obtain hexavalent chromium. Molybdenum, vanadium, iron and copper were removed with cupferron and then oxidation of trivalent chromium.Colour was developed using 0.2 N H_2SO_4 and pH meter to adjust 1.

3.1.3.16 Lead (Pb)

Lead is a serious cumulative body poison. Natural waters seldom contain more than 5µg/L, although much higher values have been reported. Lead in water supply could come from either industrial; mine, smelter discharges and/or forms from the dissolution of old lead plumbing. These cases are not common in the study area. Tap water that is soft, acid, and not suitably treated may contain lead resulting from attack on lead service pipes or solder pipe joints. This was determined using the Dithizone method through the following procedure. The sample was digested with concentrated acid (HNO_3). 50 ml ammoniacal citrate- cyanide solution was added, mixed and cooled to room temperature and 10 ml of dithizone working solution was added, then absorbance of extract was measured at 510 nm using dithizone working solution. Concentration of five standards and blank against absorbance was plotted. The concentration of lead in extract from curve was determined and all concentration is µg Pb/10 ml final extract and determined from the following calculation:

$$\text{Mg Pb/l} = \frac{\mu g\ Pb\,(in\,10\,ml,\ from\,calibration\,curve)}{mL\ sample}$$

3.1.3.17 Cadmium (Cd)

This was determined using dithizone method through the following procedure: To the digested sample 3 drops of thymol blue was added and adjusted with 6 N NaOH to the first permanent colour with pH of 2.8. 1 ml of sodium potassium tartrate solution, 5 ml NaOH-KCN solution 1, 1 ml NH_2OH. HCL solution, 15 ml dithizone solution were added and also and 0.25 ml NH_2OH.HCL solution and 15.0 ml working dithizone solution were added first followed by 5 ml NaOH-KCN solution ii was added. Cadmium concentration was obtained from the calibration curve and calculated using the following equation

$$\text{mg Cd/L} = \frac{\mu g\ Cd\ (in\ approximately\ 15\ ml\ final\ volume}{mL\ sample}$$

3.3.19 Bacteriological Quality

Inadequate or poor bacteriological quality of water for drinking and domestic use may result in a number of water borne, water washed, water based and water related diseases (Schoeneich, 2002). The most dangerous are water borne diseases which may be caused by ingestion. Water borne diseases are caused by pathogenic bacteria, which are introduced to the water by faeces or urine of a carrier, either a person or a warm blooded animal. Typhoid, cholera, bacillary dysentery, and hepatitis are most common water borne diseases, although they are also transmitted by other route which permits faecal material to reach mouth, such as food contaminated by flies or by dirty hands.

Ideally drinking water should not contain any pathogenic microorganism. At least it should be free from bacteria indicative of pollution with excreta. But there is no universal bacterial test for evaluation of how safe is the water for drinking. Bacteria from the coliform group are indicators of faecal pollution and they are always present in large number in the faeces of man and warm blooded animals thus permitting their detection.

Most commonly used is coli form count as indirect indicator of faecal pollution. The coli form bacteria are not harmful. They are only present in gut of humans and animals as well as faecal

wastes. They survive for long in water and thus indicate possible presence of harmful pathogenic bacteria, which are more difficult to identify during bacteriological analysis of water. Water where number of coli form organisms in 100 cm^3 of water is zero is safe for drinking.

3.3.19.1 Escherichia Coli (E. coli) and Total Coli Form

These are the most frequent coli form type found in human gut. It is rarely found outside the gut. It survives for the shorter time in water than other coli form species, and it does not multiply outside the human body. Presence of Escherichia coli is interpreted as an evidence of faecal pollution, although absence of this organism does not indicate safe water. The following was the procedure used in determining E. Coli and Total coli-form in groundwater sampled from hand dug well of the study area, using the membrane filtration method. 100 ml of sample was filtered through membrane filtration equipment which was vacuum pumped. 2 ml of the prepared media was taken and put on the observation pad in a petri dish and was allowed to settle for four hours. It was then incubated for 17 hours after which the number of spots on the observation pad was immediately counted under the microscope. The test went concurrently for both E. coli and total Coli form. The colour formed was yellow for both. Temperature for E. coli is 44^0C and the peak colour at 44^0C indicated the absence of E. coli. Incubation temperature for total Coli form was 37^0C while peak colour indicated sample was free from bacteria.

CHAPTER FOUR

4. RESULTS

The hydrogeological mapping was done on the scale 1:50,000, with measurements of coordinates, elevation of the ground surface above sea level using the global positioning system (GPS).Rainy and dry season water level measurement of 78 hand dug wells at different locations tapping the various aquifers of Bima, Gombe Sandstones, Yolde, Pindiga and Keri-Keri Formations underlying the study area (**Figure 3**). Meteorological data collected from Nigerian Meteorological Station Gombe were evaluated. Finally, Physico-chemical and bacteriological analysis of groundwater sampled from 20 hand dug wells tapping the different aquifers were carried out (**Table 12**).

4.1. Analysis of Climatologically Components

4.1.1 Rainfall

The study area starts experiencing rainfall in the month of April and this seizes in the month of October with little drop in some years in November (**Table 1**).The number of rainy days in the area varies, but about 215 days experience rainfall annually.

4.1. 2 Rainfall Pattern

The rate of recharge into the Bima Sandstone, Yolde Formation, Pindiga Formation, Gombe Sandstone and Keri-Keri Formation Aquifers depends on the intensity of rainfall. An understanding of the long term rainfall is necessary so as to know the quantity of water to pump and when to reduce pumping rate not to deplete the aquifer. (**Table 1**) shows variations of monthly rainfall in the study area and high variability in rainfall with August having a maximum of 306.02 mm and five rainless months that run from March to December, while April and October have very little rainfall (**Table 1**).

Table 1: Mean Monthly and Annual Rainfall (mm) for the Study Area from 2001 to 2007 data Source: (NIMET,2007)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual rainfal
2001	0	0	0	3.9	9.82	17.42	29.1	43.27	26.13	4.5	0	0	134.14
2002	0	0	0	3.7	11.73	16.24	30.2	45.02	25.4	4.04	0	0	136.33
2003	0	0	0	3.7	9.89	19.1	30.07	39.99	27	3.3	0	0	133.05
2004	0	0	0	3.13	10.56	17.15	26.98	43.46	24.2	4.2	0	0	129.68
2005	0	0	0	3.7	12.2	14.42	27.25	46.99	28.15	6	0.5	0	139.21
2006	0	0	0	3.2	9.68	18.7	26.98	45	27.99	4.9	0.2	0	136.65
2007	0	0	0	3.4	9.92	19.33	34	43.16	24	5.1	0	0	138.91
Total rainfall/month	0	0	0	24.73	73.8	122.36	204.58	306.89	182.87	32.04	0.7	0	

4.1.3 Evaporation and Evapotranspiration

Gombe Meteorological Station measures evaporation rate for the study area for the year 2001 to 2007. The evaporation rate varies from 17.07 cm in the month of March having the highest rate and 2.64 cm in the month of August with the lowest rate. **Table 2** shows mean monthly evaporation for the study area from Gombe Station. This was measured using an open pan of 122 cm known as the Evaporimeter.

Table 2: Mean Monthly and Annual Evaporation (cm) Measured by Evaporimeter for the Study Area from 2001 to 2007 data Source: (NIMET, 2007)

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Evaporation (cm)	14.06	14.25	17.07	14.14	9.63	5.83	4.01	2.64	3.86	5.86	12.44	11.36	115.15

Evapotranspiration is also a major factor in the water balance of the study area which is used to describe water loss from soil and vegetative surface, vis-a-vis the water budget. Though transpiration is an important factor, unfortunately field data are not available. However, potential

evapotranspiration was calculated using the Thornthwaite method, which assumes the dependence of evaporation on the temperature and length of the day of the study only and was expressed thus:

$$E_p = 16\,(10T/J)^{a}$$

Where E_p ---------- month potential evapotranspiration (mm)

T---------- Average air temperature (ºC), calculated from daily mean temperature

J---------- Annual heat of index, i.e. the sum of the 12 monthly heat indices, j.

$J = (T/5)^{1.514}$

a---------- cubic function of J

$a = 1.6/100T + 0.5$

Table 3: Computation of Evapotranspiration of the Study Area using Thornthwaite Method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ep	76.32	72.86	71.10	70.36	71.31	73.30	74.23	72.95	74.13	72.95	73.31	74.73

4.1.4 Temperature

The dry season begins in the month of October and runs through early April. During the largely rainless period the dry dust-laden harmattan winds of the Tropical Continental Mass blows in from the north-eastern part of the country (Offodile, 2002).The temperature remains relatively uniform throughout the year except, for the diurnal nature.

The mean monthly air temperature ranges from 24.7°C in January to 31.91°C in April which is the hottest month just before the advance of rain front from the southwest. The coolest months in the study area are January and December when the average daily temperature may fall to 24.70ºC and 25.29°C respectively, (Gombe Meteorological Station), 2007). **Table 4** shows variation in the mean monthly temperature for the study area.

