# SPATIAL-TEMPORAL VARIABILITY IN THE WATER QUALITY OF HAND DUG WELLS IN MINNA AND ENVIRONS, NIGER STATE, NIGERIA

**BY**

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## ABSTRACT

Spatial-temporal variability in the water quality of hand-dug wells was investigated in Minna and Environs. Hand dug well water pollution is a major problem in the study area. Hence, the need to carry out groundwater quality assessment using spatial analyst tool in GIS in the study area becomes imperative. The Study analysed selected physicochemical and microbiological parameters of hand dug well water. Mixed methods approach of quantitative and qualitative research methods were adopted. A total of twenty four water samples were collected for both rainy and dry season from four locations and taken to the laboratory for the physicochemical (colour, odour, pH, Temperature, Turbidity, Conductivity, TDS, Cl– SO4, NO3, Acidity, Alkalinity, TH and TSS) and bacteriological (*S. aureus, P. aeruginosa, E. coli, S. typhi*) analysis in order to determine the level of pollutant concentration and the results were compared with NSDWQ and WHO standards. Standard laboratory testing methods were applied. Statistical analyses was conducted using one way ANOVA and Duncan PostHoc. WQI and Inverse Distance Weighted Technique in GIS were used for spatial distribution of Parameters. The results indicates that the physicochemical parameters analysed were within the NSDWQ and WHO recommended standards for both rainy and dry season except colour, odour $Cl^-$ and TH which exceeded the permissible standards. Just one sample and four samples during the rainy and dry season were recorded brown and slightly brownish respectively. Odour was detected in two samples only in the rainy season. The TH was significantly ($p<0.05$) highest in MK (626.67±174.58 mg/l) and MT (540.00±255.02) during dry season than the rainy season exceeding the NSDWQ (2007) and WHO (2011) limits of 500 mg/l respectively. While $Cl^-$ were significantly highest in MK (389.95±48.39 mg/l) and MR (291.88±49.35 mg/l) exceeding the permissible limit of 250 mg/l given by NSDWQ and WHO respectively. The result of microbiological parameters indicated that all the sample wells were significantly contaminated with the pathogenic bacteria and have exceeded the NSDWQ permissible limit of 0 cfu/ml. except that seasonal variation shows that *S. aureus* was not detected during dry season in MR and *P. aeruginosa* was not detected in CH and MT during rainy and dry seasons respectively. The results of WQI indicates that the physicochemical aspect of the water in the study area belongs the excellent and good water quality class during the rainy season while excellent, good and poor were recorded during the dry season. The study revealed that the physicochemical parameters of the well water samples of the study area are generally suitable for drinking and for domestic purposes while for the microbiological parameters shows that there is high contamination of pathogenic bacteria which is an indication of faecal contamination due to poor sanitation and hygiene. The hardness of the water should be soften for domestic purposes through the use of Soda and simple home white vinegar to neutralise excess calcium. The contaminated wells with pathogenic bacteria should be chlorinated with the help of a professional using at least unscented household liquid bleach of 1 gallon (3.79 litres) for a shallow or dug well of about 5.45 metres deep. Water contaminated with pathogenic bacteria should be boiled before use. The individual well owners should provide protective cover for the Wells and ensure proper hygiene and sanitation around the well water environment. Finally, treated water/boreholes should be made for all residence in Minna and environs.

## TABLE OF CONTENTS

**CHAPTER THREE**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATES

# ABBREVIATIONS

| | |
|---|---|
| APHA | American Public Health Association |
| ANOVA | Analysis of Variance |
| BOD | Biochemical Oxygen Demand |
| BIS | Bureau of Indian Standards |
| CH | Chanchaga |
| CO | Chemical Oxygen |
| COD | Chemical Oxygen Demand |
| DPIPWE | Department of Primary Industries, Parks, Water and Environment, Tasmania |
| EC | Electrical Conductivity |
| EPA | Environmental protection Agency |
| FCT | Federal Capital Territory |
| GWQI | Ground water quality index |
| GPS | Global Positioning System |
| GIS | Geographic information System |
| HMI | Heavy Metal Pollution Index |
| MGS | Maryland Geological Survey |
| MR | Morris |
| MK | Maikunkele |

| | |
|---|---|
| MT | Maitumbi |
| NESREA | National Environmental Standards and Regulations Enforcement Agency |
| NBS | Niger State Bureau of Statistics |
| NSDWQ | Nigerian Standard for Drinking Water Quality |
| NTU | Nephelometric Turbidity Units |
| PLI | Pollution Load Index |
| PCA | Principle Component Analysis |
| pH | Potential of hydrogen |
| TDS | Total Dissolved Solid |
| TH | Total Hardness |
| TSS | Total Suspended Solids |
| TNTC | Too Numerous To Count |
| UNESCO | United Nations Educational Scientific and Cultural Organization |
| UNICEF | United Nations International Children's Emergency Fund |
| USEPA | US Environmental Protection Agency |
| WHO | World Health Organization |
| WREN | Water Resources Education Network |
| WQI | Water Quality Index |
| WAI | Weighted Arithmetic Index |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the Study

Before the existence of boreholes and hand dug wells, rainfall, streams, ponds, and rivers were the major sources of drinking water to the people of Nigeria. In contemporary Nigeria, boreholes water can be access in some areas as a result of development. Lack of rapid development, economic capabilities and high population rate, the boreholes water is either not adequate or not affordable to common man. Therefore, the common man had to resort to digging wells as the only alternative source of water for drinking and for daily domestic and commercial purposes (Bremer and Harter, 2012). However, 52% of Nigerians cannot access improved water supply for drinking (Orebiyi *et al.*, 2010).

Groundwater is seen as the most essential and valuable natural resources, expected to be free from contamination. However, this water resource is often contaminated by numerous ways (Ponniah *et al.*, 2012). Groundwater gets contaminated with various contaminants produced from diverse sources such as agriculture, industrial and domestic. The abundance of this significant natural resource has been taken for granted increased use of ground water and contaminate generated has crossed the limits of sustainability in many parts, due to rapid change in land use form. Population growth has led to marvellous increase in demand for fresh water due to extreme agricultural activities. With rapid growth in population and industry, quality of groundwater become vulnerable by disposal of municipal and industrial solid waste (Raju *et al*., 2011).

Groundwater pollution take place when wastewater is reverted to the hydrological cycle (Azadeh and Basavarajappa, 2009). Severe application of fertilizers, agrochemicals, sewage/drain water and mining activities on major lineaments are observed to be a serious threat to groundwater quality (Azadeh and Basavarajappa, 2009). Water is vital for human survival and reproduction of all biotic life and is the key to socio – economic development and quality of life (Ponniah *et al.*, 2012).

Related water diseases are accountable for 80% of different sickness in the developing countries and eradicate more than 5 million persons every year (United Nations Educational Scientific and Cultural Organization (UNESCO, 2007). The major drinking water sources, principally in African countries are from surface water, boreholes, deep and shallow wells, dug outs, streams and rivers which are mostly of poor quality. Water quality is an increasing concern all over the developing world (United Nations International Children's Emergency Fund (UNICEF, 2013) and sources of water for drinking are continuously threatened from contamination. This has both public health and socio-economic consequences (UNICEF, 2013). Faecal contamination of drinking water is a chief contributor to diarrhoea and other water borne diseases, and is accountable for the death of millions of children each year (UNICEF, 2013).

Groundwater usually varied in quality depending on the geographical location, recharge water quality, lithology and environmental influences etc. The valuation of hydro chemical flow systems is centred on the availability of information of groundwater chemistry. Concurrently, the elements responsible for groundwater quality are the geological site, source rocks property, constituents of recharge water, soil formation, lithology and the length of time that the water body has been trapped underground (Faniran *et al.*, 2004; Giridharan *et al.*, 2008). These driving elements and their interrelations create critical groundwater quality (Nishanthiny *et al.,* 2010). Nonetheless, water to be fit for different uses is determined by the physicochemical, biological and radiological properties of water (Ondor and Addo, 2013).

The dependency on Groundwater resources are on a very high level since it is utilised for various activities ranging from domestic, agriculture, commercial and industrial. This high dependency resulted in pressure on existing groundwater resources in relation to quality and quantity (Piscopo, 2001). Groundwater susceptibility to contamination is the tendency and possibility for all form of contaminants to get to the water table after introduction at the ground surface (Scotland and Northern Ireland forum for Environmental Research (SNIFFER, 2004). The groundwater generated by a well or the one confined within an aquifer of any geographical area has some susceptibility to contamination from anthropogenic activities.

Therefore it is important to acquire information about the groundwater quality to contamination to allow groundwater planning and management by relevant authorities. Additionally, the information obtained on groundwater quality can simplify the selection of suitable locations for certain human activities so that the negative effects on groundwater are reduced to the least and protection of groundwater is attained (Adnan and Iqbal, 2014).

## 1.2 Statement of the Research problem

A number of studies have been conducted on groundwater quality both in developed countries and Africa particularly Nigeria. These including Ndamitso *et al.* (2013); Eseoghene *et al.,* (2013); Amadi *et al.* (2015); Paul and Salifu (2015); Duvbiama and Egbuna (2013), which provided useful information on groundwater quality. However, based on the published thesis and journals, little studies were carried out in the study area with regard to groundwater quality and none of these published thesis and journals have utilised spatial analyst tool in GIS to map the distribution of groundwater pollutants of the study area. The present study is intended to bridge this gap.

Sequel to series of public complains by residents of Morris community in Minna to National Environmental Standards and Regulations Enforcement Agency (NESREA) of Niger State Field Office on the pollution of their groundwater (Hand dug wells) sources, which may be from the chemical effluent emanating from the production processes of fertilizer blending plant of Morris Nigeria Limited situated within the community. Compliance monitoring and inspection carried out by NESREA reveals that the facility usually keeps their chemical raw materials directly on bare ground in an open space (NESREA, 2018), these may be a potential point source of groundwater contamination.

Consequently, the need to carry out groundwater quality assessment in the study areas becomes imperative in order to provide useful information to aid policy formulation, planning and implementation.

## 1.3 Aim and Objectives of the Study

The aim of this research is to investigate the spatial-temporal variability in the quality of hand-dug wells in Minna and environs. The aim will be achieved through the following Objectives to:

a. Analyse the physicochemical parameters of the sampled Hand dug well water.

b. Determine the microbiological parameters of the sampled Hand dug well water.

c. Map the distribution of groundwater pollutants.

## 1.4 Research Questions

1. What are the concentration levels of physicochemical parameters of the sampled Hand dug well?

2. What are the concentration levels of microbiological parameters of the sampled Hand dug well?

3. What are the distribution of groundwater pollutants?

## 1.5 Justification for the Study

Besides air, water is vital to human life as the human body cannot usually live longer than several days without. Water is not only vital to life but to every living cell and organ in the body, which is beyond half of the human body weight (Akpe, 2011). Inadequate sanitation contaminates water ways worldwide and is also among the most important causes of water contamination (UNICEF and WHO, 2008). In a statement issued by WHO 2011, 2.4 billion people globally live without better-quality sanitation facility. Around the world, at least 2 billion people use faecal contaminated drinking water sources. Contaminated water can cause diseases such as diarrhoea, dysentery, typhoid, polio and cholera. Contaminated drinking water is evaluated to cause five hundred and two thousand (502, 000) diarrhoeal deaths every year (WHO, 2018).

According to WHO, there are 2.1 billion persons lacking safe drinking-water services as at 2015, out of this figure 423 million individuals are collecting drinking water from exposed wells and springs (WHO, 2018). Likewise in Nigeria the figures indicates that 70 million Nigerians are devoid of access to clean drinking water, lack of access to better sanitary services by 102 million Nigerians and open defecation by 33milion Nigerians. (Akpe, 2011). To further justify the study Ndamitso *et al.* (2013) in their article stated that getting good drinking water is among the challenges faced by many households in Minna and other parts of Niger State which has led to the dependency on other water sources to augment the unreliable supply made by the government.

Inadequate regulating and controlling of urban, industrial, and agricultural wastewater means the drinking-water of hundreds of millions of people could be contaminated or chemically polluted. Diarrhoea is the disease known around the world to be associated with contaminated food and water besides other hazards. schistosomiasis was reported to have affected about 240 million people – usually caused by parasitic worms when an individual is exposed to infested water, it is a very chronic disease (WHO, 2018).

This research study will serve as a contributing document to existing knowledge in the area of water quality and management for the general public, water board managers, governments and for further research in this area. Water supply in Minna is obviously insufficient specifically during the dry season and many inhabitants depend on hand-dug wells and boreholes for their daily water needs. Hence the need to find out the Contamination status of groundwater from the study area (Amadi *et al.*, 2015).

## 1.6 Scope and Limitations of the Study

This Study focused mainly on the investigation of the spatial-temporal variability in the quality of hand dug wells Minna and environs, Niger State. The scope of the study covers four (4) selected areas in Minna and Environs. These areas include: Maitumbi (MB), Maikunkele (MK), Chanchaga (CH) and Morris (MR). A total of 24 water samples from 12 wells for both rainy and dry seasons were collected. Three samples were collected from each of the selected areas to determine the physicochemical and microbiological properties of the Hand dug well water samples and compare the results with Nigerian

Standard for Drinking Water Quality (NSDWQ), NESREA and World Health Organisation (WHO) standards for drinking water quality and finally produce distribution of groundwater pollutants thematic maps of the study areas.

The study was limited by lack of funds, considering the land mass and dependency on groundwater sources in Minna and environs more Well water samples should have been collected from other locations to increase the spatial extent of the study area but the water samples collected were limited to 24 from 12 Wells for both rainy and dry season.

## 1.7 Study Area

### 1.7.1 Location

The four (4) Study areas are found in Bosso and Chanchaga Local Government areas located in Niger state. The state lies between Longitude 3˚30' and 7˚20'E and Latitude 8˚22' and 11˚30'N of Guinea Savanna vegetation zone in the north central part of Nigeria which is also classified as the middle belt of Nigeria.