Table 4: Variation in the mean monthly temperature for the study area from 2001 to 2007 data source: (NIMET, 2007)

Time (month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. (ºC)	23.32	27.89	30.65	31.91	30.31	27.25	25.96	27.76	26.09	27.76	27.23	25.29

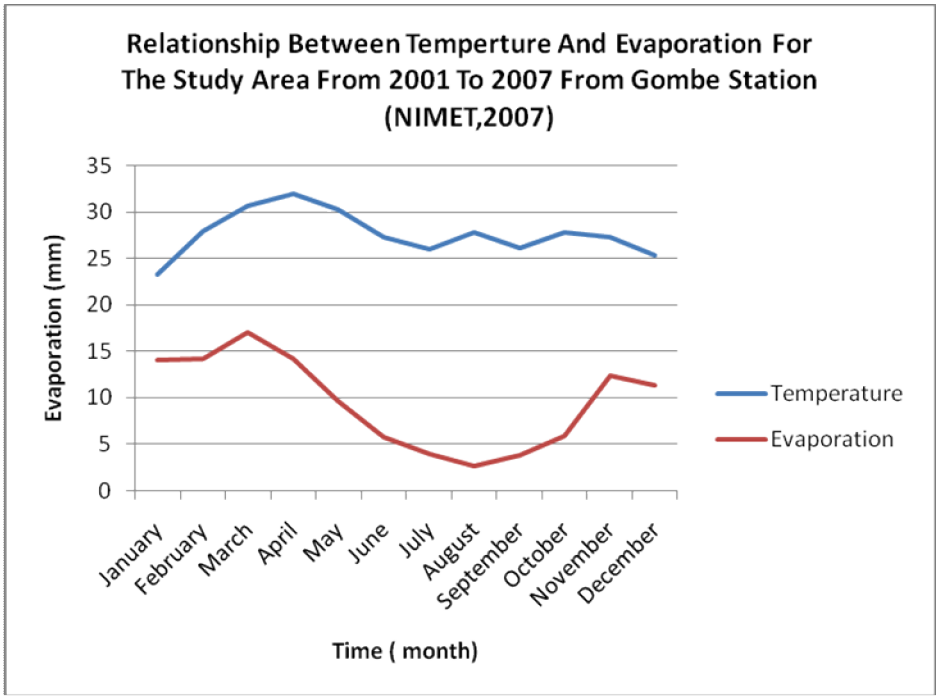


Figure 4: Graph of trends of air temperature and evaporation for the study area from Gombe Metrological Station. (Plotted by M.Tafida from data in Table 4; data source: NIMET (2007)

Figure 4 shows the relationship of evaporation and air temperature in the study area. As s should be expected, it tends suggest that evaporation in the area rely strongly on air temperature more than any other climatologic factor. However, air humidity also influences it.

The pattern of annual evaporation described above reflects the pattern of prevailing climatic conditions, especially sun's radiation, temperature and humidity. In December and January temperatures are relatively low because of the prevalence of the cool harmattan and the

accompanying dust haze, which reduces the amount of heat reaching the earth's surface. On the other hand, the potential evaporation values are lower in June to October owing to the higher relative humidity, greater amount of cloud cover consequent decreases sun radiation. Potential evaporation should decrease with increase in precipitation while actual value increases with increase in precipitation (Offodile, 2002).

4.1.5 Humidity

Relative humidity is the amount of moisture in the air compared to what the air can "hold" at that temperature, when the air can't "hold" all the moisture, and then it condenses as dew, which is expressed in percentage is measured for the study area. (**Table 5**) shows the variation in the mean monthly relative humidity for the study area, between 2001 and 2007.

Table 5: Variation in the mean monthly relative humidity for the study area from 2001 to 2007 data source: (NIMET, 2007)

Time(month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (ºC)	26.00	23.00	23.29	49.14	58.29	70.14	77.57	81.00	77.43	62.29	35.00	23.57

Relative humidity in the study area varies between 23.29% in the month of February recording the lowest humidity for the year and 81% in August recording highest rainfall (**Table 5**). The humidity excess in the study area is about 900 (mm) per annum with the minimum recorded in April and maximum in August which is the peak of rainy season. During intense rainfall as seen between Junes to Septembers (**Table 1**). The rate groundwater recharge (Infiltration) into the formations of the study area is higher at this time than most meteoric infiltration into the groundwater system in other months.

The climatological components of the study area which include rainfall, temperature, relative humidity and evaporation are inter-related i.e at sunny time when temperature is fairly high the moisture at the surface of the earth evaporates which can't be dissipated into open air, but rather collected in the air beneath the cloud and gathers into cloud which later condense and fall

back as rainfall. So therefore, where temperature is fairly high in the study area (**see Table 1**), the relative humidity is also high (**see Table 5**), evaporation lower these bring about increase in rainfall as seen in (**Table 1**). Figure 4 show the relationship between these climatological components.

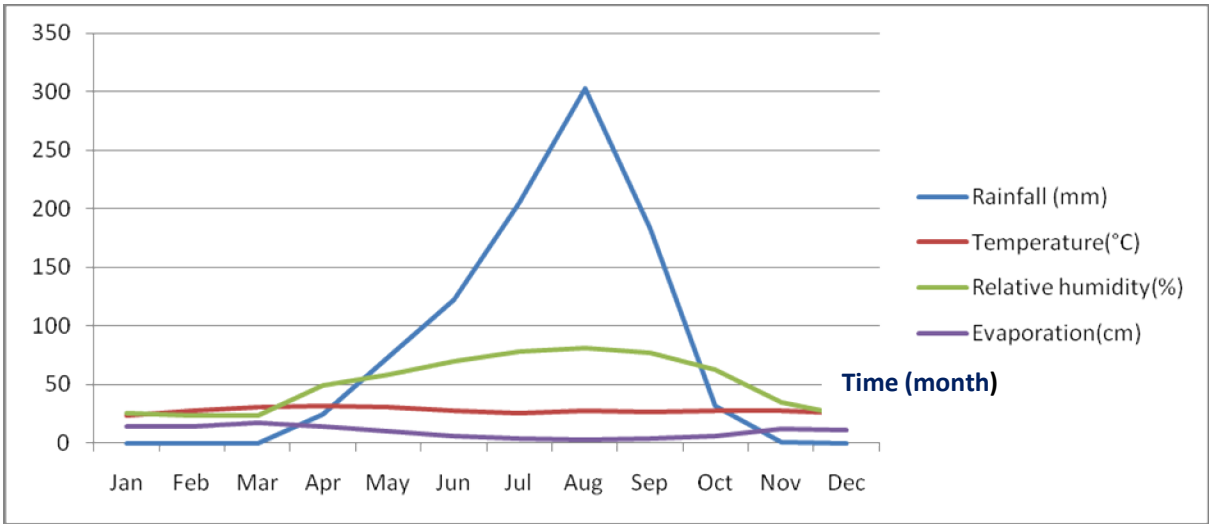


Figure 5: Relationships between mean monthly rainfall (mm), relative humidity (%); temperature (°C) and evaporation (mm) from 2001 to 2007. (Plotted by M.Tafida from data in Table 4; data source: NIMET (2007).

4.1.1.6. Water Budget

Water budget was computed for the area, which is precipitation minus evaporation drawn up based on climatic factors, by comparing the availability of water with potential evaporation which shows humidity excesses during the months of rainy season (**Table 5**).

Table 6: Computed Water Budget from Precipitation and Evaporation for the Study Area from 2001 to 2007. (Data source NIMET, (2007)

Time (month)	PRECIPITATION (mm)	EVAPORATION(mm)	EXCESS/ DEFICIT(mm)
January	0	14.07	-14.06
February	0	14.25	-14.25
March	0	17.07	-17.07
April	24.73	14.14	+10.59
May	73.80	9.63	+64.17
June	122.36	5.83	+116.53
July	204.59	4.01	+200.58
August	302.89	2.64	300.25
September	182.87	3.86	+179.01
October	32.04	5.86	+26.18
November	0.7	12.44	-11.74
December	0	11.36	-11.36
Total	+943.98	-115.16	+828.82

Table 7: Measured Groundwater Level of the Study Area

S/N	LOCATION	COORDINATE		ELEVATION OF GROUND SURFACE (mamsl)	DEPTH OF WATER LEVEL (M)		ELEVATION OF WATER LEVEL (mamsl)	
					SEASON			
		LATITUDE	LONGITUDE		RAINY	DRY	RAINY	DRY
1.	Gwani	10˚43'002″	11˚44'18″	262	27.12	1.34	234.88	-
2.	Difa	10˚21□419″	11˚25'57″	264	13.07	14.72	250.93	249.28
3.	Kwali	10˚19□701˚	11˚24'90″	288	14.54	14.64	273.46	273.36
4.	Wajarin Tasha	10˚16'814	11˚24'52″	315	14.85	18.35	300.15	298.65
5.	Wajarin Doma	10˚17'725″	11˚23'86″	292	7.64	7.88	284.36	284.12
6.	Tudun Wada B.	10˚16'188□	11˚23'81″	296	5.61	6.84	290.39	289.16
7.	Saruje	10˚15'165″	11˚23'44″	304	7.91	9.10	296.90	294.90
8.	Garin M. Ali	10˚18'320″	11˚21'69″	311	17.04	17.95	293.96	293.05
9.	Zambuk	10˚11'402″	11˚21'11″	305	17.07	18.8	287.3	286.2
10.	Lakkau	10˚17'112″	11˚23'88″	303	1.21	7.07	301.79	297.93
11.	Abulbula	10˚34'087″	11˚39'85″	270	14.72	15.86	255.28	254.14
12.	Old Liji	10˚32'030″	11˚23'80″	390	19.47	30.59	370.53	359.41
13.	Arawa 1	10˚81'990″	11˚10'33″	443	11.05	14.23	431.95	430.77
14.	Arawa 2	10˚81'991″	11˚10'33″	344	10.75	12.87	333.25	331.13
15.	Kanuel	10˚16'403″	11˚12'98″	388	4.88	8.34	383.12	381.66
16.	Bogo	10˚16'274″	11˚13'45″	391	9.34	12.56	381.66	380.44
17.	Dangar	10˚15'062″	11˚21'38″	366	5.94	6.87	360.06	359.13
18.	Yerima Kolo	10˚29'054″	11˚21'52″	259	5.11	6.95	253.89	252.05
19.	Jurara	10˚29'533″	11˚23'73″	256	16.59	18.80	239.41	237.2
20.	Malleri	10˚54'531″	11˚42'43″	252	12.65	14.06	239.32	237.94
21.	Tinja	10˚56'473″	11˚42'84″	265	6.24	7.73	258.76	258.27
22.	Wuro Joyi	10˚55'729″	11˚40'42″	274	9.83	10.59	264.17	263.71
23.	Jauro Yaya	10˚46'228″	11˚37'08″	270	0.66	6.27	269.34	265.73
24.	Tabra	10˚25'370″	11˚20'33″	412	3.44	8.50	408.56	403.50
25.	J. Hammadu	10˚31'829″	11˚33'55″	307	4.67	7.41	302.33	299.59
26.	Pantami	10˚16'822″	11˚09'13″	851	4.81	3.66	846.19	847.34
27.	U. Dawaki	10□17'637″	11˚09'59″	460	23.92	24.17	436.08	435.83
28.	U. Shamaki	10□ 17'941″	11˚10'15″	457	21.72	23.43	435.28	433.57

S/N	LOCATION	COORDINATE		ELEVATION OF GROUND SURFACE (mamsl)	DEPTH OF WATER LEVEL (M)		ELEVATION OF WATER LEVEL (mamsl)	
					SEASON			
		LATITUDE	LONGITUDE		RAINY	DRY	RAINY	DRY
29.	Kundulum	10˚19'329″	11˚10'51″	417	7.95	14.79	409.05	404.21
30.	Feshare	10˚19'87″	11˚10'52″	428	8.32	14.72	419.68	415.28
31.	Wuro Yerima	10˚19'88″	11˚10'81″	446	12.85	17.65	433.15	430.35
32.	Poli	10˚20'58″	11˚10'53″	438	28.52	30.14	409.48	407.86
33.	Gawari	10˚20'31″	11˚14'84″	418	21.08	18.39	396.92	399.61
34.	Wuro Londe	10˚16'"	11˚17'89″	377	7.83	9.29	369.17	367.71
35.	Kwadon	10˚16'75″	11˚18'57″	350	6.51	9.07	343.49	342.93
36.	Foli	10˚16'34″	11˚19'01″	363	5.87	8.21	357.13	356.79
37.	Kanawa	10˚61'14″	11˚19'00″	377	18.89	20.70	358.11	356.30
38.	Garin Yerima	10˚ 51'96″	11˚20'46″	371	20.15	20.57	351.45	350.85
39.	Baure	10˚16'2″	11˚20'96″	344	3.61	6.24	340.39	339.76
40.	Gambagi	10˚17'16″	11˚21'36″	333	15.18	18.32	317.82	316.68
41.	Lubo	10˚22'54″	11˚21'36″	337	16.78	17.55	320.22	319.45
42.	D. Fulani	10˚25'79″	11˚22'18″	314	6.17	8.08	307.83	305.92
43.	Garin Bawa	10˚ 27'81″	11˚22'78″	276	1.06	4.87	374.94	271.13
44.	Mallam Sidi	10˚28'70″	11˚28'70″	257	5.58	6.58	251.42	250.42
45.	Z. Kiyari	10˚28'3″	11˚16'30″	357	5.19	7.06	351.81	349.94
46.	Galawo	10˚30'8″	11˚30'83″	313	4.96	6.41	308.59	306.59
47.	Danaje	10˚30'19″	11˚30'29″	345	11.74	13.54	333.26	331.46
48.	Bure	10˚33'94″	11˚30'08″	322	13.71	15.71	308.29	306.29
49.	Dumbe	10˚35'37″	11˚30'24″	308	8.20	10.63	299.8	297.4
50.	Daniyash	10˚36'76″	11˚30'29″	320	8.43	13.85	311.57	308.15
51.	Sabon Gari	10˚35'84″	11˚32'11″	309	7.24	5.0	301.76	304.00
52.	Gerkwami	10˚36'96″	11˚27'27″	281	8.19	10.52	272.81	272.48
53.	Wakili Abba	10˚37'82″	11˚26'14″	307	2.79	4.90	305.21	303.1
54.	Jabtari	10˚42'97″	11˚42'97"'	293	2.32	7.89	290.65	287.11
55.	Mettako	10˚40'23″	11˚36'59″	293	7.30	10.63	285.7	284.37
56.	Jannawo	10˚40'70″	11˚37'18″	313	6.89	10.84	306.11	304.16
57.	Mallam Baba	10˚39'08″	11˚34'16″	333	18.55	19.82	314.45	313.18
58.	Liji	10˚28'30″	11˚23'11″	386	1.08	4.39	384.92	381.61
59.	Gidim	10˚29'65″	11˚24'61″	366	6.38	8.52	359.62	357.48

S/N	LOCATION	COORDINATE		ELEVATION OF GROUND SURFACE (mamsl)	DEPTH OF WATER LEVEL (M)		ELEVATION OF WATER LEVEL (mamsl)	
					SEASON			
		LATITUDE	LONGITUDE		RAINY	DRY	RAINY	DRY
60.	Shongoyel	10˚32'06″	11˚26'49″	352	11.73	13.51	340.27	338.49
61.	Burajawa	10˚33'76″	11˚34'70″	287	12.43	14.57	274.57	272.43
62.	Kurba	10˚34'08″	11˚21'17″	363	1.84	7.18	361.16	355.82
63.	Gambomi	10˚37'65″	11˚23'60″	357	1.35	3.30	355.65	353.70
64.	Wuro Dole	10˚38'73″	11˚25'83″	365	3.40	5.83	361.60	359.17
65.	Mal. Hamma	10˚41'59″	11˚27'70″	353	6.24	9.21	346.76	343.79
66.	G. Baraya	10˚41'88″	11˚28'57″	341	5.35	10.99	335.65	330.01
67.	M. Kellumi	10˚40'99″	11˚30'97″	321	4.49	7.08	316.51	313.93
68.	Wuro Gabdo	10˚45'43″	11˚31'72″	316	3.36	6.55	312.64	309.45
69.	Yelwa	10˚43'29″	11˚30'70″	325	19.12	81.61	305.88	303.39
70.	Yantari	10˚42'54″	11˚30'68″	329	5.33	8.17	323.67	320.83
71.	Musa Gudu	10˚45'24″	11˚25'85″	408	24.40	26.54	383.60	381.46
72.	Bentere	10˚41'87″	11˚23'06″	414	26.34	27.33	387.66	386.67
73.	Zangoma Isa	10˚30'10″	11˚21'59″	240	12.78	13.09	227.22	226.91
74.	Kurugu	10˚29'42″	11˚18'34″	270	7.40	9.13	262.60	260.87
75.	Doho 1	10˚26'38″	11˚13'88″	390	31.35	31.45	358.65	358.55
76.	Doho 2	10˚25'38″	11˚13'37″	437	25.73	25.74	411.27	410.91
77.	Kolori	10˚23'45″	11˚11'35″	404	42.78	44.55	361.22	359.45
78.	Galdimari	10˚23'69″	11˚30'83″	400	47.14	48.05	352.86	351.95

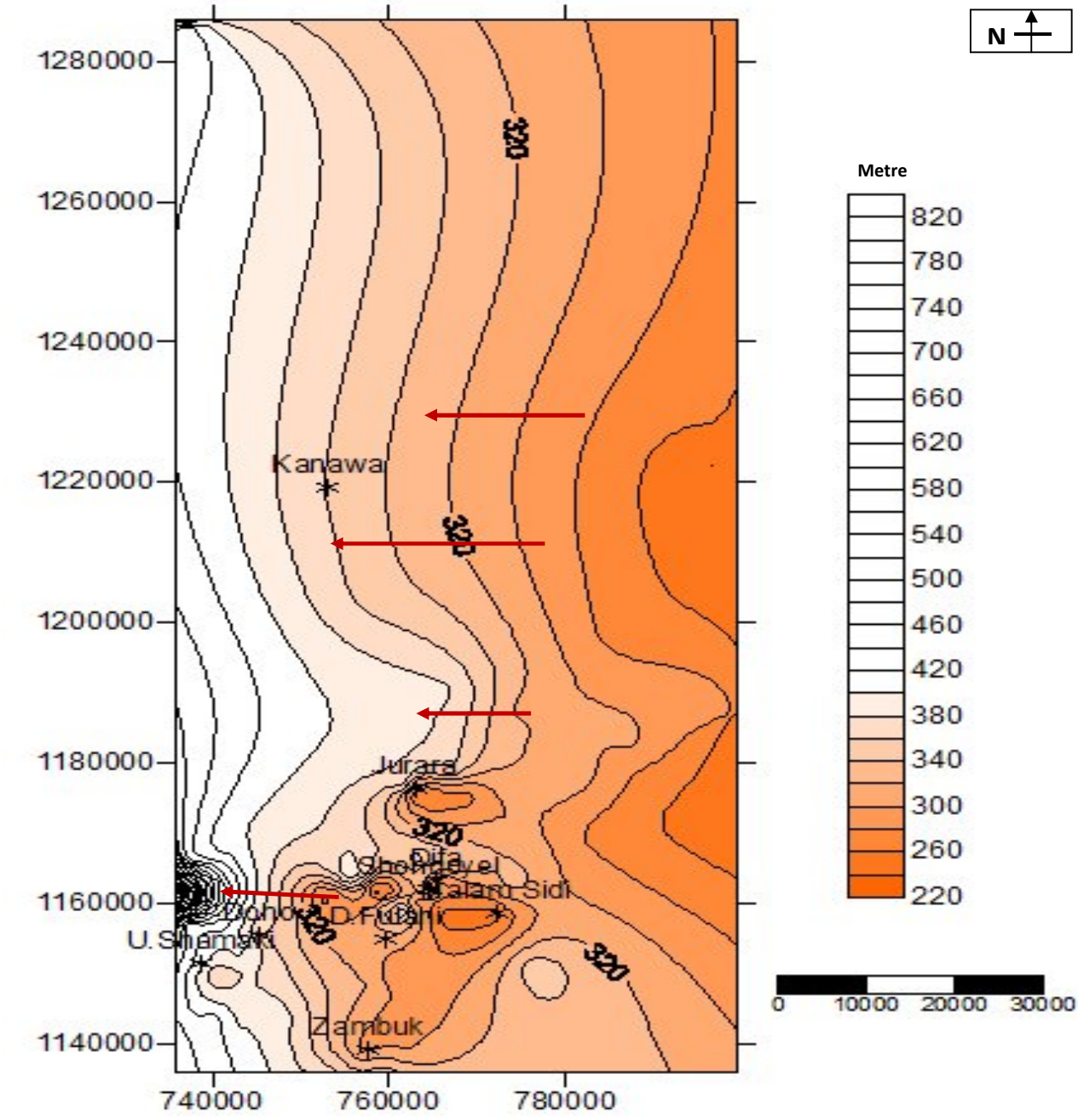


Figure 6: Contour map showing elevation and direction of groundwater flow in the study area during rainy season