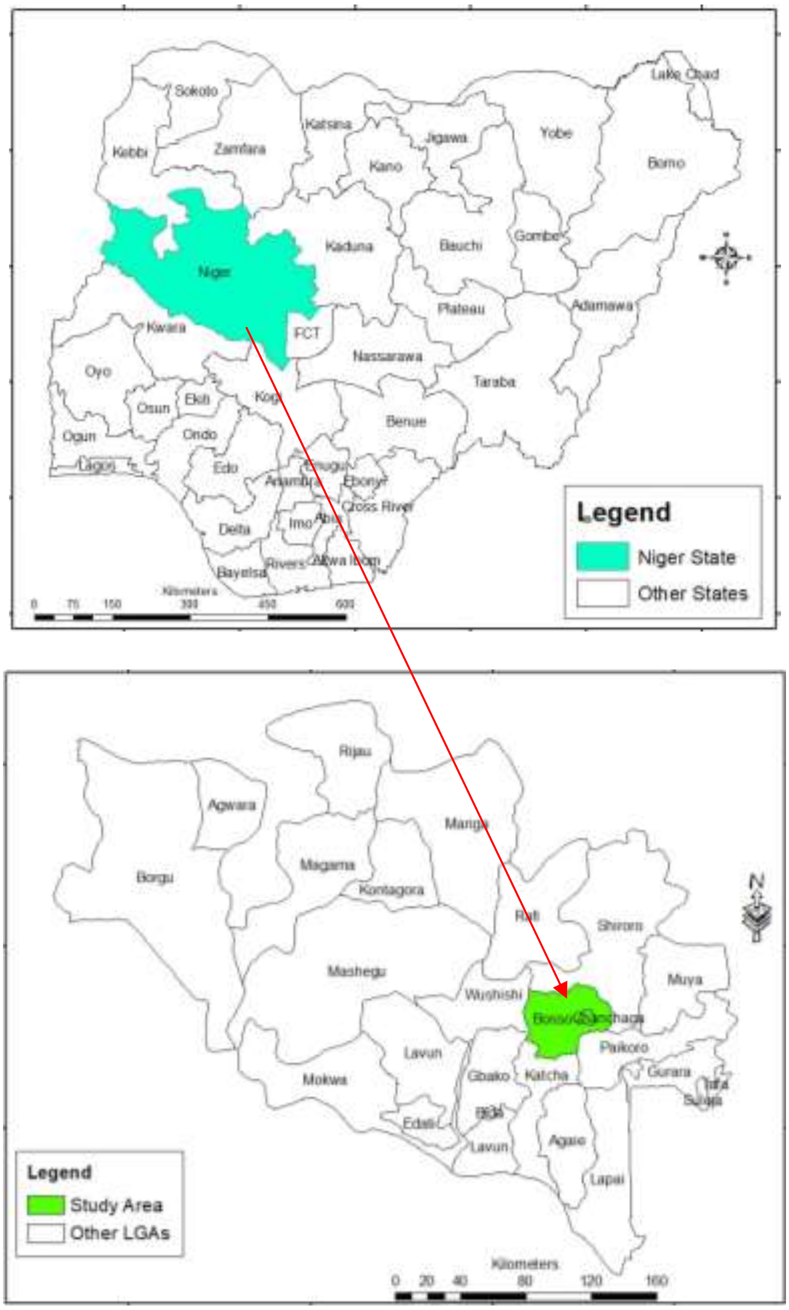


**Figure 1.1: The Study Areas in Niger State and Nigeria**
**Source**: Remote Sensing and GIS Laboratory, FUTminna, 2019

Niger State land mass covers 76,363 square kilometres or about 8% of Nigeria's total land area. This makes the state outsized every other state in Nigeria. Niger State shares common boundaries with six states in the country and one international namely; Kebbi and Zamfara state in the North, Kaduna State and Federal Capital Territory (FCT) Abuja in the Northeast and Southeast of Niger state respectively. Kwara and Kogi States in the South and Benin Republic in the west (Ayinde *et al.,* 2013).

### 1.7.2 Climate

The study area is characterised by distinct rainy and dry seasons with annual rainfall ranging from 1,100mm in the northern parts to 1,600mm in the southern parts of the state. The highest temperature recorded is typically not more than 94$^{o}$C between March and June, while the lowest temperature in record is normally between December and January. However, rainy season's duration is about one hundred and twenty (120) days in the southern areas to about one hundred and fifty (150) days in the northern areas of the State. By and Large, the rich soil and hydrology of Niger State permits the cultivation of most of Nigeria's staple crops and still allows ample opportunities for foraging, fishing and forestry development (Ayinde *et al.*, 2013).

### 1.7.3 Geology of the study area

There are two major soil types in Minna and its environs this include the Sedimentary belt in the southern and south western ends of the area and pre-Cambrian Basement complex rock which is found in abundance above 80 percent of the area. The Sedimentary formation, lies within the middle belt sandstones, it majorly consist of fine grained sandstones combine with grits, siltstone and clay lens. On the other hand the Basement complex comprises of a variety of rock types which are categorised into three broad group (Niger State Bureau of Statistics (NBS, 2017).

- The Igneous rocks in the study area are mostly of biotitic granite and syenite. The rock domes and great hills are mostly made up of granites found in the north eastern and north western parts of the state (NBS, 2017).

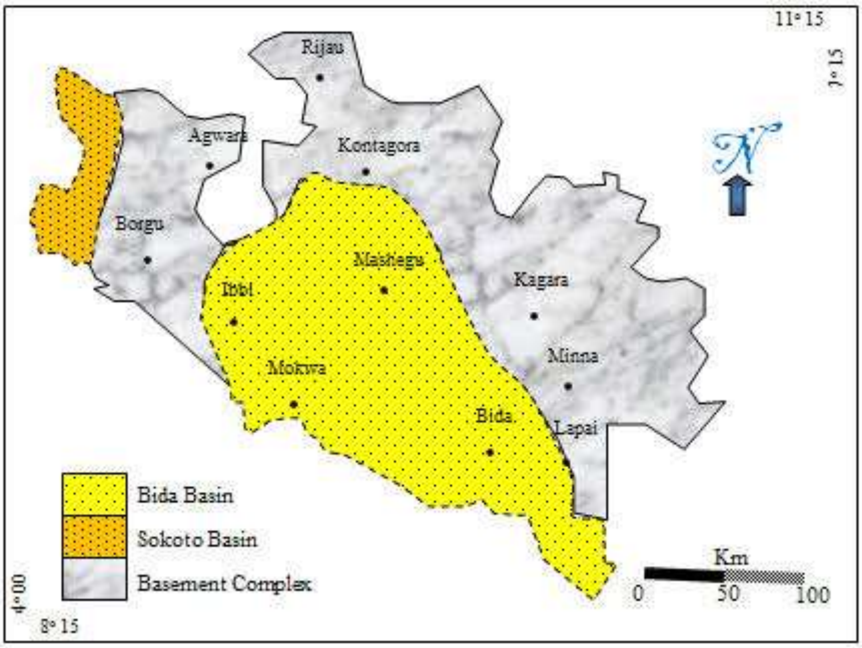


**Figure 1.2: Generalised geological map of Niger state**
**Source**: Idris, et al., 2014.

- The second group is the migmatites and genesis complex which are seen as metamorphic rocks, comprising of gneiss, migmatite, granite and porphyritic gneiss. (NBS, 2017).
- Thirdly, Schists, including biotite/muscovite schists, muscovite and tale schists with quartzite intrusive formed the rugged landscape in the eastern and southern parts of the state (NBS, 2017).

The migmatite, granite, gneiss and biotite granite feature the site of the area. These are rocks of medium to high strength which were not assumed to pose serious threat to engineering activities and the rocks are largely quartz-rich and acidic types which formed the general sandy nature of the soil, particularly on the Robo and Rubochi plains. The plains are known to contain the best fertile soils and the best agricultural lands of all the plains while the abundance of sand in most soils in the area accounts for the relatively high erosion status. Nevertheless, one significant benefit about the types of rocks and soil found in the state is that these rocks and soil are available as construction materials in the form of building stones, quartz and pistolitic gravel, building sands and earth for use as foundation materials (NBS, 2017).

### 1.7.4 Soils and vegetation

There are three main types of soil found in the State. These soils include the hydromorphic soils, ferruginous tropical soils and ferrosols. The major soil type is the ferruginous tropical soils, mainly derived from the Basement Complex rocks, and also from old sedimentary rocks. Such ferruginous tropical soils are best for the cultivation of groundnut, maize, guinea corn and millet (NBS, 2017).

The type of soils basically found in the wide flood plain of the Niger River are the Hydromorphic or waterlogged soils. The soils drain poorly and are usually greyish or sometimes whitish in appearance resulting from the great content of silt. The Niger trough harbours sandstone formations on which Ferrosols developed. They are characterise with red colour rich with clay sub soil noticeable in the landscape. Termite hills mark the landscape, expecially between Mokwa, Bida and Kontagora. These can been observed along the major highways in the state (NBS, 2017).

The study area is located within the Savana zone vegetation of Nigeria, however, patches of rain forest, are seen in the plains that form one of the enduring northern-most mature forest vegetation in Nigeria. The vegetation of the study area is categorised as part of the main Savannah vegetation types of park or grassy which occupies nearly 53% of the whole area and where the vegetation is annually; the Savana woodland covers 12.8% of the rugged and less accessible parts of Robo and Rubochi plains and surrounding hills as the main areas of its occurrence. The Shrub Savannah and the ridges dominates nearly 12.9% of the land extent which is seen extensively in rough terrain close to hills (NBS, 2017).

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

In this chapter, the concepts of groundwater systems and its associated environmental factors leading to groundwater contamination in the context of groundwater quality were reviewed. Related studies were also reviewed on groundwater quality issues in Nigeria and beyond, all aimed at investigating whether the water consumed by people, animals, plants, for industrial activities and agricultural purposes meet the standard quality or not for both developed and developing countries as the main focus in this chapter.

### 2.1 Concept Study

#### 2.1.1 Groundwater system

Groundwater is a fresh water resources existing in the open spaces and fractures in rock and sediment underneath the Earth's surface. It is originated from rainfall or snow, which then percolate and moves through the soil into the groundwater system, where in due course resurface back to streams, lakes, or oceans (Stephen, 2015). Groundwater occurs almost in all places below the land surface and is an important part of a complex water cycle that involves constant movement of water on Earth (Alley, 2009). Nevertheless, groundwater makes up almost 1% of the water on Earth (most water is in oceans). But, groundwater makes up nearly 35 times the quantity of fresh water resources found in lakes and streams. Groundwater is found everywhere beneath the Earth's surface, but is commonly limited to depths not more than 750 meters. The amount of groundwater is like a 55 meter thick layer spread out over the entire earth surface (Stephen, 2015).

Groundwater take place in two primary zones, the unsaturated zone also called (vadose zone) and the saturated zone. The vadose zone is simply the terrestrial subsurface of

Earth's that extends in depth from the surface to the regional water table in the ground. Subsurface constituents which are not saturated, Soil, and a transiently flooded capillary fringe are all elements of the vadose zone. The subsurface constituents include incompletely weathered soils and un-weathered parent constituents aterial. The vadose zone may not be deep (<1 m) or very deep to hundreds of meters, depending on the depth to the water table. This zone does not have high water content but low in relation to saturated zone found below the water table. Therefore the former is commonly known as the unsaturated zone. Over head the capillary fringe, vadose-zone open spaces are mostly filled with air, by means of thin water films coating solid particles. Pore spaces turn out to be filled with water when rainfall seep into the ground, followed by drainage and gradual drying (Holden and Fierer, 2005).

Nevertheless, the saturated zone lies straight below the vadose zone commonly referred to as aquifers and are composed of permeable parent materials that are saturated (wet) with water. Like the vadose zone, aquifers are usually areas of poor plant nutrient accompanied by abundant dissolved oxygen. The line between the unsaturated zone and the saturated zone is not consistently distinct one, because the water table can increase or decrease subject to rainfall events. The area that makes up this somewhat diffuse boundary is called the capillary border. Aquifers function as a primary source of clean water for most part of the world (Pepper and Gentry, 2014).

### 2.1.2 Aquifer formations

Aquifer is a word used to describe hydro geologic systems. This is a geologic unit that can store a substantial amount of water in the ground with high permeability (Ge and Gorelick, 2015). The geology of an area determines the existence of an Aquifer, which defines whether the rocks are porous or not, and is closely related to good hydrological explanation. Based on the worldwide aquifers distribution and hydrogeological explanations, productive aquifers are found in areas of rocks that are more permeable such as limestone, sandstone and gravely rocks while the less productive are establish in rocks of poorer permeability such as clays and basaltic shales and granitic rocks (Puri, 2013).

Aquifers may take place at numerous depths, those that are close to the earth surface are not only expected to be used for irrigation and domestic purposes, but are also more likely to be topped up by the local rainfall. Groundwater resources can actually be harvested from limestone hills or mountains in many parts of desert or close to it. Shallow aquifers that contains water and were exploited for man use include the Jebel Akhdar in Oman, parts of the Sierra Nevada. The Lebanon and anti-Lebanon ranges between Syria and Lebanon, part of the Atlas Mountains in North Africa (en.wikipedia.org/wiki/Aquifer).

### 2.1.3 Types of aquifer formations

Aquifers occur in various sizes and their source and composition is different. They might be small covering a few hectares in area, or so big, lying beneath the earth's surface tens of hundreds of square kilometres. Aquifers may be some meters thick, or they may measure hundreds of meters from top to bottom (Government of Canada, 2013). Aquifers can be of two types:

- Unconfined Aquifers - is the most occurring type of aquifer, usually this type of Aquifer exposes its water table to the Earth's atmosphere through the zone of aeration (Stephen, 2015). These aquifers are determined by the water table and this is the water level observed in a borehole. The deepness to the water table differs according to features such as season and tidal effects, topography, geology and the amount of water being thrust from the aquifer. Generally, unconfined aquifers are recharged by stream water or rain percolate directly into the overlying soil. Various areas of coastal sands and alluvial deposits in river valleys are examples of unconfined aquifers. (Department of Primary Industries, Parks, Water and Environment, Tasmania (DPIPWE, 2017)

- Confined Aquifers – these aquifers are not too common, but they come into existence when an aquifer is confined between layers of strata that does not allow water to percolate (aquitards) (Stephen, 2015). According to (DPIPWE, 2017) further described confined aquifer as a rock entity which allows water to percolate through it and are typically deeper beneath the ground than unconfined aquifers. These aquifers are covered by relatively impervious rock or clay that restricts groundwater movement in or out of the confined aquifer. This water existing in a confined aquifer with natural pressure and will upsurge inside a borehole drilled into the aquifer, and could come up to the ground surface, which form an artesian flow. The level to which the water rises is called the potentiometric surface.