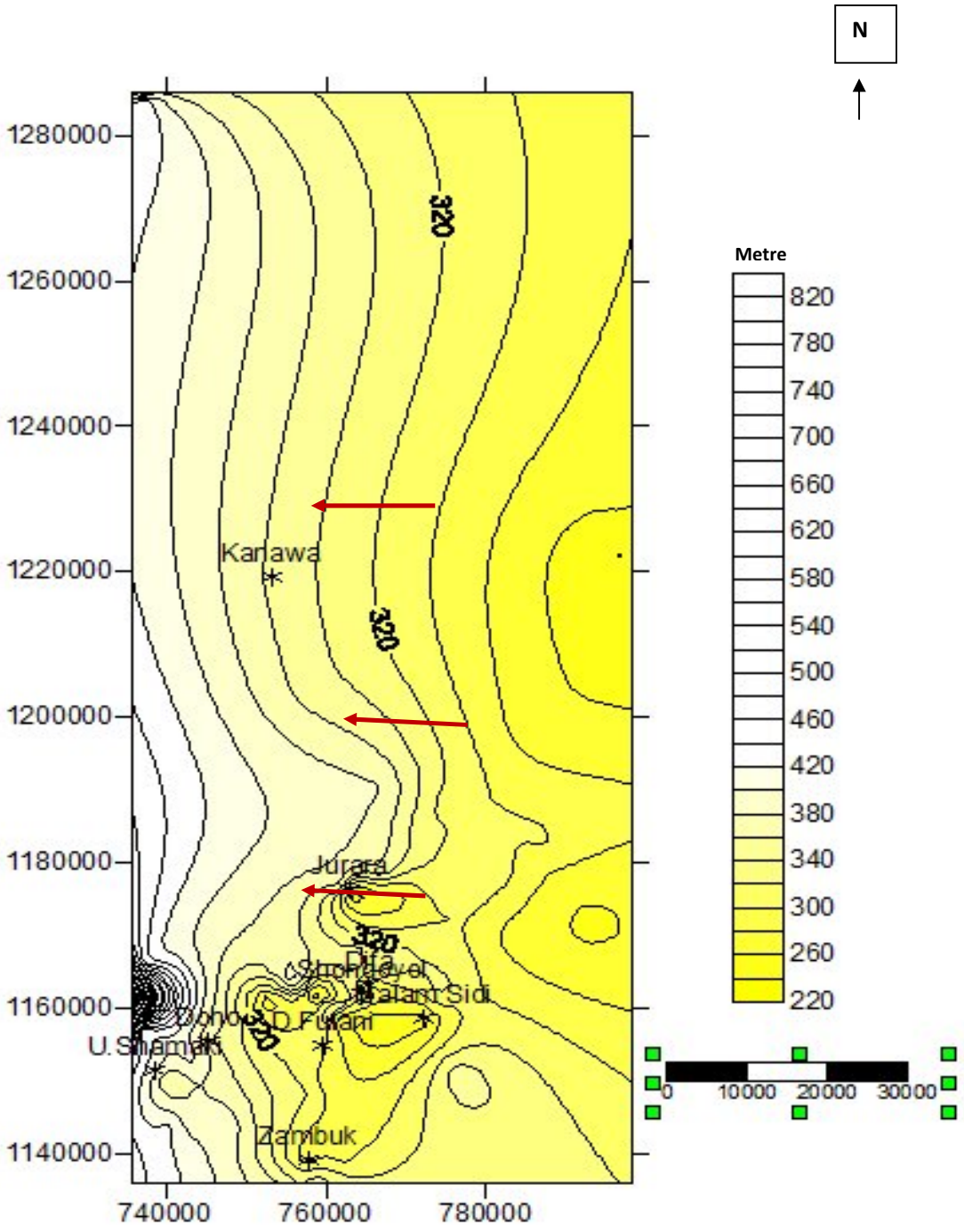


Figure 7: Contour map showing the direction of groundwater flow in the study area during the dry season

Table 8: Physical analysis of groundwater samples from hand dug wells of the study area

S/No	Location	Geo_Formation	Appearance	Colour(Pt-co)	Odour	Taste	Temp.(°C)	pH Value	Conductivity(µs/cm)	Turbidity (NTU)	TDS(mg/l)	DO2 (mg/l)
1	Tabra	Gombe Sandstone					31.8	6.33	480	6.7	230	3.02
2	Baure	Gombe Sandstone					32.9	6.21	220	2.19	110	4.36
3	Kanawa	Gombe Sandstone					32.5	6.03	290	7.09	150	3.26
4	Lakau	Gombe Sandstone					32.3	6.84	1560	0.42	790	1.35
5	Kwali	Gombe Sandstone					32.8	7.12	390	0.24	190	3.45
6	Gurajawa	Gombe Sandstone					32.2	7.42	770	2.25	390	2.52
7	Wuro Lunde	Gombe Sandstone					31.5	6.14	190	0.61	90	1.93
8	Lubo	Gombe Sandstone					34.1	5.76	280	15.6	140	3.05
9	Deba Fulani	Yolde Formation					33.4	6.24	120	0.3	60	2.17
10	Yeri Kolo	Pindiga Formation					34	6.92	290	1.58	140	2.37
11	Jurara	Pindiga Formation	slightly Turl	10			35.2	7.18	85	33.9	430	6.67
12	zangoma Kyar	Yolde Formation					32.8	5.98	230	6.16	110	1.88
13	Bure	Gombe Sandstone		40			30	6.76	130	1.47	60	2.34
14	Gerkwame	Gombe Sandstone		50			31.6	6.4	940	12.88	470	2.86
15	Old Liji	Yolde Formation		10			31.7	8.18	720	11.29	360	4.18
16	Gambomi	Gombe Sandstone		50			31.1	7.26	240	19.9	120	1.16
17	Madu Kellumi			30			30	6.7	720	2.71	360	1.75
18	Yelwa	Gombe Sandstone		50			35.7	6.06	280	81.1	140	1.81
19	Doho	keri-keri		50			25.5	7.09	930	8.75	470	2.73
20	Kundullum	keri-keri		40			27.1	5.95	840	12.57	420	3.67

Table 9: Chemical analysis of groundwater sampled from hand dug well of the study area

	Location			Tabra			Baure			Kanawa			Lakau			Kwali			Gurajawa			Wuro Lunde		
	Geo-Formation			Gombe Sandstone																				
	Unit	Mol wt	Valency	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%
Cations	Sodium	23	1	5.5	126.5	2.498	40.8	938.4	8.2589	80	1840	37.0236	180.6	4154	49.93	100.5	2312	39.04	182.5	4198	62.947	102.5	2358	34.44
	Potassium	39	1	5.6	218.4	4.313	5	253.2	2.2285	2.8	109.2	2.19727	3.5	136.5	1.641	5.3	206.7	3.491	6.5	253.5	3.8015	4.6	179.4	2.621
	Magnesium	24.3	2	1.2	14.58	0.288	0.02	1.013	0.0089	0.8	9.72	0.19558	1.85	22.48	0.27	0.25	3.038	0.051	0.75	9.113	0.1367	0.56	6.804	0.099
	Calcium	40	2	235	4700	92.81	200	10128	89.138	150	3000	60.3646	200	4000	48.09	170	3400	57.42	110	2200	32.992	215	4300	62.82
	Manganese	55	3	0.005	0.092	0.002	0.02	1.013	0.0089				0.004	0.073	9E-04				0.02	0.367	0.0055	0.08	1.467	0.021
	Iron	55.8	3	0.2	3.72	0.073				0.5	9.3	0.18713	0.3	5.58	0.067				0.4	7.44	0.1116			
	Lead	207.2	2	0.001	0.104	0.002																		
	Cadmium	112.4	2	0.003	0.169	0.003																		
	Chromium	52	2	0.006	0.156	0.003				0.002	0.052	0.00105							0.003	0.078	0.0012			
	Aluminium	27	3	0.04	0.36	0.007	0.8	40.51	0.3566	0.17	1.53	0.03079				0.02	0.18	0.003	0.04	0.36	0.0054			
	Sum			-	**5064**	**100**	**245.8**	**11362**	**100**	**234.1**	**4969.8**	**100**	**386.3**	**8318**	**100**	**276.1**	**5921**	**100**	**300.2**	**6668**	**100**	**322.7**	**6845**	**100**
Anions	Chloride	35.5	1	12	426	10.82	93	3302	69.662	199	7064.5	88.1898	421	14946	80.64	280	9940	91.69	331	11751	81.457	226	8023	90.9
	Fluoride	19	1	0.15	2.85	0.072	0.42	7.98	0.1684	0.04	0.76	0.00949	0.2	3.8	0.021	0.19	3.61	0.033	0.5	9.5	0.0659	0.08	1.52	0.017
	Nitrate	62	2	23.9	740.9	18.82	24.3	753.3	15.895	24.3	753.3	9.40384	24.3	753.3	4.064	24.3	753.3	6.949	19.4	601.4	4.169	24.3	753.3	8.535
	Carbonate	60	2	20.3	609	15.47	0.15	4.5	0.095		0	0		0	0	0	0	0		0	0		0	0
	Sulfate	96	2	43	2064	52.43	14	672	14.179	4	192	2.39684	59	2832	15.28	3	144	1.328	43	2064	14.308	1	48	0.544
	phosphate	94	2	2	94	2.388		0	0		0	0		0	0		0	0		0	0		0	0
	Ammonia	17	1	0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0