## 2.2 Groundwater Quality

Water quality is seen to be the biological, chemical, physical and radiological characteristics of water (Diersing, 2009). According to encyclopedia.com Groundwater quality refers to the state of water that is situated below the Earth's surface. Differences in groundwater quality depends on the physicochemical parameters that are significantly affected by geological formations, changes in sea level increase and human activities (Kumar *et al.,* 2012). The chemistry of groundwater is much impacted by rock constituents, soil and contaminant sources such as mining, clearing of land, saline intrusion, industrial, extreme irrigation activities and domestic wastes (Schiavo *et al.*, 2006). The particular usage of water in specific places can be determine by the chemical composition of groundwater (Maryland Geological Survey (MGS, 2019).

Commercial, domestic and industrial wastes including high rate of agricultural use of modern fertilizers and pesticides are the main dangers to the quality of groundwater (Ofodile, 2002). These contaminants may permeate into aquifers through seepage and thereby contaminating it. The erection of soak-away septic tanks in many household across Nigeria has caused increase in the concentration of Nitrate in groundwater resources in many parts of the country (Taiwo, 2012).

### 2.2.1 Contamination of groundwater

Contamination is the act or process of causing water, land or air environment to be unclean and unsafe or unfit for use particularly when caused by environmental contamination with man-made waste such as gasoline, oil, sewage and chemicals. This leads to impurity, poisoning, presence of impurities or harm to the consumers (Fagoyinbo and Dairo, 2016). Water contamination may also arise naturally due to natural chemicals existing in the groundwater such as fluoride, dissolved salts, iron and manganese, radionuclides, arsenic and trace metals (Iyyanki *et al.*, 2017). Contaminates from the earth's surface may find their way through the soil and end up in the groundwater. For example, pesticides and fertilizers may enter and contaminates groundwater supplies over time. Road salt, toxic materials from mining areas, and spent motor oil also may percolate into groundwater. Additionally, it is likely that groundwater can be contaminated from waste that is not treated from septic tanks and tanks of toxic chemicals stored underground and leaky landfills (Groundwater foundation, 2019)

Also according to https://en.wikipedia.org/wiki the pollutant often generates a contaminant plume inside an aquifer, figure 2.1. Water movement and distribution within the aquifer wide-spreads the pollutant. Its increasing boundary, referred to as plume edge, can interconnect with groundwater wells or daylight into surface water such as seeps and springs, making the drinking water not safe for humans and wildlife consumption. Nearly every identified distance of groundwater contamination has been revealed only after a drinking water supply was affected (Iyyanki, 2017).

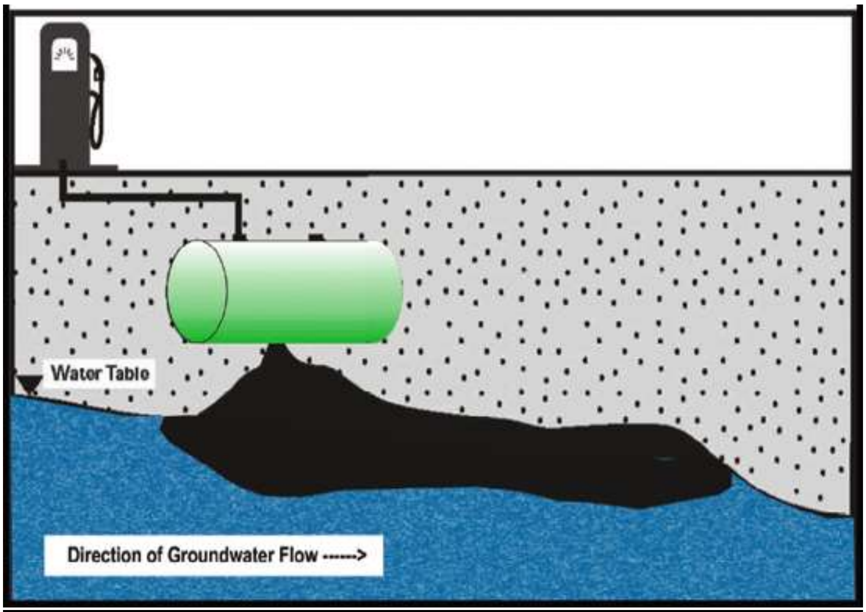


**Figure 2.1 Contaminants Plume**
**Source**: Centre for Instructional Technology (2016)

### 2.2.2 Contaminant sources classification

Water resources contamination and the respective quality of groundwater degradation are caused by countless anthropogenic activities which result in the alteration of physicochemical characteristics of water (Talabi and Kayode, 2019). With the increasing rate of possible contamination sources, efforts to classify them have been increasing also. Agencies and experts in the field of groundwater contamination have often followed their own categorisation (Zaporozec *et. al.*, 2002).

Classification of Groundwater pollution sources can be based on various parameters such as origin, geometry of the source and transmission rate. Contamination sources resulting from origin might be natural or human influence, geometry of the source might be point source (septic tanks, landfills, waste dumps, underground tanks), linear (roads) and non-point (nitro pollution, acid rain and uranium decay) while the transmission rate signifies constant and frequent transmission of pollutant. Table 2.1 shows the classification of sources.

**Table 2.1: Classification Methods for Groundwater Contamination Sources**

| S/N | Classification | Examples |
|---|---|---|
| 1 | By way of release | Discharge sources; transport sources |
| 2 | By origin | Domestic sources; agricultural sources |
| 3 | By chemical type | Heavy metals; hydrocarbons; pesticides |
| 4 | By location | Above ground surface; below surface |
| 5 | By character | Point, Non Point (diffuse), and line sources |

Sources: Zaporozec *et al.*, 2002.

### 2.2.3 Contamination of groundwater sources

Contamination of groundwater mostly begins at the land surface and is categorized as either point source, for example leakage from septic tank, or non-point source, for example from agriculture-related compounds. Probably the greatest threat is exposure to undetected contamination. The risk posed by contamination and the cost and effectiveness of remediation depend upon the type of contaminant, the geologic environment and the exposure pathways (Brown, 2013). At many locations, the origin of contamination cannot be cost-effectively remediated to levels targeted and functional management or groundwater capture must carry on at all time (Beckie, 2013).

Contamination sources that are commonly known are the ones influence by man, which usually include: disposal of solid waste, municipal and industrial wastewater, various application of fertilizers, pesticides and insecticides, disposal of by-products and waste from mining activities and nuclear energy waste (Talabi and Kayode, 2019). Similarly, groundwater may be contaminated through natural processes, i.e., the outcomes of cycles or of natural occurrences. These sources include the following: easy to dissolve rocks (gypsum, mineral salt etc.), extreme evaporation particularly in low aquifers which causes rise of groundwater and salt deposition, degradation of water sources in places situated in geothermal/volcanic fields, rock oxidation, seawater intrusion, decay of radioisotopes from highly rich uranium bedrock, and chemical reactions of elements in the atmosphere or in the water (Talabi and Kayode, 2019).

### 2.2.4 Point source and non-point source contamination

Another major concern in water quality management is to examine the point and non-point sources of water. From the last few decades, advancement in technology providing new innovation in industries and urbanizations in developing nations have emerged, therefore the challenges of point and non-point sources likewise has increased which seems to be a serious threat to the environment (Khan *et al.,* 2012). There are various potential water contamination sources which can be classified as point sources and non-point (diffuse) contamination sources. Point source refer to any visible, confined and discrete conveyance, including but not restricted to any pipe, ditch, channel, tunnel, well, conduit, container, discrete fissure, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which contaminants are or may be release. This term does not include the release of agricultural storm water and return flows from irrigated agriculture (US Environmental Protection Agency (USEPA, 2017). Key point sources include domestic and industrial wastewater effluent treatment plant, which can be found in urban, industrial or agricultural regions (Lapworth *et al.,* 2012).

It is not unusual that wastewater treatment plants, combined sewage-storm water overflows treatment plants or inappropriate treatment of hospital sewages does not provide a final effluent of proper quality. Specific organic micro pollutants could end up in surface and groundwater (Singhal *et al.,* 2014). Industrial activities such as, mining, factories, livestock farms, food processing and landfill sites are further examples of point sources of groundwater pollution.

While diffuse sources of pollution are sources that does not emanate from a detectable pollution confined, or discrete conveyance e.g. leading of agrochemicals (Zaporozec *et al.,* 2002). The discharge from diffuse sources are usually irregular, related to rainfall or snowmelt periods, running over and seeping the ground. As the runoff occurs, it carries along with it natural and ma-made pollutants, dropping these pollutants into rivers, wetlands, ground waters, lakes and coastal waters (USEPA, 2017). Diffuse sources of pollution are often challenging to detect and the pollutant may cover wide geographical areas (Lapworth *et al.*, 2012).

Diffuse sources of contamination may include human and pet wastes, microorganisms, nutrients,: emissions from Automobile, salts from irrigation practices, forestry, oil and gas development, runoff and leachate from construction activities, mining and logging activities and several land use activities which can have negative impact on the water quality (Khan *et al.,* 2012). Agriculture and anthropogenic activities are also partaking in the declining the quality of water. The quality of water is generally influenced by anthropological processes in rural and urban region (Ayeni and Soneye, 2013). Consequently, contamination of surface water usually results in respective groundwater contamination.

## 2.3 Effects of Land Activities on Groundwater

Many anthropogenic activities can negatively impact groundwater quality as well as quantity. For several years it was commonly believed that the sieving abilities of the soil secured groundwater from contamination by human activities on the surface. Nevertheless, with the new findings of man-made organic chemicals in groundwater in the 1970s, led to the realization on how widely our actions may affect groundwater. Those activities that can have a negative effect on groundwater can be categorized in four groups: urbanization, Mining/Industry, waste disposal, and agricultural practices (Water Resources Education Network (WREN, 2011).

### 2.3.1 Effects of urbanization on groundwater

Various human activities and land use practices, which multiply with urban development, can impact groundwater negatively. For example, burial ground may contaminate groundwater. A well-known effect of urbanization is groundwater recharge diversion. Soils that have been concealed with impermeable surfaces such as parking lots, streets, roofs, clearly cannot absorb the rain water. As a consequence a great amount of the water from rain and snow melt goes straight into streams without recharging the groundwater. High population in a given place may also lead to extreme withdrawal of water from aquifers. This can result in significant aquifer drawdown which leads to reduction of the quantity of stream flow. Stream water quality then bear the consequences due to high discharge of effluent from sewage treatment plant. Extreme pumping in coastal regions can cause salt water to be pulled into aquifers and wells. Polluted stream water may also find its way into drinking water wells. High rate of population is accompanied with industrialization and proliferation in number and different types of industrial activities, out of which many can potentially contaminate groundwater. Groundwater have been contaminated in several instances from leaking storage tanks. Individual home owners also impact groundwater through a number of activities. These include inappropriate disposal of spent oil and over use of inorganic fertilizer and pesticides on home lawns and gardens. Home owners apply four to eight times the quantity of fertilizers and pesticides per acre than applied in farms. Golf courses are also not left out as a source of groundwater contamination from over application of inorganic manure and pesticides (WREN, 2011).

### 2.3.2 Mining and industrial activities

Mining and industry are possible risk for groundwater contamination. The inappropriate management and dumping of hard and liquid waste from mines and factories, accidents, and leakages may become sources for contamination. These sources might be located at the terrestrial surface, in the unsaturated zone, or beneath the water table. Generally, but not entirely, they are point sources that could result to exact contaminant plumes in the groundwater system (Zaporozec *et al.*, 2002).

Mining coal, both shallow and deep into the ground, results in alteration of groundwater quantity and quality. When mines interconnect with aquifers and pull water into itself, groundwater storage become obstructed and could drop the water levels in wells. Furthermore, the sulphur present in coal reacts with oxygen and water to form sulphuric acid. The consequential acid mine drainage reduces water quality as it permeates into aquifers or discharges into streams. As iron, sulphate, manganese and dissolved solid concentrations increases in well water can be the consequence. For instance various aquifers in mining coal regions of Pennsylvania may not be used anymore in for supplying drinking water due to contamination from mining activities. Oil wells produce saltwater which is separated from the oil and kept in surface lagoons. If not appropriately lined, these lagoons may drip and release saltwater to groundwater. Methane may move from gas wells that are under pressure and has been detected in private water wells. Abandoned and left open gas and oil wells can as well be a source of contamination of groundwater. An uncovered well simply means inviting illegal dumping spot for waste. Inappropriate covering and cementing or depreciated casings may cause contaminants to spread between aquifers (WREN, 2011).

### 2.3.3 Effects of waste disposal on groundwater

The most identified source of groundwater contamination is that of urban and industrial waste dumping sites (WREN, 2011). As the population of man increases, so does the waste generated every day. This waste is retrieved and taken to specific sites called landfills where it is buried. Furthermore, it is mandatory for all landfills to have a protecting sheet at the bottommost in other to avoid the waste water from leaching into the ground. However, certain landfills do not have that protective sheet, and in certain situation, the landfill is fractured. As a consequence such landfills leaks of contaminants, such as acid from car battery, household chemical, and products from medical waste into the groundwater. Additionally, poorly designed septic systems discharge bacteria, viruses and household chemicals into the groundwater and render it unhealthy for human ingestion. Poorly kept septic tanks likewise causes leakages thereby contaminating groundwater. It is highly important that septic waste is treated before it is dump into the ground. Similarly, there are various places around the world where harmful goods such as radioactive elements, war chemicals, electrical electronic waste, and related products are disposed. These waste sites continue to increase in number day by day. In several situations, harmful products in disposal sites are not effectively monitored. Absence of appropriate checking and upkeep of such sites leads to seepages of hazardous substances into the groundwater (Benjamin, 2018).

### 2.3.4 Effects of agriculture on groundwater

Frequent farming practices such as application of pesticides and fertilizer are being examine on the high level because groundwater samples have shown nitrates as well as pesticides in some instances. The most prevailing challenge is high concentration of nitrate from intensive use of manure and fertilizer (WREN, 2011). Agriculture is conceivably one of the most prevalent anthropogenic activities which may affect groundwater, though forestry can likewise have certain negative effects on the groundwater resource. The activities include the growing of crops, livestock farming and logging. Storing and dumping of manure, hoarding of materials, and a huge number of other activities carry the menace that groundwater resources can be affected. Even though the agricultural practices are practiced on the land surface, percolating rain water and irrigation water can take the related contaminants deep into the groundwater. Specifically, the use of fertilisers, pesticides, and manure in a widespread open spaces may contribute to severe pollution of greater portions of a groundwater system. This contrast to the regulation of point source contamination, the actions to be adopted to manage the dangers from diffuse farming sources and forestry activities are regularly far more complex. There are enormous farming practices menacing groundwater resources but the significant ones include: Stockpiles and crop debris, forestation and deforestation, Animal waste, application and stowage of pesticides, application and stowage of fertilisers and irrigation return flow

(WREN, 2011).