	Location			Lubo			Bure			Gerkwame			Gambomi			Kundullum			Madu Kellumi			Yelwa		
	Geo-Formation			Gombe Sandstone																				
	Unit	Mol wt	Valency	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%
Cations	Sodium	23	1	165.5	3807	53.287	98.7	2270	34.48	132.5	3048	37.07	150.3	3457	38.11		0	0	210.2	4835	48.75	159.1	3659.3	52.18
	Potassium	39	1	6.1	237.9	3.3304	5	195	2.962	3.5	136.5	1.661	6	234	2.58	4.7	183.3	3.916	5.5	214.5	2.163	6.6	257.4	3.67
	Magnesium	24.3	2	14.5	176.2	2.4663	9.5	115.4	1.753	18.7	227.2	2.764	6.3	76.55	0.844	13.6	165.2	3.53	5.2	63.18	0.637	15.5	188.33	2.685
	Calcium	40	2	145	2900	40.597	200	4000	60.76	240	4800	58.39	265	5300	58.43	216.6	4332	92.54	240	4800	48.41	145	2900	41.35
	Manganese	55	3	0.6	11	0.154				0.011	0.202	0.002				0.021	0.385	0.008	0.002	0.037	4E-04	0.009	0.165	0.002
	Iron	55.8	3	0.6	11.16	0.1562	0.15	2.79	0.042	0.45	8.37	0.102	0.2	3.72	0.041	0	0	0	0.2	3.72	0.038	0.4	7.44	0.106
	Lead	207.2	2											0	0		0	0		0	0		0	0
	Cadmium	112.4	2	0.001	0.056	0.0008							0.001	0.056	6E-04		0	0		0	0		0	0
	Chromium	52	2											0	0	0.003	0.078	0.002		0	0		0	0
	Aluminium	27	3	0.06	0.54	0.0076				0.02	0.18	0.002	0	0	0	0	0	0	0.02	0.18	0.002	0.01	0.09	0.001
	Sum			**332.3**	**7143**	**100**	**313.4**	**6583**	**100**	**395.2**	**8220**	**100**	**427.8**	**9071**	**100**	**234.9**	**4681**	**100**	**461.1**	**9916**	**100**	**326.6**	**7012.7**	**100**
Anions	Chloride	35.5	1	327	11609	92.824	194	6887	73.17	262	9301	85.7	379	13455	91.18	428	15194	87.37	424	15052	88.27	355	12603	81.94
	Fluoride	19	1	0.01	0.19	0.0015	0.57	10.83	0.115	0.03	0.57	0.005	0.76	14.44	0.098	0.19	3.61	0.021	0.84	15.96	0.094	0.47	8.93	0.058
	Nitrate	62	2	24.3	753.3	6.0235	13	403	4.281	17.5	542.5	4.998	10.5	325.5	2.206	24.3	753.3	4.332	25.3	784.3	4.599	11.9	368.9	2.399
	Carbonate	60	2		0	0		0	0		0	0		0	0		0	0		0	0		0	0
	Sulfate	96	2	3	144	1.1514	44	2112	22.44	21	1008	9.287	20	960	6.506	30	1440	8.28	25	1200	7.037	50	2400	15.6
	phosphate	94	2		0	0		0	0		0	0		0	0		0	0		0	0		0	0
	Ammonia	17	1	0	0	0	0	0	0	0.09	1.53	0.014	0.11	1.87	0.013	0	0	0	0.05	0.85	0.005	0	0	0
	Sum			**683.7**	**12506**	**100**	**520.9**	**9413**	**100**	**674.7**	**10854**	**100**	**818.1**	**14756**	**100**	**687.4**	**17391**	**100**	**911.3**	**17053**	**100**	**694**	**15380**	**100**

	Location			Deba Fulani			Yeri Kolo			Jurara			zangoma Kyari			Old Liji			Doho		
	Geo-Formation			Yolde Formation			Pindiga Formation			Pindiga Formation			Yolde Formation						keri-keri		
	Unit			mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%	mg/l	meq/l	meq%
Cations	Sodium	23	1	125.7	2891	44.85	140.6	3234	42.437	200.3	4606.9	53.6463	150.3	3457	46.91	225.2	5180	71.13	171.6	3947	50.896
	Potassium	39	1	5	195	3.025	6.3	245.7	3.2243	4.5	175.5	2.04366	4.8	187.2	2.54	3	117	1.607		0	0
	Magnesium	24.3	2	13.1	159.2	2.469	19.8	240.6	3.157	16.4	199.26	2.32034	15.7	190.8	2.589	20.1	244.2	3.354	0.2	2.43	0.0313
	Calcium	40	2	160	3200	49.64	195	3900	51.18	180	3600	41.9212	176	3520	47.77	87	1740	23.9	190	3800	49.003
	Manganese	55	3	0.009	0.165	0.003	0.005	0.092	0.0012	0.002	0.03667	0.00043	0.009	0.165	0.002	0.001	0.018	3E-04			
	Iron	55.8	3	0.009	0.167	0.003				0.3	5.58	0.06498	0.7	13.02	0.177	0.05	0.93	0.013	0.1	1.86	0.024
	Lead	207.2	2							0.002	0.2072	0.00241	0.004	0.414	0.006						
	Cadmium	112.4	2				0.001	0.056	0.0007	0.001	0.0562	0.00065							0.001	0.056	0.0007
	Chromium	52	2										0.001	0.026	4E-04						
	Aluminium	27	3	0.08	0.72	0.011							0.03	0.27	0.004				0.38	3.42	0.0441
	Sum			-	**6446**	**100**	**361.7**	**7620**	**100**	**401.5**	**8587.54**	**100**	**347.5**	**7369**	**100**	**335.4**	**7282**	**100**	**361.9**	**7755**	**100**
Anions	Chloride	35.5	1	268	9514	94.04	377	13384	93.065	443	15726.5	77.3277	373	13242	93.61	449	15940	91.66	376	13348	87.689
	Fluoride	19	1	0.38	7.22	0.071	0.21	3.99	0.0277	0.93	17.67	0.08688	0.33	6.27	0.044	0.58	11.02	0.063	0.84	15.96	0.1048
	Nitrate	62	2	18.6	576.6	5.699	24.3	753.3	5.2382	24.3	753.3	3.704	24.3	753.3	5.326				24.3	753.3	4.9488
	Carbonate	60	2	0.65	19.5	0.193															
	Sulfate	96	2				5	240	1.6689	80	3840	18.8814	3	144	1.018	30	1440	8.28	23	1104	7.2527
	phosphate	94	2																		
	Ammonia	17	1																0.04	0.68	0.0045
	Sum			-	**10117**	**100**	**763.2**	**14381**	**100**	**869.7**	**20337.5**	**100**	**745.2**	**14145**	**100**	**784.9**	**17391**	**100**	**763.4**	**15222**	**100**

Table 10: Bacteriological analysis of grondwater sampled from hnd dug well of the study area

Location	Tabra	Baure	Kanawa	Lakau	Kwali	Gurajawa	Wuro Lunde	Lubo	Bure	Gerkwame	Gambomi	Kundullum	Madu Kellumi	Yelwa
Geo-Formation	Gombe Sandstone													
Unit	Cfu/100ml													
Total coli cfu/100ml	0	0	1	0	0	1	0	1	0	2	1	0	0	0
E.Coli(cfu/100ml)		0	0		0	0	0	0	0	1	1	0	0	0

Location	Deba Fulani	Yeri Kolo	Jurara	zangon	Old Liji	Doho
Geo-Formation	Yolde Formation	Pindiga	Pindiga	Yolde Formation		keri-keri
Unit	Cfu/100ml					
Total coli cfu/100ml	0	0	2	1	2	1
E.Coli(cfu/100ml)	0	0	1		1	0