## 2.4 Analysis of Physicochemical Parameters of the Sampled Hand Dug Well Water.

Singh *et al.* (2015), assessed the quality of groundwater in parts of Chandauli-Varanasi region in order to define its suitability for drinking and agricultural purposes.

Urbanization and farming practices is perceived to be a problem because it has a lot of negative effect on the groundwater quality of the study area. A sum of 70 ground water samples were retrieved randomly from diverse sources such as hand pump, hand dug and bore wells, the collected samples were examined for major cations and anions. The domination of cations and anions were in the order of Na > Ca > Mg > K and HCO3 > Cl > SO4 > NO3 > F. The technique employed for the laboratory examination to determine the level of anions and cations were flame photometer (Elico CL-378), UV-3200 double beam spectrophotometer model and titrimetric method. The Piper classification for hydro geochemical facies shows that alkaline earth surpasses alkalis and weak acids surpasses strong acid. Water quality index (WQI) rating was calculated to compute the total water quality for drinking my man. From the findings 7% and 10% of the total groundwater samples revealed water unsuitable for drinking purposes before and after monsoon period respectively. This was due to the effect of leaching of ions, direct release of untreated domestic effluents and farming activities. Residual sodium carbonate values shows that 6% of the sample were not suitable for irrigation intent in both dry and rainy seasons as a result of low absorptivity of the soil. The calculated values of Pollution Index (PI) shows excellent to good quality of the water to be used for irrigation in both seasons. As per Wilcox's diagram (1948) and US salinity laboratory grouping, almost all the groundwater samples analysed were found suitable for irrigation except one sample which is not suitable for irrigation uses. The study concludes that the general quality of groundwater in post-monsoon season in all chemical elements were found to be higher due to dissolution of surface contaminants during the percolation of rainwater at some areas due to farming and domestic activities.

Dan *et al.* (2018) assessed the physicochemical quality of drinking water used by the inhabitants of Sô-Ava based on the standards of Beninese and those given by WHO. According to the paper in rural and peri-urban areas of Benin where public water supply systems are insufficient or nearly absent, the inhabitants drinks water of unascertained qualities and from numerous sources. An aggregate of 67 water samples were evaluated during the rainy season of July, 2017 and in the dry season of January, 2018 for some physical and chemical parameters using standard procedure. The outcome from the laboratory were calculated by the use of spreadsheet in Excel program and then processed with the XLSTAT 17 a software for statistics and also descriptive statistic such as maximum, minimum, mean and standard deviation method of analysis were used. The results of these analyses disclose that the physical and chemical characteristics of the water used for drinking in Sô-Ava conform to the drinking water standards of WHO and Benin except for the following parameters whose percentages are: pH (41.80%); turbidity (25.37%); the colour (16.42); ammonium (17.91%); iron (40.30%); Nitrites (4.48%); Residual chlorine (91.05. Therefore, the study concluded that the physical and chemical properties of the water investigated from the community of Sô-Ava during the study time may be considered acceptable and present no threats for consumers. However the study recommended that hygiene measures should be implemented at the water point, when conveying and storing of water.

Correspondingly, Samuel *et al.* (2016), assessed the levels of selected physicochemical water quality parameters in fifteen hand dug wells in Bolgatanga of the Upper East region of Ghana. The impact of seasonal changes and nearness to contamination sources on the concentrations of some parameters of the well water samples were evaluated. Descriptive statistical method of data analysis were employed. The results shows that turbidity, pH, conductivity, Total Hardness (TH) and Total Dissolved Solid (TDS) increased in concentration levels during the rainy season, resulting from permeations of storm water. The study concludes that the qualities of the water samples were impacted by the circumstances of the immediate environment. Consequently, water from the hand dug well are unfit for drinking and for domestic uses, until standard treatment are carried out. The Study recommended that the wells should be disinfected before use. Furthermore, the hand dug wells in the study area should be erected at least 1 m above ground and sited at least a distance of 30m from any source of contamination to avert runoffs and other pollutants from contaminating the wells during rainy seasons.

Unhealthy drinking water is one of the major challenge in undeveloped countries according to Sorlini *et al.,* (2013), for these problem to be solved a cooperation project was established by the ACRA Foundation in the Logone gorge (Chad-Cameroon). Water sources available in the surrounding villages were sampled generally from open wells, boreholes, some piped waters, as well as rivers and lakes. The samples were examined for their physicochemical quality in order to detect the contamination problems and recommend suitable solutions. Descriptive statistics such as maximum, minimum, median, mean, and deviation standard were employed to compute the data and similarly correlation among samples were determined by principal component analysis (PCA) by applying stat box 6.6 software (Stat Box logiciels, Grimmersoft, France). The outcome of the valuation established that in the studied area there were a number of parameters of health and aesthetic concern. Raised levels of lead were detected both in aquifers and in surface waters, these warrants further assessments of the existence of lead pollution in the Logone valley. Additionally, various groundwater sources are affected negatively by parameters of aesthetic concern, such as turbidity, iron and manganese. However, these parameters do not have any health implication, raised levels of these parameters made the inhabitants of these area to restrain themselves from the use of improved water supplies, and prefer surface water sources that are microbial contaminated. The use of different water sources, upgrading of water supply structures and treating water are likely a way out to better the standard quality of drinking water in the Logone valley.

Ibrahim and Mohammed (2015), carried out a research in Al Hayer situated in the northeast of Al Ain area of the United Arab Emirates. They identified Groundwater abstraction for domestic, industrial and agricultural application to be the reason for the main decline in the aquifer consequently deteriorating the groundwater quality. The study aims to detect the causes impacting the groundwater quality in this area, and to find out the recharge mechanism for the study area and to comprehend the conduct of key ions in regional groundwater by applying hydrogeochemical and isotopic methods. The hydrochemical study of 37 retrieved samples of groundwater indicated that the groundwater is categorized by moderate salinity and high level of cadmium in certain samples. Consequently, Al Hayer groundwater is unsuitable for domestic applications. Groundwater samples were assessed for agricultural practises by calculation of Sodium Adsorption Ratio (SAR), TH, $Na^+$ percentage and MAR. By employing these parameters, Al Hayer groundwater was found to be satisfactory for agricultural usages in 60% of the overall samples. Three water origins have been recognized; the first origin is paleo-marine water, whose genesis is from magnesium chloride water category, signifying over withdrawing of deep water. The second is meteoric water, whose genesis is from sodium sulphate-water category, signifying an incidence of permeation of rainfall and ion exchange processes. The third one is meteoric water, whose genesis is from sodium bicarbonate-water category, detected only in a small number of samples. The hydrochemical evaluation revealed that the dominance of sodium and chloride in the study area is as a result of untreated agricultural effluents and this gives a hint of moderate-to-high saline water in the studied area. Isotope evaluation of hydrogen and oxygen of 29 groundwater samples put forward that the study area has two distinct zones. The first one is represented by majority of groundwater samples and located below the local meteoric water line (LMWL) and to the west of the study area, which signifies high level of evaporation. Meanwhile, the second zone is situated overhead the LMWL and to the east of the study area in near to Northern Oman Mountains, which showed quick percolation of rainfall into main aquifer of the study area with no evaporation. Hence the study concludes that all investigations indicated that the groundwater is unsuitable for domestic application as a result of high level of TH which has health risk as shown by various samples collected while most of the groundwater samples were certain to be suitable for irrigation. Intermittent valuation for groundwater should be conducted as one of the major strategies for better control and the government should also come up with a working plan for improving the quality of groundwater were recommended.

Also, in a related studies by Lukubye and Andama (2017), evaluated the physicochemical quality of drinking water sources. Springs, shallow wells, boreholes and rainfall, were selected in Mbarara municipality of Uganda for this analysis. World Health Organization (WHO) drinking water guidelines and other guidelines were used to compare the level of the analysed parameters in light of the increased anthropogenic activities in the municipality. A sum of 70 water samples were retrieved from intended selected boreholes, springs, and rainwater and wells in Nyamitanga, Kakoba and Kamukuzi divisions of Mbarara municipality with several anthropogenic activities. American public Health Association (APHA) standard procedures were applied to analyse the physicochemical parameters and descriptive statistics were applied to calculate the laboratory results. The study shows that the mean temperature and pH ranged between $18.07^0$C-$23.45^0$C and pH 5.74-7.54, respectively. The mean Dissolve Oxygen (DO) values were seen to be between 4.84 and 12.86 mg/l; while mean Biological Oxygen Demand (BOD) was within the range of 1.83 - 7.71 mg/l. The mean for TDS and electrical conductivity (EC) of the water samples ranged, between 33.40-569.20 mg/l and 29.30-1139.90 µS/cm respectively. Furthermore, the least and maximum mean for TH were 70.00 and 264.00 mg/l, respectively. The recorded mean temperatures for every single one of the water sources exceeded the WHO given temperature of $15^0$C, which makes drinking water palatable. The samples collected from Boreholes in Nyamitanga and Shuhaddea Secondary Schools, the samples collected from wells in Kisenyi, the samples collected from spring in Kiswahili, and the samples collected from rainwater in Mbarara University of Science and Technology (MUST) had mean pH below the WHO minimum standard value of 6.5 therefore all the samples are considered acidic. Borehole in Nyamitanga secondary school, spring in Kisenyi, shallow wells in Nyamitanga and the rainwater in MUST had mean values for DO below the range 10 - 12 mg/l as given by WHO. Borehole in Shuhaddea Secondary School and the well in Kisenyi had average values for BOD above the range of European Union standard values ranging between 3-6 mg/l. TDS and EC of the total water samples fall of the WHO maximum limits of 1000 mg/l and 1500 µS/cm respectively. TH was also below the recommended WHO limit of 1000 mg/l.

Nevertheless, rainwater analysed in MUST was observed to be moderately soft whereas the other drinking water sources revealed moderate to full TH. The physicochemical properties of some of the examined water sources in Mbarara municipality have been conceded primarily by the high anthropogenic activities particularly landfills, Crop lands, transportation, latrines, animal and municipal wastes at the area of the water sources. Henceforward, the study highly recommends Mbarara municipal council to guarantee appropriate sanitation and water safety plans for the sampled drinking water sources to evade further pollution from anthropogenic activities.

Similarly, Bodrud-Dozaa *et al.* (2016), investigated groundwater quality in the Faridpur district of central Bangladesh based on preselected 60 sample wells. Water assessment indices and a few statistical methodologies such as multivariate statistics and geostatistics were used to describe water quality as the main factor for regulating the groundwater quality in relation to drinking purposes. EC, TDS, Ca2+, total As and Fe values of groundwater samples exceeded the international and Bangladesh standards as shown by the study. Ground water quality index (GWQI) showed that roughly 47% of the samples belong to the good water class quality for drinking purposes. The heavy metal evaluation index (HEI), heavy metal pollution index (HPI) and degree of contamination ($C_d$), indicated that most of the samples belong to the low level of pollution. Though, $C_d$ offer better option than other indices. Principle component analysis (PCA) proposes that groundwater quality is mainly related to geogenic that is rock–water interaction and anthropogenic source such as agrogenic and domestic sewage in the study area. Subsequently, the outcomes of cluster analysis (CA) and correlation matrix (CM) are also consistent with the PCA outcomes. Geostatistical modelling determined the spatial distributions of groundwater quality properties. The exponential semivariagram model is validated as the best fitted models for most of the indices values. The study believes the results will offer an insights for decision makers ensuring appropriate actions for groundwater quality management in central Bangladesh.

While on the other hand Paul and Salifu (2015), assessed the presence of anions in groundwater from shallow wells in Minna metropolis, Niger state, Nigeria. The carefully chosen Parameters such as Fluoride Sulphate, Nitrate and Chloride were determined. Just 27 samples from 9 different locations within Minna capital city were retrieved for examination in the laboratories and descriptive statistics and pearson single-tailed correlation statistical methods of data analysis were used. The outcomes acquired revealed the average concentrations of the parameters to be in the range of 6 – 21.6 mg/l for Nitrate, 29.4 – 84.5 mg/l for Sulphate, 44 – 141.6 mg/l for Chloride and 0.17 and 0.32 mg/l for Fluoride. These results were compared to WHO standards, which revealed water from shallow hand dug wells in Minna city met the water quality standards.

Accordingly Ndamitso *et al.* (2013), in his article stated that to ensure adequate supply of water for drinking, packed water has been introduced to give healthy, disinfected and affordable drinking water. Nevertheless, trends have caught up some packaged water as carriers of disease transmission. According to them, the physicochemical studies of carefully chosen packed water, or else called "pure water" were conducted. Exactly ten products were retrieved from the packaging factories of 5 samples each per products and were examined weekly for one month. The results gotten were compared with Environmental Protection Agency (EPA) and WHO standards for drinking and recreational water. Their pH values, except for Sabo Best was 6.26±0.02 and were within the stated WHO/EPA standards of 6.50-8.50. The respective 1.63±0.10 and 1.54±0.10 mg/dm3 for Evershine and Supreme waters were above the 0.3 mg/dm3 iron standard just as the respective copper and nitrate values of 1.19±0.14, 1.27±0.10, 1.48±0.10 and 86.81±0.62, 124.47±1.36, 141.70 ± 0.00 mg/dm3 for Golden Age, Supreme and Sabo Best mean values were higher than the respective 1 and 50 mg/dm3 standards for copper and nitrates. Other parameters fall within the EPA and WHO standards. Conclusively, sachet water manufacturers in the studied area who have not been able to meet the international standards for some parameters should be obligated and regulated by the proper authorities to appropriately treat their samples for conformity.

Amadi *et al.* (2015), also assessed the quality status of groundwater from hand dug wells in Minna city, North central Nigeria using geo-statistical methods. A sum of 18 samples were retrieved from hand dug wells and transported straight to the laboratory for physicochemical examination as first the objective of their research. The outcome of the examination presented shows that majority of the physicochemical parameters analysed where in line with the standards for safe drinking water recommended by the NSDWQ and WHO except the following parameters Mn, Fe, NO3, colour level in some places exceeded their respective recommended limit for a clean water. The detected high level concentration of Mn and Fe can be linked to bedrock dissolution through weathering processes whereas the deepened concentration of NO3 may be as a result of fertilizer usage by farmers in the study area. These parameters dissolving in water usually impacts the colour. The pH, showed that the water is slightly alkaline. The main water category in the study area as revealed in their study by Piper diagram, Stiff and Durov diagrams is Mg–HCO3-. The water quality index value shows that the quality of the water in the study area is poor whereas the result of metal pollution index showed that the water in the area is moderately polluted.

Another study was conducted by Ishaku (2012), on Seasonal differences of groundwater quality in Jimeta-Yola area was examined by selecting few chemical pollutants. The summed water samples retrieved from the studied area were 56 wells. The study applied the use of spectrophotometer Modelled 2010, USA in examining chemical from the collected water sample. The examined data from the laboratory were further analysed using Multivariate Statistical Analysis. The outcomes showed that pollutant loading transpired in the dry and rainy seasons. The fresh groundwater varied from slightly acidic to alkaline in rainy and dry seasons. The mean values of BOD, COD and chloride were found above the standards recommended for drinking water quality during the rainy season from hand dug wells and boreholes. The mean values of Nitrate and ammonium ion during dry and rainy seasons hand dug wells and boreholes were found above the standard limit of WHO. The spatial distribution of EC and TDS showed that the leachates from the disposal sites are major source of groundwater contamination. The differences in pollutant spreading is influenced by depth to water and depth of the well. There were increase in the concentration of COD, BOD, nitrate, phosphate and chloride, and decrease in level of ammonium ion with the depth of water in hand dug wells during the dry season, and COD, phosphate, ammonium ion, chloride and nitrate increase with the depth of water, and decrease in BOD during the rainy season. COD, ammonium ion and chloride increase with well depth, and decrease in COD, BOD, nitrate, phosphate in boreholes during the dry season while COD, BOD, nitrate, ammonium ion, phosphate and chloride decrease during the rainy season. Perfect correlation was revealed in the leachate samples during the dry season whereas nearly perfect correlation was revealed during the rainy season. The contaminants in both hand dug wells and boreholes showed strong positive correlations in both dry and rainy seasons which is an indication of shared source. Factor analysis shows that groundwater chemistry is controlled by human activities, saline, ammonification and natural mineralization. Appropriate waste dumping practice should be encouraged and boreholes should equally be drilled to deeper levels were recommended.

Similarly, Gbadebo, *et al.* (2018), examined the quality and suitability of local groundwater for home uses in Ifewara, Osun state. They collected one borehole groundwater samples and 26 hand dug wells sample which were taken for physicochemical examination. The examined data was received from the laboratory and Statistical analysis was further conducted on the data in order to categorize the water resource into separate group and sub-groups. Results from the study indicates that the cationic and anionic levels vary as follows: $Na^+$(0.2-3.5 mg/l), $K^+$ (0.1-15.1 mg/l) $Ca^{2+}$ (16-96 mg/l), HCO3 - (16-176 mg/l), $Mg^{2+}$ (3-104 mg/l), $NO_3^-$(0.18-11.43 mg/l), $SO_4^{2-}$ ,(1.24-21.3 mg/l), $C1^-$ (2-52 mg/l), and $PO_4$(0.01-0.75 mg/l). The study also shows that the water is fresh with TDS value (avg. 93.8 mg/l) and a neutral pH (avg. 6.8) within the permissible range (6.5-8.5). Hydrogeochemical assessment of the groundwater discloses that it is primarily of the $CaHCO_3$ type while the remaining once belong to the Mixed CaMgCl type. The sample water chemistry was perceived to have been strongly subjective to dilution and weathering processes at shallow depth. The study concluded that the groundwater in Ifewara and environ is suitable for human consumption with a least salinity hazard making it suitable for irrigation usage.

Duvbiama and Egbuna (2013), equally investigated physicochemical properties of hand dug wells in the North western area of Akure, Nigeria. The study collected 36 hand dug wells for the examination of physicochemical parameters such as pH, temperature, EC, redox potential (Eh), TDS, Ca, Mg, Na, K, HCO3, Cl, SO4, total alkalinity, TH and acidity. The outcome of the analysed water samples from the wells revealed that all the wells except wells 8 and 31 have their samples within the WHO guideline value. The high concentration of the physicochemical parameters in wells 8 and 31 might be associated with geologic setup of these areas. The study states that majority of the inhabitants of the area rely on the water sources from the well for consumption and other domestic needs. Conclusively, all the sampled wells are suitable for consumption purposes excluding wells 8 and 31. Any source of drinking water should be sited not less than 35 meters away from all form of contamination sources and public awareness creation and education on health risk related with the consumption of polluted water as well as indiscriminate siting of wells should be avoided where strongly recommended.

Also in Onitsha city, water quality were evaluated by Charles (2014), to define the effect of urbanization on groundwater resources. Physicochemical parameters analysis were conducted on 15 well water samples collected using standard methods of titrimetric, photometric and spectrophotometry. ANOVA and simple correlation as a Statistical techniques were used to test stated hypothesis. The values of pH for the samples ranged from 3.33 to 6.06. Consequently, two-thirds of the samples from the boreholes revealed significant acidic character, whereas one-fifth of the sampled water revealed dilute characteristics. All the samples revealed high level melted chloride ion. Pains were taken to incorporate the likely sources of the perceived phenomena from previous studies, which adequately showed that urban development coupled with population growth and urban activities serve as a threat to groundwater contamination. The study recommended several mitigation actions including treating the water taken from the wells in situ before supply and drinking to assist in checkmating the occurrence of pollution of groundwater supplies in the study area and henceforth preserve a resilient water quality.

A systematic study was carried out by Aniekan (2018), in order to appreciate the spatial, temporal and seasonal changes of the hydrochemical processes regulating the water chemistry in Cross River State, Nigeria. This is based on the point that existing aquifers are susceptible to pollution and no complete study existing in the literature to address this challenge. Groundwater samples were retrieved for a 3 year duration from 12 sites to cover three micro seasons which are the wet, dry and transitional dry seasons. Mean, media, maximum, minimum, standard deviation as conventional statistics were used for the analysis including correlation and factor analysis were executed by means of statistical package (STAISTICA) and spreadsheet in Microsoft Excel were all applied for the data analysis. The Results of the research shown that the groundwater samples were moderately acidic (pH 4.01–7.57), fresh (TDS < 1000 ppm) and soft–hard (hardness 8.67–194.38 mg/l). The following physicochemical parameters: Na, Ca, Mg, HCO3, Cl and SO4 of the groundwater samples had concentration below the WHO maximum limit Where the concentrations of As, Cd, Cr, Cu, Cu, Mn, Pb and Zn were also below the WHO maximum limit. Nevertheless, no limits were given by WHO for Co and Mo. The richness of main cations and anions were in the following order: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $Cl^{-} > HCO_3^{-} > SO_4^{2-}$ for all the diverse sampling scenarios. Explanation of the investigative data revealed predominance of water types such as $Na^{+}$–$Cl^{-}$ > $Ca^{2+}$–$Cl^{-}$ > $Ca^{2+}$– $HCO_3^{-}$. Chemical data show that regardless of the scenario considered, the water chemistry is controlled by silicate and carbonate weathering, brine dissolution, ion exchange, biological and anthropogenic activities. Similarly, the results recommend good quality water for consumption and agricultural uses based on national and international guides and standards. The study further recommend constant monitoring and treatment for acidic and high nitrate water which will help in protect against future contamination and sustainable application of the groundwater resources.

Similarly, Iyama and Edori (2014), studied the water quality of the Imonite Creek in Ndoni, River State by choosing some water quality parameters. These include BOD, phosphate, DO, TDS, pH, nitrate, temperature and turbidity. Although heavy metals such as Mn, Fe, Pb, Zn and Ca were studied, they recorded unimportant and trace amounts. The creek water was explored for a duration of eight months by means of five stratified sampling stations of A, B, C, D and E. The study employs standard techniques for the examination of the water quality parameters. The result revealed the mean values for the selected water quality parameters in the sampled months of June, September, November and January were BOD 0.27, 0.28, 0.33 and0.33 mg/l; DO 3.8, 3.78, 2.72 and 2.73 mg/l; pH 7.43, 7.53, 7.03 and 6.95; Temperature 26.70, 26.40, 26.08 and 24.94$^0$C; TDS 27.20, 26.40, 28.00 and 28.00 mg/l; Total phosphate 0.28, 0.37, 0.09 and 0.05 mg/l nitrate 0.88, 0.74, 1.28 and 0.97 mg/l; Turbidity 134, 138, 334 and 337 NTU respectively. Nevertheless, low pollution possibilities as a result of negligible values were recorded, the creek water is not clean due to the turbidity and aesthetics but safe for other profitable uses. The study concluded by emphasising the necessity to locally regulate the ejection of waste into the creek waters particularly during the dry season where ponds like are left as a result of the landscape of some marked stations. In other to improve it, there must be enforcement by the local authorities to ensure strict compliance by the inhabitants. Additionally, the investigation of the water quality of Imonite creek may function as a reference line meanwhile, no related studies have previously been carried out and the result can serve as a baseline for the government to resolve water challenges of the large populace of the local dwellers.

While Ganiyu *et al*. (2016) studied groundwater pollution due to leachate movement in a solid waste disposal site in Ibadan South West of Nigeria, they applied both geophysical and hydrochemical techniques. The major objectives of the paper were to delineate groundwater pollution as a result of leachate infiltration and thus valuation of quality of groundwater from immediate hand dug wells adjoining the disposal site for consumption purposes. A sum of ten resistivity traverses were attained of the interior and exterior of the disposal site by applying Wenner configuration with continuous electrode separation ranging from 5 to 25 m. RES2DINV and RES3DINV softwares were applied in inverting and processing of 2D resistivity data. Geochemical and hydrochemical facies of groundwater samples collected were analysed according to APHA standards and Piper Trilinear software respectively. The inverse resistivity models of the subsurface from 2D and 3D imaging showed little resistivity value less than 10 Ω m assumed to be leachate while 3D inverse sections permit demarcation of leachate, weathered layer, and bedrock and leaching path from the disposal site. The level of migration was more obvious in the southern part of the dumpsite. Therefore there could be potential contamination of low groundwater system as disposal site get old. The outcome of the physicochemical data examine revealed that the samples were within the limits of WHO/NSDWQ for consumption. Nonetheless, most of the investigated parameters with higher values were noticed in well 1 due to its closeness to the disposal site and well 10 due to its closeness to agricultural activities environment. Explanation of Piper diagram revealed $CaHCO_3$ to be dominant facies in the region whereas alkaline earth metals ($Ca^{2+,}Mg^{2+}Ca^{2+,}Mg^{2+}$) and weak acids ($HCO_3^-$, $CO_3^-$) are and the major cations and anions during both rainy and dry seasons. Groundwater in the study area is of fresh, hard and alkaline in nature. Resistivity technique should be repeated and accompanied by chemical evaluation of groundwater samples from immediate hand dug wells adjoining the disposal site should be embraced for identifying the future position of leachate plume in space and time.

## 2.5 Determination of Microbiological Parameters of the Hand Dug Sampled Well water.

Dan *et al.* (2018) also examined the bacteriological quality of the drinking water used by the inhabitants of Sô-Ava centred on the Beninese standards and those established by WHO. According to the research in rural and peri-urban places of Benin where community water supply systems are nearly nor in existence, the people drink water of numerous sources of unidentified qualities. A sum of 67 groundwater samples were investigated in July, 2017 rainy season and in January, 2018 dry season for certain bacteriological parameters using the standard procedures. The result from the laboratory analysis were calculated using spreadsheet in Microsoft Excel and then further processed using XLSTAT 17 statistical programme and likewise descriptive statistical technique of analysis were applied. The results of the evaluation showed that the bacteriological analyses indicated a high total aerobic Mesophilic flora pollution, faecal coliforms, Escherichia. Coli (*E. coli*) faecal enterococci in 89.55%, 82.09%, 50.75% and 70.15% of the examined water samples respectively. The proportion of faecal enterococci to faecal coliforms showed that the source of faecal contamination was anthropological in 59.7% of the water samples and animal in 40.3% of the water samples. Therefore, the study concluded that the bacteriological examination indicated that 89.55% of the water pumped is of doubtful quality and hence does not conform to the water quality criterions recommended by WHO and the Republic of Benin. Conversely, the study recommended that sanitation measures should be adopted. Consumption water ought to be purified by numerous family through chlorination process for the populace affected and household awareness campaign on the implementation of basic hygiene and sanitation measures have as well been recommended for hygiene and sanitation services.

Correspondingly, in the same study by Samuel *et al.* (2016) assessed the levels of selected microbial water quality parameters in 15 hand dug wells in Bolgatanga of Ghana. The impacts of seasonal changes and closeness to contamination sources on the concentrations of certain parameters of the hand dug well water samples were examined and descriptive statistical technique of data investigated were applied. The results revealed that, total and Faecal coliforms in the 15 sampled wells surpassed the WHO recommended limits for clean water during the dry season. There was increased in the concentration level of Total coliform and faecal coliform during the rainy season and attributing this to percolation of storm water. Consequence of the distance from contamination sources was as well obvious on faecal and total coliform counts, as the concentration reduces with increasing distance from contamination origin. The study concludes that the qualities of the water samples were negatively impacted by the circumstances of the immediate environment. Therefore, the wells water are not fit for consumption purposes as long as they are not treated appropriately. The Study recommended that the wells should be disinfected before usage. Similarly the wells in the study area should be located not less than 30 metres away from any source of contamination to avoid runoffs and other impurities from polluting the wells during rainy seasons and finally education and application of regulations on safe drinking water by the Ghana Standards Authority be intensified.

Eseoghene *et al.* (2013), conducted a study to determine the microbiological quality of drinking water sources in Fulani settlement in Gidan Kwano, Minna, Niger state. The study collected 30 water samples cumulatively from streams, wells and tap sourcess to assess for Total coliform and total viable counts (TVC) by means of multiple tube fermentation tests and the pour plate technique respectively. The Isolates were recognized using standard biochemical laboratory tests whereas statistical package for the social sciences (SPSS) version 16 were applied for the data calculation. The results showed that all the water sources were contaminated with high coliforms above the limits given by the Standard Organisation of Nigeria (SON) including total viable counts for all the water samples collected were also found above the limit of 100 cfu/ml. Most Probable Number (MPN) of coliforms count ranged from 3 MPN/100ml to 1100 MPN/100ml. All the samples collected from various water sources were polluted by the following bacterial pathogens *Citrobacterdiversus*, *Citrobacterfreundii, Klebsiellapnuemoniae, Proteus vulgaris, Salmonella enteric* and *Serratiamarcescens*. The result of study indicates contamination of all the water sources in the study area. The paper recommended that Hygiene practices ought to be improved so as to decrease pollution by microbial flora and well head covering or casing should be provided for all the wells around the localities to decrease external sources pollution.