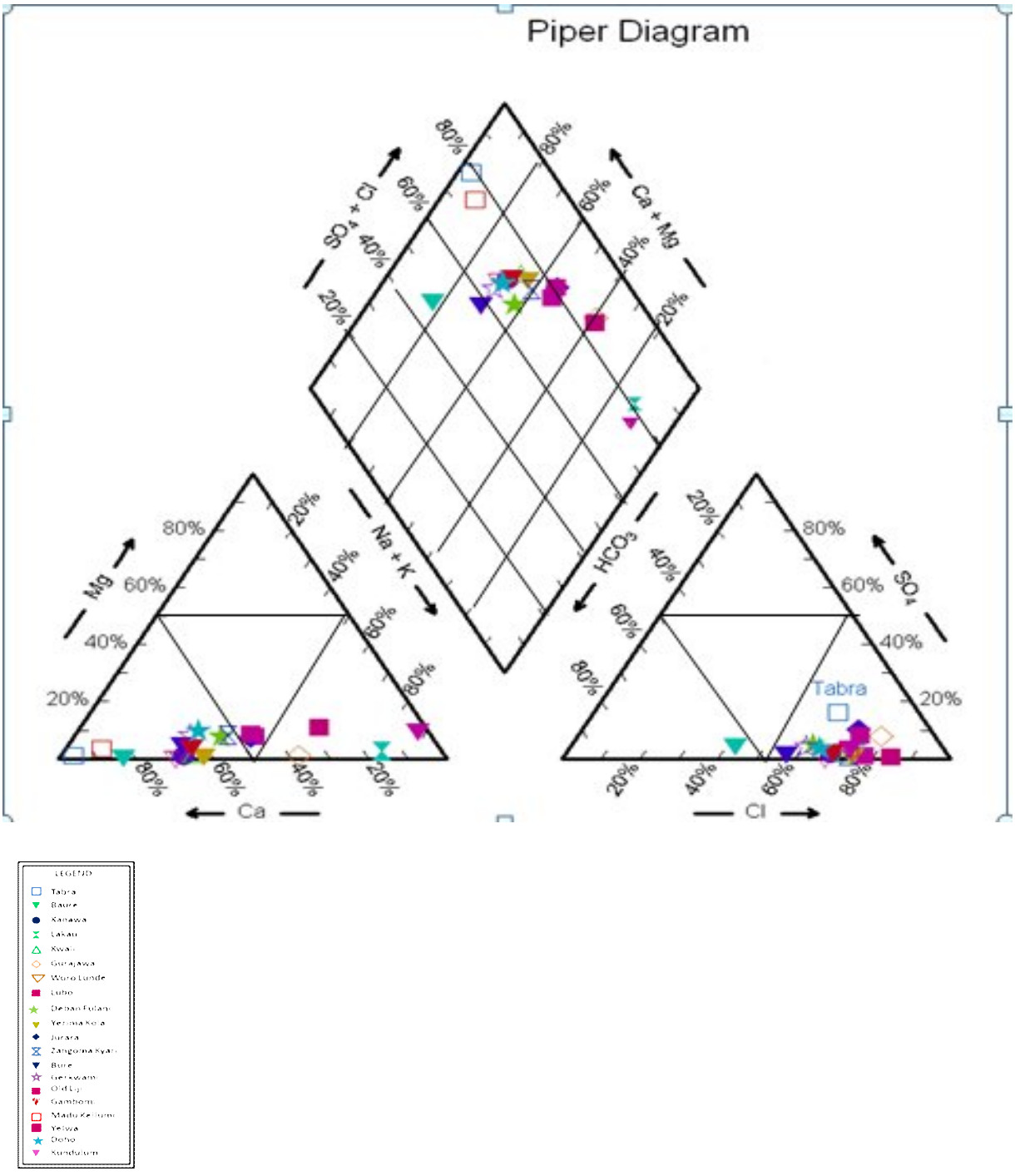


Figure 8: Graph of chemical classification of water from shallow wells in the study area in percent of total equivalents per million (Modified after Piper, 1944)

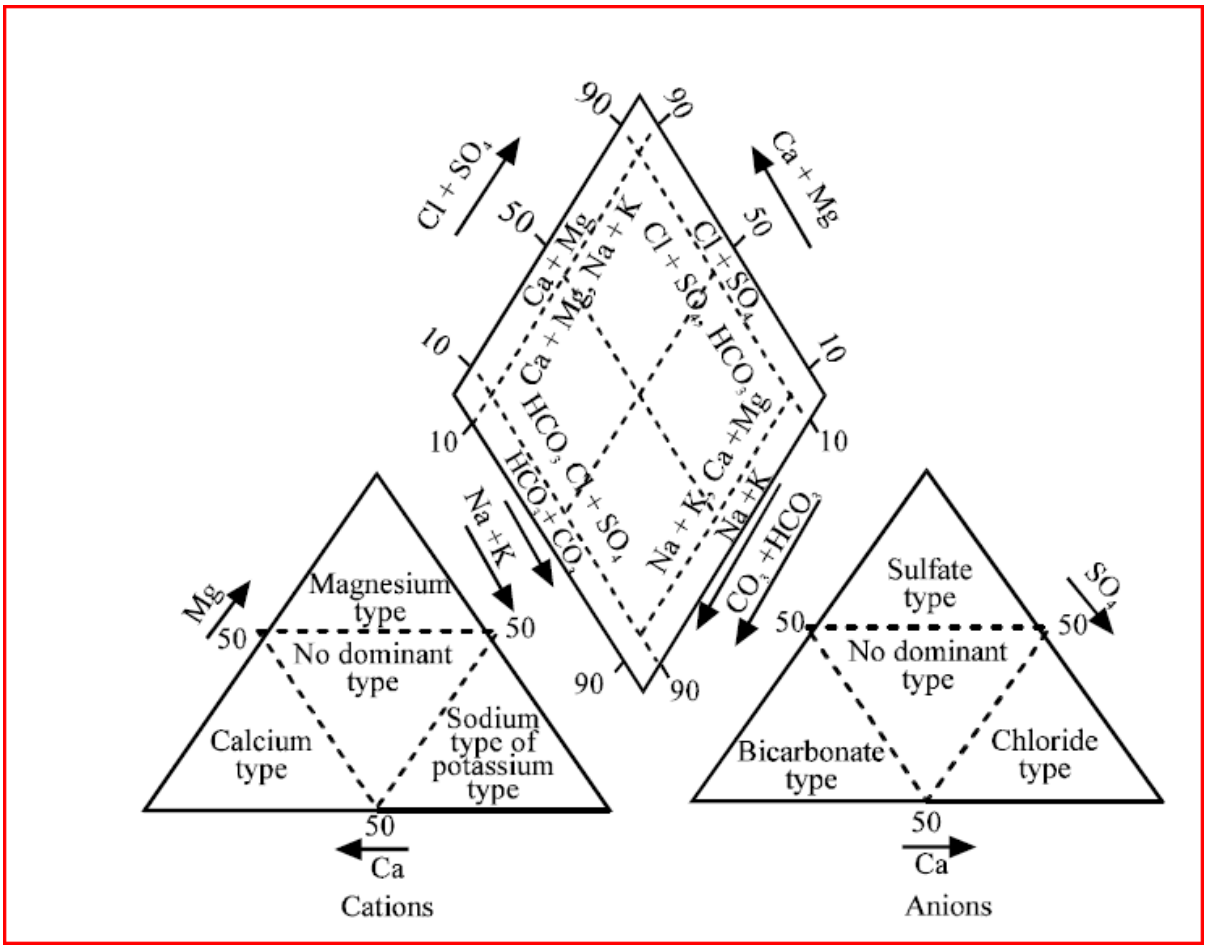


Figure 9: Water type classification using the piper trilinear diagram. Water types are designated according to the domain in which they occur on the diagram segment (Back, 1961 and Hanshaw, 1965)

Table 11: Chemical analysis of groundwater sampled from boreholes of the study area

GWANI																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	Filtration	Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150			0.03	1.5	0	0
Measred Values	clear	40	Unobjectionable	Unobjectionable	28.3	8.26	120	16.48	60	0.11	0.03				0.05	3.5		
TABRA																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	Filtration	Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measured Values		80	Unobjectionable	Unobjectionable	27.9	7.82	2070	9.54	1050	0.02	0.05		0.1		1.05	0.33	0	0
GARIN BARAYA																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	membrane Filtration	membrane Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measred Values		10	Unobjectionable	Unobjectionable	27.7	8.29	210	1.07	100	0.24	0.06				0.02	3.85	0	0
DABA FULANI																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	membrane Filtration	membrane Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measured Values	Slightly cloud	90	Unobjectionable	Unobjectionable	28.3	7.87	510	17.9	260	0.75	0.19				0.02	3.93	0	0
KANUWAL																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Kunuwal																		
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	membrane Filtration	membrane Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measured values	Clear		Unobjectionable	Unobjectionable	27.3	6.4	960	0.68	480	0.12	0.03				0.04	0.48	0	0
					kundulum													
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
KUNDULUM																		
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	membrane Filtration	membrane Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measured values	Clear	10	Unobjectionable	Unobjectionable	23.9	6.78	450	16.7	480	6	1.36				0.7	0	0	0
GERKWAME																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	membrane Filtration	membrane Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measured values	Clear	60	Unobjectionable	Unobjectionable	23	6.67	1000	5	50	1	0.28				0.9	0.16	0	0
JURARA																		
Parameter	Appearance	colour	Odour	Taste	Temp.	pH	Conductivity	Turbidity	TDS	Nitrate	Nitrite	Hardness	Aluminium	Magnesium	Iron	Flouride	Total coli form	E-coli
Unit		pt-co	TON		°c		us/cm	NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	cfu/100ml
Method	Visual	Photometer 5000	Perceived	Human Tongue	Thermometer	pH meter	Conductivity meter	wagtech Photometer	Coductivity meter	Photometer 5000	Photometer 5000	Photometer 5000			Photometer 5000	Colometric DR890	Filtration	Filtration
NSDWQ		15	Unobjectionable	Unobjectionable	Ambient	pH	1000	5	500	50	0.2	150	0.2		0.03	1.5	0	0
Measured values	cloudy	90	Unobjectionable	Unobjectionable	22.9	7.12	1140	8.08	570	20	4.55				0.05	0.39	0	0