Coliform examination was also conducted in the same studies by Ndamitso *et al.* (2013) in their work, the coliform examination of carefully chosen packaged water, else called "sachet pure water" were carried out. The results gotten were compared with EPA and WHO standards limits for drinking and recreational water. The pure water pH values, excluding Sabo Best which had 6.26 ± 0.02, were within the stated EPA/WHO standards of 6.50 - 8.50. The coliform levels of Federal University of Technology Minna (FUTMin) was 75.00 ± 2.00, Happy Days had 75.00 ± 2.00 and Carry More had 23.33 ± 0.33, based on the MPN, the sachet pure water were not fit for drinking since they could also contain other bacteria associated in gastro-intestinal water borne diseases. Conclusively, water vendors in Minna ought to be obligated to use safe groundwater sources like appropriately covered wells and boreholes in order to reduce contamination by faecal bacteria as recommended.

Amadi *et al.* (2015) in the same studies also assessed the quality status of groundwater from hand dug wells in Minna metropolis, using geo-statistical method for microbiological analysis. The presented analysed result indicates total coliform concentration in some places to exceed their respective recommended limit for a safe drinking water. The occurrence of total coliform in sample water is a sign of faecal contamination due to poor sanitation. Hand dug wells should be sited far away from septic tanks, boiling of the water in areas with heavy bacterial contamination before use and excellent hygiene practices were recommended.

Ishaku (2012), on Seasonal changes of groundwater quality in Jimeta-Yola area also investigated some microbes. The study retrieved 56 water samples and applied titrimetric and membrane filtration procedures for bacteriological analysis in the laboratory while Multivariate Statistical Analysis were employed for the analysis of data processed from the laboratory. The results showed that the mean coliform counts exceeded the recommended WHO limit in both seasons of shallow and deep aquifers. There were decline in coliform with depth of water in shallow aquifer during the dry season, and decline in coliform during the rainy season. There was also decline in coliform in deep aquifer during the dry season. Coliform indicated no depth control during the same period. Best environmental waste disposal practices were encouraged and drilling deep boreholes were similarly recommended.

Victoria and Ismail (2011), stated that in Nigeria, insufficient supply of pipe borne water is a major challenge; therefore numerous homes have wells as a primary source of water for the household uses. They evaluated 40 wells in Agbowo community for the investigation of Total Aerobic Bacteria Counts (TABC) and Total Coliform Counts (TCC). The position and distances of wells away from septic tanks were measured using the Global Positioning System (GPS) device and a tape rule respectively. All the samples from the wells had high TABC of 4.76±1.41 log CFU/mL and TCC of 2.29±0.67 log CFU/mL counts which surpassed the international given standard of 0 per 100 mL of clean drinking water. There were no significant ($p$>0.05) differences in the microbial counts among protected and unprotected wells. The mean distance of 8.93±3.61m of wells from the septic tanks was below the limit of 15.24 m or 50ft given by USEPA. TABC multiplied with a decline in distance between the wells and septic tanks although not significant ($p$<0.05). A feeble positive correlation of r2 =0.021 resulted between the distance from septic tank and CC, while a feeble negative correlation of r2 = –0.261 was acquired between the TCC and TABC. The study highlights the necessity to established standards for the positioning of wells away from septic tanks at the same time bearing in mind all potential sources of well contamination as well as treatment of ground water before use.

Akaha and Christopher (2012), analysed bacteriological properties of groundwater samples from 19 shallow hand dug wells of about 10m deep in parts of Makurdi Metropolis which incorporate a major source of water for domestic uses. The study evaluated the quality in respect of the closeness of the hand dug wells to exposed solid waste dumpsites and some uncovered pit latrines. Results indicates that there is a concern of bacteriological contamination facing the hand dug well water which could be from the badly constructed pit latrines and unhealthy sanitary practices. The coliform count with a high mean value of 17 per 100 mg coupled with shallow water table, vadoze zone aquifer and uncased hand dug wells will likely intensify the risk of water borne infections in the future. The study recommended that appropriate authorities in the states should support the campaign for sanitation of the environment, proper siting and building of pit latrines, and best environmental practices on litter and sewage dumping by the people. Specifically, the termination and transformation of the open disposal site and selection of some to function as protected landfill.

Farouq *et al.,* (2018), determined the effects of septic tank on the quality of groundwater from hand dug Wells. Water samples were retrieved from ten hand dug Wells across Effurun for the examination of faecal coliform. The results showed the existence of faecal coliform in all ten sampled locations ranging from 10.70 -29.00 cfu/100ml. The study concluded that there was possible contamination in the hand dug wells caused by the septic tank as a result of its closeness to the Wells, the distances between septic tanks and Wells did not meet the minimum recommended distance of 50ft, including the fact that some of the Wells do not have Well head covers. The sample water the ten various places were not safe for drinking. Therefore, it alarms severe community health concerns to the inhabitants of these region. Boiling of water before use was greatly recommended in other to remove faecal coliform.

### 2.6 Mapping the Distribution of Groundwater Pollutants

Annapoorna and Janardhana (2015), studied the suitability of groundwater quality of 22 wells sited in the rural areas surrounding Ingaldhal defunct copper mine in Chithradurga district of Karnataka for consumption purpose created on a number of water quality parameters. Standard procedures for physicochemical examination of samples from groundwater were used. Spatial distribution maps were set for the particular parameters using Geographic Information System (GIS). The results of examined samples revealed the following concentration ranging between pH 7.61-8.34, EC 950-3120 μS/cm, TH 410-1400 mg/l, TDS 594-1913 mg/l, $F^-$ 0.15-1.43 mg/l, $NO_3^-$ 14-162 mg/l, $HCO_3^-$ 417-574 mg/l, $SO_4^2$- 68-286 mg/l and $Ca^{2+}$ 59-150 mg/l, $Mg^{2+}$ 49-250 mg/l, $Na^+$ 38-290 mg/l, $K^+$

6-58 mg/l. The ionic dominance for the major cations and anions were in the order of $Mg^{2+}$ >$Na^{+}$ > $Ca^{2+}$ > $K^{+}$ and $HCO_3$- > Cl- > $SO_4^{2}$- > $NO_3$- > $Fe^{-}$ > $F^{-}$ > $CO_3$- respectively. Majority of the samples studied exceeded the limit set by both WHO (2011) and Bureau of Indian Standards (BIS) authorities for drinking water. GIS capabilities were used to categorize zones with suitable groundwater quality for consumption purpose. The Gibbs diagrams displayed that the groundwater samples fall both in the rock and evaporation dominance fields as well as nearly 18% samples fell outside the defined fields signifying incorporated mechanisms for hydrochemistry such as intensive weathering and low rates of evaporation in addition to input from the human activities. The plots on the piper diagram indicated that groundwater of the Ingaldhal and neighbouring regions consists of 4 hydrochemical categories, these categories includes, Ca-Mg-$HCO_3$ category (n=9), Ca-Mg-$SO_4$ (n=6), mixed category, Ca-Na-$HCO_3$(n=6) and Na-Cl category (n=1). The study conclusively mentioned that groundwater samples of different parameters shows that groundwater in several part of the study area is chemically unfit for consumption purpose as well as recommending constant monitoring of the quality of the groundwater in the area as more pumping of groundwater might escalate the values of some of the parameters such as EC, TDS, Mg2+, NO3- and F and depreciate the water quality in near future which eventually will prove to be devastating for the inhabitant residing in that area.

Ponniah *et al.* (2012) conducted similar studies on Spatial Analysis on Groundwater Quality Investigation in Tamilnadu North Chennai, India. The study collected 26 samples from open wells and boreholes and investigated for geochemical differences and quality of groundwater during pre and post monsoon periods. Water quality single feature maps were produced for groundwater properties such as TDS, Hardness, Corrosivity ratio, Chloride/Bi-carbonate ratio, Stuyfzard's Grouping, and salinity using GIS. Groundwater quality of north Chennai has been investigated using combination of terrain layers such as lithology, rainfall, landforms, soil and drainage. Results were compared with WHO and Indian standard Institution for drinking water standards which shows that all samples investigated were not fit for drinking purposes. Based on the study several places during pre-monsoon season, water quality is above the desirable limit while during post monsoon season the water is suitable. Seawater interference occurred in several places. The study reveals that quality of ground water varies because of extra rainwater restoring into the groundwater system through permeation. The study concluded that the degree of decline in water quality is so disturbing that an individual needs to think on what will occur in a decade when no any sustainable conservation is practiced. The paper recommend that the declining of ground water quality ought to be monitored by restoring groundwater through rainwater collecting and monitoring seawater interference and that the present fresh groundwater resources must be maintained appropriately.

Similar studies were carried out by Adnan and Iqbal (2014), using Spatial Analysis to assess the groundwater quality in the Peshawar district, Pakistan. According to them GIS based analysis was conducted in Peshawar district so as to assess the susceptibility of groundwater contamination. To evaluate the objectives 105 groundwater quality samples were retrieved from the study location. The study employed spatial statistical methods and spatial interpolation to map out the spatial and directional distribution of every single parameter by means of ArcGIS 10.1. The result showed that a strong positive correlation of TH was found with Alkalinity at 0.7, calcium at 0.6, Magnesium at 0.8, and $Cl^-$ at 0.7. Similarly, positive correlation of 0.7 was found between $Cl^-$ and Magnesium. Conclusively, all the parameters except $NO_3$ and pH were seen to be greatly accumulated in the core city as well as in the Northeast and Southeast area of the region. The study recommends that water management plants should be set up at numerous localities to simplify supply of drinking water for the people.

Saleem *et al.* (2016), analysed the underground water quality of Greater Noida region, Uttar Pradesh (U.P), India employing WQI. The study collected nine physicochemical parameters such as Calcium, $Cl^-$, $SO_4$, Magnesium, TH, Fluoride, $NO_3$, TDS and Alkalinity from 10 various sites in the year 2015. This study reveals 90% water samples were to be good quality and only 10% of the water samples falls under moderately poor class. The WQI ranges from 16.49 to 64.65. The study recommended that the Well water be treated before consumption and also the area be safeguarded from pollution.

Naser *et al.* (2016) stated that fluorosis remains to be a widespread problem in Yemen. Additional regions are becoming affected by fluorosis in various areas of the nation. As a problem they tried to investigate the origin of fluoride (F-) in the groundwater of the negatively impacted areas through an investigative study of three places in the southern area of the upper valley Rasyan, governorate of Taizin Yemen. The study inventories and collected 93 Well samples from various aquifer. The results of the investigated parameters formed the attribute data base for analysing and mapping of spatial distribution of f- in groundwater samples of the study place using Map info GIS software. The average concentration of f- in Al-Dabab and central region ranges from 0.85 mg/l to 2.83 mg/l as minimum and maximum respectively. The areas whose f- concentration exceeded the WHO limit value of 1.5 mg/l are the central and Al-Hawban area with the values of 82.76% and 75% respectively. The sewage and garbage are the major human source of water pollution with natural pollution by the water rock interaction. The main challenges are absence of appropriate treatment of the sewage and absence of good drainage structure in the study area. The study recommends immediate need for awareness creation to inform young Yemenis about fluorosis and simple intervention actions to avoid long term health implications.

Basavarajappa and Manjunatha (2015), stressed that Water is the major source for engineering, domestic, agricultural, industrial, and multipurpose uses which impacts surface as well as groundwater capacity. The study location is within the semiarid region and regularly experiencing shortage of water and quality challenges. The existing study produces the primary data to map the spatial difference of groundwater quality in Precambrian solid rock topography of Chitradurga District through Geo-informatics method. Pains have been taken to assess the sum of 50 typical groundwater samples (C1 to C50) collected from wells in various parts of the study location in April, 2012 during pre-monsoon period to evaluate its parameters such as F-, $NO_3^-$, Carbonate ($CO_{3-}$), Cl-, Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Sodium (Na+), $SO4^{2-}$, Iron (Fe), Potassium (K+), TDS, Potential of Hydrogen (pH) and TH. Groundwater quality is seen to be more controlled by rock-water contact & residence time of water in aquifers and affected by both humans and geogenic influences at various locations. Each lithological units, water bodies, farming lands and major features are mapped and digitized using IRS-1D, PAN+LISS-III satellite data through GIS programme in other to evaluate the potential pollution of groundwater quality by rock-water contacts, agro-chemicals and storing & movement of water. This paper emphasises the capabilities of Geo-informatics method in preparation of more constant and precise baseline info forecasting the groundwater quality in Precambrian hard rock topography of the study area; which is an appropriate model in similar geological environments.

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 Materials

The primary data source that were used for the present study include the following instruments: personal observations, photographs, Global Positioning System (GPS), water samples test, field work and water sampling form. The secondary data were sourced from Journals, Maps, Articles, thesis, online materials, electronic books, NESREA, NSDWQ, WHO and research studies).

**Table 3.1 List of Equipment**

| Serial No. | Materials | Purpose |
|---|---|---|
| 1 | Digital Camera | Taking Photos |
| 2 | Measuring Tape | Measuring Depth |
| 3 | Rope | Measuring Depth |
| 4 | GPS Garmin 76Xc Model | Recording Coordinates of sample locations |
| 5 | Tags | Labelling sample |
| 6 | Pencils and other writing materials | Data Recording |
| 7 | Base Maps | Mapping and Locating Sample wells |
| 8 | Plastic Bottles | Collecting water sample |
| 9 | Cellophane | Used to cover the plastic Bottles |
| 10 | Well water sampling form | Field Data recording |
| 11 | Thermometer | Taking Temperature Reading |
| 12 | Plastic Coolers (ice chest) | Storage of water samples |

**Source**: Authors Data Compilation 2019

### 3.1.1 Sample collection

Fresh samples of Hand-dug well water were collected from the randomly selected wells that are not less than 100m apart, using passive sampling (zero purge) method. The samples were collected in October 2018 for rainy season and March 2019 for the dry season. All the sampling containers were washed with distilled water and then washed again with the target water before sampling. The fresh samples of groundwater were collected manually in a clean 1 L plastic container from Maitumbi (MB), Maikunkele (MK), Chanchaga (CH) and Morris (MR). Transparent polythene were placed on each of the containers with a tight fitting lid to make them air tight. All the necessary attribute of the well were recorded on the water sampling form. The containers were labelled accordingly and stored in the plastic coolers (Ice chest) filled with Ice cubes (Plate I) and transported immediately for physicochemical and microbiological laboratory analyses at Jesil Pharmaceutical Limited, Minna Niger State. Table 3.2 describes the location of water samples collected.