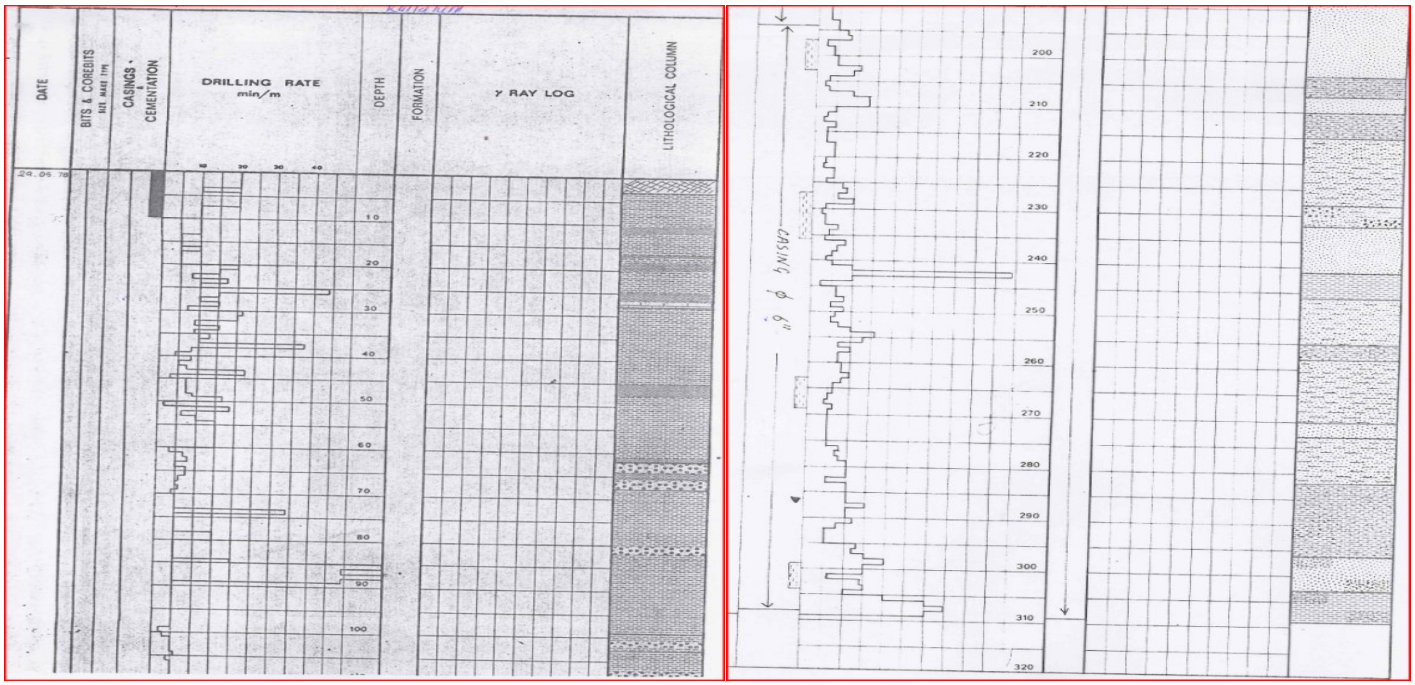


Figure 10: Borehole logs of Kundulum Village of the study area penetrating Gombe sandstoneFormation

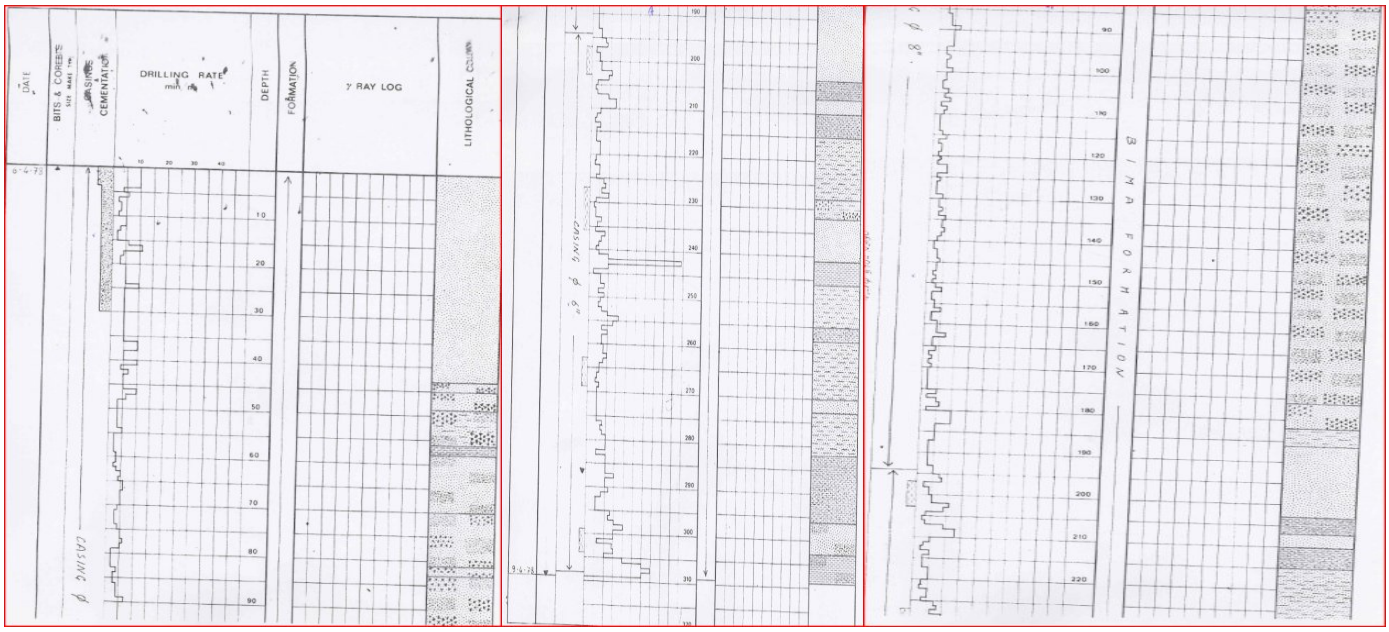


Figure 11: Borehole logs of Arawa Village of the study area Penetrating Gombe Sandstone Formation



Figure 12: Borehole logs of Gurajawa Village of the study area penetrating Bima Sandstone Formation

CHAPTER FIVE

5 DISCUSSION AND CONCLUSION

5.1 Discussion

5.1.1 Climatological Component

Evaluation of the climatological data of the study area show that evaporation in the study area reached its peak in the month of March, when temperature is highest and least around August when precipitation is highest and temperature relatively high (**Table 1**). Water budget calculated from precipitation and evaporation indicates that the study area experiences water surplus between 2001 to 2007 in the study area. This surplus goes to form both the surface and groundwater reserves (resources) of the study area (**Table 6**)

5.1.2 Groundwater Elevation of the Study Area

The Topography controls the movement of groundwater in the subsurface and areas with similar compositions and structures are seen as the same aquifer. The groundwater elevation from the hand dug wells of the study both during the dry and rainy season is dominantly shallower at the eastern part and deeper toward the western part (**Figure 6 and 7**). These are due to recharge by Dadidn Kowa Lake which flows from eastern towards the western parts of the study area (**Figure 3**).

5.1.3 Physical Analysis of Groundwater from Hand-Dug Well of the Study Area

The physical parameters analysed for groundwater sampled from hand dug wells of the study area include pH, Temperature, Colour, Odour, DO_2, Conductivity, Turbidity and Total dissolved solid (TDS). These were compared with the permissible limit of Nigerian guided level water quality standard 2007, to determine their suitability for both domestic agricultural and industrial use.

5.1.3.1 Total Dissolved Solid (TDS)

The increase in dissolved solids in irrigation water affects soil efficiency, growth and yield of crops. Total Dissolved Solid should not exceed 2000mg/l for long term irrigation. Based on (Wilcox, 1955) classifications of water using TDS, all the water samples analyzed are classified as best quality water for irrigation because all TDS values are below 500mg/l.

5.1.3.2 Turbidity

This is caused by the presence of suspended matter such as clay, silt, and fine particles of organic matter, Plankton, and other microscopic organism. Measure how much light can filter through the water sample. Turbidity is objectionable for aesthetic reasons. Indicative of clay or inert suspended particles in drinking water. May not adversely affect health but may cause need for additional treatment following rainfall variation in groundwater turbidity may be an indicator of surface contamination. In the analysed water samples of the study area all fall within the permissible limit of Nigerian guided level for water quality standard except in Jurara, Gerkwame ,old liji, Gambomi, Yelwa, Doho and Kundullum.

5.1.3.3 Colour

Colour can be caused by decaying leaves, plants, organic matter, copper, iron, and manganese, which may be objectionable. Aesthetically unpleasing colour was measured high in Bure, Gerkwame, Gambomi, Madukellume, Yelwa, Doho and kundullum

5.1.3.4 pH

This Indicates, by numerical expression, the degree to which water is alkaline or acidic. Represented on a scale of 0-14 where 0 is the most acidic, 14 is the most alkaline and 7 is neutral. High pH causes a bitter taste; water pipes and water-using appliances become encrusted; depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine when pH is high. Low-pH water will corrode or dissolve metals and other substances. The pH of water sampled from the study area is within the permissible limit of Nigerian guided level for of water quality standard 2007.

5.1.3.5 Odour

Certain odours may be indicative of organic or non-organic contaminants that originate from municipal or industrial waste discharges or from natural sources. In the study area it was seen within the limit.

5.1.3.6 Taste

Some substances such as certain organic salts produce a taste without an odour and can be evaluated by a taste test. Many other sensations ascribed to the sense of taste actually are odours, even though the sensation is not noticed until the material is taken into the mouth.

5.1.3.7 Electrical Conductivity

Abnormally high conductivity in the study area is accompanied by abnormally high content of sodium, chloride, nitrite, nitrate, and sulphate. These high values were measured in Lakau with the highest value of 1560 μScm-1 which is above the permissible limit of the Nigerian guided level. It is an indicator of organic pollution in the groundwater. This was measured concurrently with total dissolved solids (TDS) and temperature in the field.

5.1.3.8 Salinity Distribution

The parameter is determined from measured conductivity and dissolved solids (table 8) of the study area.

Table 11: The range of Salinity determinant parameter used for the study area

Properties	Conductivity (μΩ/cm)	Dissolved solid (mg/l)
Low salinity, no detrimental effects expected	< 250	<200
Medium salinity, detrimental effects to sensitive crops	250-750	0-500
High salinity, adverse effects on many crops	750-2250	500-1500
Very high salinity, suitable only for salt tolerant plants	2250-5000	1500-3000

Based on the Chemical analysis of water from hand dug wells of the study (**Table 8**) and the range of salinity determinant parameter (**Table 11 and 12**) forty percent (40%) of the water sampled from the study area are of medium salinity status, this means that this group of water can have detrimental effects on crops that are sensitive to salinity, while sixty percent are of low value salinity with no detrimental effects on crops. Waters that may have detrimental effects on sensitive crops are mostly from the Gombe formation, which is prone to leaching from the overlaying Kerri-Kerri formation, because of the formation is porous and permeable which aided infiltration and leaching of any salt into the formation below it.