Plate I. Various Samples Collection from the Study Area

**Table 3.2 Description of Sampling Sites for Rainy and Dry Seasons**

| Serial No. | Sample Code rainy season | Sample Code dry season | Sample Site | Location | Well Depth in Metres | Coordinates of sample Point |
|---|---|---|---|---|---|---|
| 1 | MK. 1 | MK. 13 | Maikunkele | Besides Danyalidi Filling Station | 2.5 | N09$^0$41´06.3´´ E006$^0$28´27.9´´ |
| 2 | MK. 2 | MK. 14 | Maikunkele | Solidmark Filling Station | 6.5 | N09$^0$41´10.0´´ E006$^0$28´27.4´´ |
| 3 | MK. 3 | MK. 15 | Maikunkele | Anguwan Dami Dami | 15 | N09$^0$41´11.8´´ E006$^0$28´24.1´´ |
| 4 | MR. 4 | MR. 16 | Morris | Beside Morris Islamiya | 4.2 | N09$^0$35´55.0´´ E006$^0$32´36.0´´ |
| 5 | MR. 5 | MR. 17 | Morris | Gidan Baban Danladi | 3.94 | N09$^0$35´50.4´´ E006$^0$32´39.0´´ |
| 6 | MR. 6 | MR. 18 | Morris | Gidan Alhaji Awiza | 5.3 | N09$^0$35´49.1´´ E006$^0$32´43.4´´ |
| 7 | CH. 7 | CH. 19 | Chanchaga | Wadata Gidan Mai Kifi | 4.0 | N09$^0$32´46.6´´ E006$^0$34´45.2 |
| 8 | CH. 8 | CH. 20 | Chanchaga | Central Mosque Alade Junction | 3.8 | N09$^0$32´26.8´´ E006$^0$34´44.1´´ |
| 9 | CH. 9 | CH. 21 | Chanchaga | Vegetable Market | 2.5 | N09$^0$32´15.7´´ E006$^0$34´46.2´´ |
| 10 | MT. 10 | MT. 22 | Maitumbi | Gidan Angulu Councilor | 10.4 | N09$^0$38´29.3´´ E006$^0$34´44.8´´ |
| 11 | MT. 11 | MT. 23 | Maitumbi | Gidan Maman Rahma | 5.3 | N09$^0$38´33.4´´ E006$^0$34´47.4´´ |
| 12 | MT. 12 | MT. 24 | Maitumbi | Gidan Anoka Ismail | 5.90 | N09$^0$38´35.5´´ E006$^0$34´43.2´´ |

**Source**: Authors Data Compilation 2018

### 3.1.1.1 Sample size

Three (3) samples were randomly collected from each of the selected study areas making it 12 samples during the rainy season and 12 samples during the dry season. Therefore, a total of 24 samples were collected from the selected study areas: (Maitumbi (MB), Maikunkele (MK), Chanchaga (CH) and Morris (MR) during the rainy and dry season. The Garmin GPS 76Xc model were used to take the latitude and longitude position of each well that was chosen.

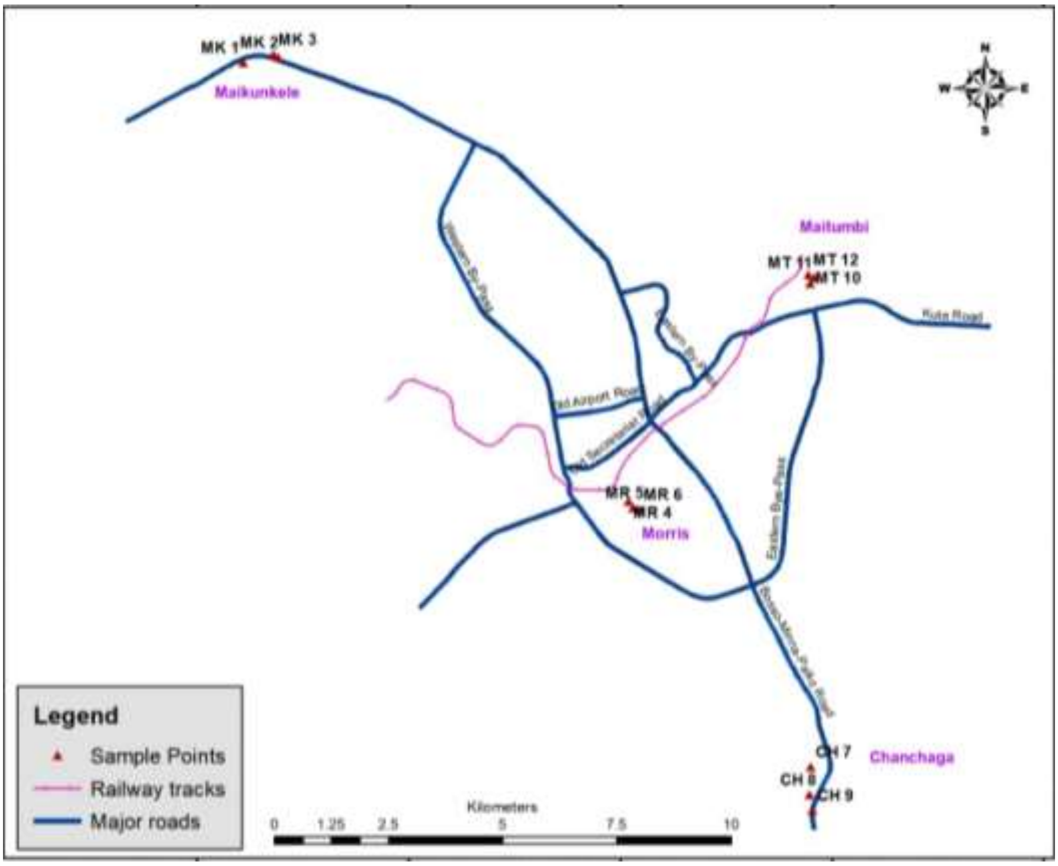


**Figure 3.1 Sample Collection Points in the Study Area**
**Source:** Author's Field Work Map, 2019

## 3.2 Method of Laboratory and Data Analysis

In this unit, the samples were analysed for relevant water quality parameters in one of the laboratories available in Minna, Niger State. The physicochemical and Biological analysis were determined including the method that were adopted for data analyses for each of the research objectives are described below.

### 3.2.1 Determinant of physicochemical parameters and analysis

The Physicochemical parameters of the water samples were analysed in accordance with National Environmental Energy Research Institute's (NEERI, 1999) standard analytical procedure for water analysis.

#### 3.2.1.1 Appearance

The beaker containing 100 ml of the sample was compared with the standard distilled water as provided in order to verify the clearness of the water sample.

#### 3.2.1.2 Odour

The odour was determined by filling the 100 ml of the sample into a clean and odourless bottle with the stopper inserted in the mouth of the bottle. The bottle were shaken vigorously for 5-10 seconds then the odour was detected by removing the 789 stopper at the mouth of the bottle.

#### 3.2.1.3 Temperature

The temperature of 100 ml of the sample were determined using a thermometer.

#### 3.2.1.4 Turbidity

The Nephelometer (Turbidometer) were calibrated according to manufacturer's operating instructions and one sample were ran with at least one standard in the instrument range that were used. The sample were agitated until the air bubbles vanish then pour the sample into the cell. The turbidity value expressed in NTU units were read from the display unit.

#### 3.2.1.5 Electrical conductivity

The conductivity probe were washed by rinsing with distilled water and then scoured with a soft tissue paper. The conductivity meter probe were dipped into a beaker holding 50 ml of the sample and the value displayed in µs/cm were documented.

#### 3.2.1.6 pH

The pH meter were calibrated using buffers 7.0 and 4.0. The pH electrode were dipped into a beaker having 100 ml in it and the displayed value was documented.

#### 3.2.1.7 Total dissolved solids (TDS)

The conductivity meter probe were inserted into 50 ml of the sample and the value shown were documented. TDS were calculated by multiplying the conductivity value with a conversion factor of 0.67.

#### 3.2.1.8 Total suspended solids (TSS)

To determine TSS, a filter paper were washed with 20 ml of distilled water and dried in an oven at 105$^{o}$C for 15 minutes. The filter paper were allowed to cool and then the weight were documented as B. The filter paper were dampened with 10 ml of distilled water and 50 ml of the already stirred water sample were measured and filtered through the dampened filter paper. The filter paper used were transferred to an oven set at 100$^{o}$C and left for 15 minutes. At the expiration of 15 minutes, the filter paper were left to cool down and weighed. The weight were documented as A. The value of TSS of the water sample were calculated thus:

$$\text{Mg suspended solids/L} = \frac{(A-B) \times 1000}{\text{Volume of sample}} \tag{3.1}$$

Where A = Weight of filter paper + dried sample

B = Weight of filter paper.

### 3.2.1.9 Alkalinity

A 100 ml of the water sample were delivered into a 250 ml conical flask and 2 drops of phenolphthalein indicator were added and stirred gently. No colour change were detected. Two drops of methyl orange were added, a yellow colour was detected and the solution were titrated with 0.01M HCl until an orange colour appears. The final burette reading were documented.

Total alkalinity were calculated using the formula:

$$\text{Total alkalinity} = \frac{A \times N \times 50000}{\text{Volume of sample used (ml)}} \tag{3.2}$$

Where:

A = Total volume of standard acid used to the final endpoint

N = Normality of the new standardized acid used.

### 3.2.1.10 Acidity

A 50 ml of the water sample were poured into 250 ml conical flask and 2-3 drops of methyl orange were added. The solution in the conical flask was titrated against 0.02M NaOH until the solution was change to faint orange colour signifying the end point. The volume of the titrant was documented and the acidity were calculated as:

$$\text{Acidity} = \frac{\text{Volume 1 (V1) of titrant used (ml)}}{\text{Volume of sample (ml)}} \tag{3.3}$$

In order to calculate the phenolphthalein acidity, 2-3 drops of phenolphthalein indicator were added to the water sample above (that is, the one that change to faint orange colour) and carry on with the titration until faint pink colour develops in the solution (that is, the end point has reached). The end point was documented as volume 2 (V2) and total acidity were calculated thus:

$$\text{Total acidity} = \frac{V2 \times N \times 50 \times 1000}{\text{Volume of sample (ml)}} \quad (3.4)$$

**3.2.1.11 Chloride**

The chloride in the water sample were calculated as outlined in ASTM (2014, D512B). A 50 ml of the water sample were measured into 250 ml conical flask and the pH was adjusted to phenolphthalein end point (pH 8.3) using NaOH solution (10 g/L). A 1 ml of potassium chromate indicator were added and mixed thoroughly. The solution were titrated against 0.1M $AgNO_3$ solution drop wise from a 50 ml burette until a brick red colour persists throughout the sample. The blank analysis were carried out using distilled water. The chloride ion concentration were calculated using the formula below:

$$Cl^- \text{ (mg/ml)} = \frac{(V1-V2 \times N \times 35450)}{S} \quad (3.5)$$

Where:

V1 = Volume of titrant used for sample

V2 = Volume of titrant used for blank

N = Normality of $AgNO_3$

S = Volume of sample taken

### 3.2.1.12 Hardness

A 50 ml of the water sample were measured into a 250 ml conical flask and 2 ml of ammonium buffer solution (pH 10.9) were added followed by one drop of solochrome black T indicator. A wine-red colour were obtained after swirling. A standard EDTA (0.1M EDTA) were added slowly with continuous stirring until a sky blue colour end point is achieved. The blank were prepared with distilled water and carryout the test as explained before. The hardness were calculated thus:

$$\text{Hardness (EDTA) as mg } CaCO_3/L = \frac{(A-B) \times M \times 100 \times 1000}{S} \qquad (3.6)$$

Where:

A = Volume of standard EDTA solution required for titration of the sample in ml

B = Volume of standard EDTA (0.1M) solution required for titration of the blank in ml

M = Molarity of the EDTA solution (0.1M)

S = Sample volume for the analysis in ml

100 = Molar mass of $CaCO_3$

1000 = Conversion factor to Litre.

### 3.2.1.13 Sulphate

The sulphate in the water sample were determined using spectrophotometric method. One hundred millilitres (100 ml) of the sample were delivered into 250 ml conical flask follow by the addition of 20 ml of the magnesium chloride buffer solution and mix by stirring continuously. A spoonful of $BaCl_2$ crystals were added to the solution, timed and stirred for 5 minutes at a constant rate (speed). The solution were then poured into 10 mm cell and the absorbance were measured within 5 minutes at 420 nm. Sulphate ion concentration were calculated thus:

$$SO_4^{2-}\ mg/ml = \frac{mg\ SO_4^{2-}\ \text{from the graph} \times 1000}{\text{Volume of sample}} \quad (3.7)$$

$SO_4^{2-}$ concentration were determined from calibration curve of sulphates using its absorbance value. The sulphate in the water sample were determined using spectrophotometric method. One hundred milliliters (100 ml) of the sample were delivered into 250 ml conical flask follow by the addition of 20 ml of the magnesium chloride buffer solution and mix by stirring continuously. A spoonful of $BaCl_2$ crystals were added to the solution, timed and stirred for 5 minutes at a constant rate (speed). The solution were poured into 10 mm cell and the absorbance were measured within 5 minutes at 420 nm. Sulphate ion concentration were calculated thus:

$$SO_4^{2-}\ mg/ml = \frac{mg\ SO_4^{2-}\ \text{from the graph} \times 1000}{\text{Volume of sample}} \quad (3.8)$$

$SO_4^{2-}$ concentration were determined from calibration curve of sulphates using its absorbance value.