Exchange of ions alters a physical characteristic of geologic material, e.g. the permeability of clay material is controlled by the percentage of Ca^{2+}, Mg^{2+} and Na^{+}. The (**Table 13**) shows classification water for agriculture based on total dissolved solid (mg/l).

Table 12: Water for irrigation (Wilcox, 1995)

TD(mg/l)	Status
200-500	Best quality
1000-2000	Water involving hazards
3000-7000	used for irrigation only with leaching and perfect drainage

5.1.4. Hydrochemical Analysis of the Water Sampled from Hand-Dug Wells of the Study Area

5.1.4.1 Determination of the Concentration of Major ions Using Piper Trilinear Diagram

The quality of groundwater sampled from hand dug well of the study area was determined by chemical analyses, the data were compiled and statistically evaluated, the basic tool used for this analysis was the Rockware software (Piper trilinear diagram) this was to determine the origin

of the chemical composition of groundwater and the relationship between water and rock chemistry, particularly as they relate to groundwater movement.

The complete analysis used to represent the concentration of constitute was expressed in milligram per litre(mg/l), which was converted to milli equivalent so that the total Meq/l of anions should be nearly equal the total Meq/l of cations .

Plots of the hydrochemical parameter of the water samples on the piper (1948) trilinear diagram (Figure 8) shows that 85% of the water sample are alkaline earth water with high alkaline proportion, whereas the remaining 15% belong to alkaline water. Furthermore, the water are classified into hydrochemical facies representing water types based on the subdivisions of the piper trilinear diagram in manner suggested by Back (1961) and Hanshaw (1965). These subdivisions are shown in (**Figure 9**).

Using water classification scheme, the water of the study area was classified into three types namely CaCl, Ca-HCO_3 and NaCl.

5.1.4.2 Nitrate

This is the stable oxidation state of nitrogen. It is formed by the oxidation of nitrite, NO_2. Organic substance in the soil is decomposed to ammonia, then oxidised by nitrosifying bacteria to nitrite (NO_2), and at the very end oxidised by nitrifying bacteria to nitrate (NO_3). Nitrate therefore tends to appear in greater concentration in water than nitrite, because it is a product of end reaction. Another source of nitrate in water is the atmosphere. Lightings from nitric acid from nitrogen present in the air. Then nitric acid is either absorbed by rain water, or removed by plants, but it can also be degraded to nitrogen under anaerobic conditions. The use of chemical fertilizer for agriculture is also another source of nitrate.

The distribution of nitrate in the groundwater studied is given in **(Table 10)** and it shows that nitrate concentration in all the water samples ranges from 3.7 – 27mg/l, and this falls within the 44mg/L recommended value.

5.1.4.3 Iron

Iron occurs widely in nature and is found in much natural and treated water. Iron is objectionable constituent in both domestic and industrial water supplies. The presence of iron affects the taste of beverages and causes unsightly staining of laundered clothes, plumbing fittings, swimming pool surface and the like. The formation of insoluble iron deposits is troublesome in many industrial applications and in agricultural water uses.

5.1.4.4 Manganese

Manganese containing mineral occur widely and manganese salts are commonly found in many natural water.

Manganese is objectionable constituent in water used for domestic purposes and industrial applications. In domestic situation, manganese will cause brown or black staining, laundry or plumbing fitting even at very low concentrations. In process application such as paper manufacturing or textile finishing similar staining can occur. Manganese salts my impact an astringent taste to drinking water supplies and in swimming pool application can give aesthetically displacing brown coloration. The calibration show manganese to be within the accepted limit.

5.1 4.5 Ammonia

Ammonia occurs as a break down product of nitrogenous material in natural water. It is also found in domestic effluents and certain industrial waste water. Ammonia is harmful to fish and other aquatic life and the ammonia level must be carefully controlled in water for used for fish farming and aquariums. Ammonia test are routinely applied for pollution control on effluents and waste water, and for the monitoring of drinking water supplies.

5.1.4.6 Sodium

Sodium ranks among the element in order of abundance and its present in most natural water. Relative concentrations may be found in brine and hard water softened by the sodium exchange process (Andrew *et al.,* 1995)

The sodium hazard is a function of both SAR and salinity; resulting too low to very high salinity and sodium based on sodium and salinity control value (Wilcox,1995) most of the water analyzed is of medium salinity and sodium waters indicating that water sample have no effect on both crops and human.

Table 13: Sodium and Salinity Control Values (Wilcox, 1995)

VALUE	SALINITY STATUS	SODIUM STATUS
<250μΩ	Low salinity water	Low sodium water
250-750μΩ	Medium salinity water	Medium sodium water
750-2250μΩ	High salinity water	High sodium water
>2250μΩ	Very high salinity water	Very high sodium water

5.1.4.7 Chromium

Chromium salts are used extensively in the industrial processes and may enter water supply for corrosion control. This study is free of industries, but yet analysed to see if chromium can be found in groundwater from the study area. Chromium may exist in water supply in hexavalent and trivalent states though the trivalent form rarely occur in potable water (Andrew *et al.*, 1995).

5.1.4.8 Cadmium

Cadmium is highly toxic and has been implicated in some cases of poisoning through food. Minute quantities of cadmium are suspected of being responsible for adverse changes in the arteries of human kidneys. Cadmium also causes generalised cancers. Cadmium also causes cancers in animal and has been linked epidemiologically with certain human cancers. A cadmium concentration of 200µg/L is toxic to certain fish. Cadmium may enter as a result of industrial discharges or the deterioration of galvanised pipe (Andrew *et al.*, 1995).

5.1.5 Bacteriological Analysis of Groundwater from Hand-dug Well of the Study Area

Bacteriological water analysis is a method of analysing water to estimate the numbers of bacteria present and, if needed, to find out what sort of bacteria they are. This was done for the study area to determined the E. coli and total coli form (**Table 10**).

5.1.5.1 E. Coli

This occurs naturally in the environment from soils and plants and in the intestines of humans and other warm-blooded animals. Used as an indicator for the presence of pathogenic bacteria, viruses, and parasites from domestic sewage, animal waste,

Bacteria, viruses, and parasites can cause polio, cholera, typhoid fever, dysentery, and infectious hepatitis, or plant or soil material. This was measure for the study area, where some fall within the Nigerian guided level water quality standard, while area like Gurajawa, Kanawa, Lubo, Gerkwame, Gambomi, Zangoma Kyari old Liji and Doho were found to contain *E.coli* above standard.

5.1.5.2 Total Coliform

These are commonly found in the environment (e.g., soil or vegetation) and are generally harmless. If only total coliform bacteria are detected in drinking water, the source is probably environmental. Faecal contamination is not likely. However, if environmental contamination can

enter the system, there may also be a way for pathogens to enter the system. Therefore, it is important to find the source and resolve the problem.

Total coliform is also an l indicators of drinking water quality. The total coli form group is a large collection of different kinds of bacteria. Faecal coli forms are types of total coli form that mostly exist in faeces. E. coli is a sub-group of faecal coli form. When a water sample is sent to a lab, it is tested for total coli form. If total coli form is present, the sample will also be tested for either faecal coli form or E. coli, depending on the lab testing method

5.1.6. Hydrophysico-Chemical Analysis of the Water Sampled from some Borehole of the Study Area

The analysis of some borehole water samples shows that colour, turbidity, conductivity, iron, fluoride and appearance are quite high **(Table 11).** This is due to the depth at which the groundwater was sampled. (**Figure 9, 10 and 11).**

5.1. 7. Analysis of Borehole Logs of some Villages in the Study Area

The borehole logs from the three villages Arawa, Kundulum and Gurajawa were analysied and Arawa was observed to be tapping the section extending from 177 to 303 m and the aquifers are lithologicaly consist of coarse sands, well sorted sandstones to fairly cemented and sorted sand which are well and the static water level 18.44m below ground level.

In Gurajawa Village the aquifer penetrated consist of alternate layers of sandstones, silt and shale (Bima Sandstone). The borehole extents 96m to 198m and the static water level was measured at 10.9 m below ground level.

In Kundulum village the encountered lithology consists of alternate layers of sandstones coarse to fine, yellowish to white and claystone. The static water level was measured at 178 m below ground level.

5.2 Conclusion

This study has helped in understanding the hydrophysico- chemical and bacteriological quality of water sampled from Gombe, Sheet 152 NE with some of the physical , chemical and bacteriological parameters falling wihin the permissible limit of Nigerian Guided level water quality standard 2007, while in some area it above the guideline level.

The study shows that forty percent (40%) of the water sampled from the study area are of medium salinity status, this means that this group of water can have detrimental effects on crops that are sensitive to salinity, while sixty percent are of low value salinity with no detrimental effects on crops. Classification of the water type using the piper trilinear diagram shows three water types namely CaCl, Ca-HCO_3 and NaCl.

Generally the water from these hand dug wells is fairly good for domestic activities. Except that Manganese, Magnesium, chloride, potassium, conductivity, colour E. coli and total coli form, were evaluated to be above the Nigerian standard for water quality in some area (**Table 10**).

The analysed borehole water samples from the area are generally within the Nigerian guided level water quality for domestic, agricultural and drinking uses, Except for water sampled from Gwani, Tabra, Deba Fulani and Jurara, where turbidity, appearance, conductivity, iron and fluoride were evaluated to be above the Nigerian guide level for water quality (**Table 10**).

Movement of groundwater from the eastern part of the area towards the western part as a result of difference in groundwater elevation trends at different could have also contributed in t the concentration of element at a particular point.

5.3 Recommendations

Physico- Chemical and Bacteriological Analysis of Sampled Groundwater from both hand dug well and borehole should be done for both rainy and dry season, so as to see the concentration in the chemical, biological and physical constituent of the water sample of the different season.

The water from borehole of the study area should be treated before consumption; this is because some of the water samples were analysied to contain fluoride above the Nigerian guided level standard for water quality.

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