### 3.2.1.14 Nitrates

A 5 ml of the water sample in a test tube were immersed in iced water and 0.4 ml of a 100 g/l solution of potassium chloride were added follow by drop wise addition of 0.1 ml of diphenylamine solution with shaking and 5 ml of nitrogen-free sulphuric acid. The test tube were transferred to a water bath at 50$^{o}$C and left for 15 minutes. At the end of the 15 minutes, any blue colour in the solution is not more intensely coloured than that in a reference solution prepared at the same time in the same manner using a mixture of 4.5 ml of nitrate-free water and 0.5 ml of nitrate standard solution (2 ppm $NO_3$)

### 3.2.2 Determinant of microbiological parameter and analysis

The microbiological parameters of the water samples were analysed using standard laboratory testing methods.

#### 3.2.2.1 Isolation of bacteria

#### 3.2.2.2 Culture media preparation

The culture media used for the isolation of the pathogenic bacteria were Cetrimide Agar (for *Pseudomonas aeruginosa*), Mannitol Salt Agar (for *Staphylococcus aureus*), Salmonella Shigella Agar (for *Shigella dysenteriae* and *Salmonella typhimurium*) and Eosin Methylene Blue Agar (for *Escherichia coli*) while Nutrient Agar and Sabouraud Dextrose Agar were used for the isolation of non-pathogenic and fungi respectively. The media were prepared according to the manufacturer's instructions.

#### 3.2.2.3 Serial dilution

Serial dilution of 1:10 was prepared from each test tube containing fresh samples of groundwater acquired from Maitunbi (MB), Maikunle (MK), Chanchaga (CH) and Morris (MR) by taking 1 ml into 9 ml of sterilized buffer peptone water using sterile needle and syringe. This gave a dilution factor of $10^{-1}$ (Collins *et al.*, 1995).

#### 3.2.2.4 Inoculation and incubation of culture media

The sterilized culture media were inoculated with a loopful from the test tube containing a serial dilution of $10^{-1}$ using flamed wire inoculating loop and then incubated at 37$^{o}$C for 24-72 hours (Cheesbrough, 2010).

#### 3.2.2.5 Enumeration of pathogenic bacteria

The enumeration of pathogenic bacteria was done by multiplying the number of viable, visible, separated and distinct colonies with the reciprocal of the dilution factor and expressed as colony-forming unit per millilitre (cfu/ml). The plates whose colonies could not be counted were expressed as too numerous to count (TNTC) (Cheesbrough, 2010).

#### 3.2.2.6 Gram staining isolated pathogenic bacteria

A loopful of the culture medium was picked using a sterile wire loop and then transferred to a grease-free glass slide. A smear was made on the slide and allowed to air dry. The dried smear was passed through a flame to fix the organism on the slide and then flooded with crystal violet for 60 seconds and then washed off with tap water. Lugol’s iodine was added to the fixed organism and allowed to remain for 60 seconds, washed with tap water and was decolourised with acetone for 30 seconds. The acetone was washed off under running tap water after which it was counterstained with safranin for 30 seconds. The slide was washed with tap water, allowed to air dry; oil immersion were added and then viewed under oil immersion objective lens of the compound microscope. When examined under the oil immersion objective lens, the Gram reactions (purple/blue indicates Gram-positive organisms and red/pink indicates Gram-negative organisms) and the morphology of the organisms were revealed (shape: cocci, rods, or others) (Brooks et al. 2007; Cheesbrough, 2010).

The physicochemical results from the laboratory were generated in triplicates and analysed statistically using Statistical Package for Social Scientist (SPSS) Version 23 and Microsoft Excel 2013. One way analysis of variance (ANOVA) with Duncan posthoc analysis was used to show the level of significant difference between variables at ($p<0.05$) and independent t-test was used to analyse and compare the difference between rainy and dry seasons.

### 3.2.3 Mapping the distribution of groundwater pollutants

#### 3.2.3.1 Water quality index (WQI)

This concept guided us to know the degree of water contamination in any place at a specific period. In general, WQI are discussed for a particular and proposed use of water. In the present study, the WQI assessment were considered for drinking purposes and acceptable limit for the drinking water were 100 (Table 3). This suggests that WQI values for any parameter greater than 100 is unfit for drinking (Amadi *et al.* 2015). WQI is simply defined as a rating reflecting the combined influence of various water quality properties on the overall quality of water which is calculated for the suitability of consumption purposes (Batabyal & Chakraborty, 2015). WQI is a method for rating quality of water, is an effective tool for investigating spatial and temporal variations in the quality of groundwater and communicate the results on the level of quality to the concerned individuals and policy makers (Mishra and Patel, 2001)

Based on the literature reviewed WQI has been applied broadly and successfully in other to evaluate the quality of groundwater. It provide an understanding of water quality issues by integrating complex data and producing a value that defines water quality status (Al-hadithi, 2012). Horton (1965) was the first person to apply the idea of WQI then later advanced by Brown *et al.* (1970) and about five years later it was improved by Deininger (Scottish development department, 1975). The development of WQI for groundwater is described in several literature works by Ramakrishnaiah *et al.* (2009), Backman *et al.* (1998), Soltan (1999), khaleed (2011), (Rizwan and Singh, 2010) and Saeedi *et al.* (2009).

**Table 3.3 Classification of WQI**

| WQI Value | Class | Explanation |
|---|---|---|
| <50 | Excellent | Good for human health |
| 50–100 | Good | Fit for human consumption |
| 100–200 | Poor | Water not in good condition |
| 200–300 | Very Poor | Need attention before use |
| 300> | Unsuitable | Need too much attention |

**Source:** (Prasad & Kumari, 2008)

**3.2.3.2 Calculation of WQI:** The WQI were calculated using the Weighted Arithmetic Index method (WAI) (Caerio *et al*., 2005; Prasad & Kumari, 2008). In order to calculate the water quality index, the NSDWQ drinking water standard was used for the calculation of WQI when the NSDWQ (2007) limits were not available WHO (2011) standards for Alkalinity where employed. The WQI was computed using 4 steps calculation. First, weight (*w*i) was assigned to each of the selected nine parameters (pH, Turbidity, Conductivity, TDS, $Cl^-$, $SO_4$, $NO_3$, Alkalinity, Total Hardness) according to its relative importance in the overall quality of drinking water (Table 3.4).

The weights assigned to each of the parameter were used in several articles; Dhawde *et al.* (2018), Patel and Vadodaria (2015), Bodrud-Dozaa *et al.* (2016) and Ramakrishnaiah *et al.* (2009) and were adopted. The maximum of 5 was allocated to $NO_3$ because of its major importance in the valuation of water quality; least weight of 1 was allocated to Turbidity and Alkalinity because of their low consequential function. Other parameters were allocated the weights between 5 and 1 based on their relative importance in water quality valuation. Second, The Relative weights ($W_i$) of chemical parameters were calculated by applying the following equation (Ramakrishnaiah *et al.*, 2009).

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (3.9)$$

Where

$w_i$ are the weights of each parameters,

$W_i$ are relative weights, and

n is the number of parameters (Ramakrishnaiah *et al.*, 2009). The computed relative weights are given in table 3.4

Third, the quality rating scale qi was calculated and assigned for each chemical parameter using this expression: $qi = (C_i/S_i) \times 100$ (3.10)

**Table 3.4 Weights and Relative Weights of Chemical Parameters**

| Parameters | STANDARDS (*Si*) | Respective Authorities | Weights (*wi*) | Relative weights (*Wi*) |
|---|---|---|---|---|
| pH | 8.5 | NSDWQ | 4 | 0.143 |
| Turbidity | 5 NTU | NSDWQ | 1 | 0.036 |
| Conductivity | 1000 µS/cm | NSDWQ | 4 | 0.143 |
| TDS | 500 mg/l | NSDWQ | 4 | 0.143 |
| $Cl^-$ | 250 mg/l | NSDWQ | 3 | 0.107 |
| $SO_4$ | 100 mg/l | NSDWQ | 4 | 0.143 |
| $NO_3$ | 50 mg/l | NSDWQ | 5 | 0.179 |
| Alkalinity | 300 mg/l | WHO | 1 | 0.036 |
| TH | 150 mg/l | NSDWQ | 2 | 0.071 |
| | | | Σ *wi*= 28 | Σ *Wi*= 1.0 |

**Source:** Author's Compilation (2019)

A Quality rating scale ($q_i$) for each parameter were allocated by dividing its Concentration ($C_i$) in each chemical parameter in each water sample by its respective Standard value ($S_i$) according to guidelines (NSDWQ, 2007 and WHO, 2011) and the result was multiplied by 100.

Where: $q_i$ = *The quality rating of the ith parameter*

*Ci= Concentration of chemical parameter in each water sample in mg/l*

*Si = is the respective drinking water standard for each chemical parameters in mg/l.*

In other to compute WQI, the sub index (SI) is first determined for each chemical parameter, as given in equation 3

$$SI = Wi \times qi \qquad (3.11)$$

*SIi is the sub index of ith parameter;*

*Wi is relative weight of ith parameter;*

*qi is the rating based on concentration of ith parameter, and*

*n is the number of chemical parameters.*

Finally, the overall water quality index (WQI) presented in chapter four were calculated by aggregating the *SI* using the following equation:

$$WQI = \Sigma SIi \qquad (3.12)$$

In this way, statistical evidence provided additional information on analysed water sample results. The analysed data were represented using Graphs, tables and maps.

### 3.2.3.3 Spatial distribution of physicochemical parameters

The GIS was integrated to produce a map that includes data relating to water quality and its distribution over the study area. The results from laboratory and of the WQI were introduced into ArcGIS environment. Spatial analysis were carried out using Inverse Distance Weighted interpolation method (Change, 2012) to show the spatial distribution of water quality across the study area. The table 3.5 shows the summarised research methodology.

**Table: 3.5 Summary of Research Methodology**

| S/N | Objectives (s) | Types of Data Required | Sources of Data | Methods of Data Analysis |
|---|---|---|---|---|
| 1 | To Analyse the Physicochemical properties of the Hand dug Well water | Primary Data | Laboratory test examinations and analysis | One way ANOVA (mean & standard deviation) figures, tables and maps |
| 2 | To determine the microbiological properties of the Hand dug well water | Primary Data | Laboratory test, examinations and analysis | One way ANOVA (mean & standard deviation) figures, tables and maps |
| 3 | To Map the distribution of groundwater pollutants. | Primary and Secondary data | Objective A Laboratory and WQI results | Spatial analysis and Inverse Distance Weighted techniques (ArcGIS 10.2) |

**Source**: Author's Field compilation 2018

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

The results obtained from the investigation on groundwater variability in the study area based on the research specific objectives are described in this chapter. The results were acquired through careful laboratory and statistical analysis of the data whilst carrying out the study; output are presented in tables, figures and maps.

### 4.1 Analysis of the physicochemical parameters of the sampled hand dug well water

The physicochemical properties of the groundwater samples collected and analysed from the study area were general found to be below the recommended standard which were not of health significant.

#### 4.1.1 Seasonal variability in the physicochemical parameters

The mean values of the physicochemical parameters of hand-dug well for dry and rainy seasons and their comparison with NSDWQ (2007) and WHO (2011) standards for drinking water are presented in Table 4.1 which showed the seasonal changes of the physicochemical parameters of water samples within each location of MK, MR, CH and MT.

According to the result obtained from the laboratory, none of the samples had any objectionable colour or odour during the rainy seasons except one (8.3%) of samples collected from MR during the rainy season were brownish in appearance and two (16.6%) of samples collected from (MK and MR) and (MK and MT) during the dry season were brownish and slightly brownish respectively, this indicates that there was higher percentage of colouration obtained during the dry season than the rainy season. These might be due to the existence of coloured organic matter (primarily humic and fulvic acids) combined with the humus fraction of soil in the sampled locations. The colouration could also strongly be caused by the presence of iron and other metals, either as natural impurities or as corrosion products (Amadi *et al*., 2012). Health-based guideline value is not given for colour in drinking-water. (WHO, 2011).

Odour was detected in two (16.6%) of water samples collected from MR and CH during the rainy season and no odour was detected during the dry season. The odour presence in drinking water should be unobjectionable according to NSDWQ and WHO drinking water standard. The odour in the said water sample might be due to the presence of organic substance or increased microbial activity in the well water. Usually, the taste buds in the oral cavity senses the inorganic compounds of metals (magnesium, calcium, sodium, copper, iron, and zinc). Water is expected to be free of objectionable odour, hence, it should not be offensive to the common consumers (WHO, 2011).

From the result in Table 4.1, the pH from MK, MR, and CH well water samples were observed to be significantly ($p>0.05$) indifferent for both rainy and dry seasons respectively except for MT which is significantly ($p<0.05$) higher in the dry season with a mean value of 7.29 ±0.17 compared to its rainy season with the value of 6.52±0.09.

The pH mean values all fall within the NSDWQ and WHO recommended permissible values of 6.5-8.5 and 6.5-8.5 respectively. The pH values of the present study consequently does not lead to the dissolution of heavy metals in the study area. This studies is in agreement with the findings of Amadi *et al.* (2015) who evaluated

Groundwater Quality in Shallow Aquifers in Minna, Nigeria. The authors observed that pH mean values was 7.8 and well placed within the WHO (2006) acceptable values of

## Table 4.1 Seasonal Variability of Physicochemical Parameters of Minna and Environs

| PARA-METERS | MK | | MR | | CH | | MT | | NSDWQ MAXIMUM LIMIT | WHO LIMIT |
|---|---|---|---|---|---|---|---|---|---|---|
| | RAINY | DRY | RAINY | DRY | RAINY | DRY | RAINY | DRY | | |
| **PH** | 7.13± 0.23$^{a}$ | 7.67± 0.18$^{a}$ | 6.64±0.0.54$^{a}$ | 7.40±0.10$^{a}$ | 6.90±0.14$^{a}$ | 6.98±0.30$^{a}$ | 6.52±0.09$^{a}$ | 7.29 ±0.17$^{b}$ | 6.5-8.5 | 6.5-8.5 |
| **Temp** | 14.2±4.97$^{a}$ | 22.87±1.27$^{a}$ | 15.77±5.38$^{a}$ | 22.73±1.37$^{a}$ | 13.20±4.05$^{a}$ | 25.47±0.44$^{a}$ | 21.70±2.35$^{a}$ | 25±2.05$^{a}$ | Ambient | - |
| **Turbidity** | 0.00±0.00$^{a}$ | 2.31±1.65$^{a}$ | 1.30±1.30$^{a}$ | 3.65±3.15$^{a}$ | 0.00±0.00$^{a}$ | 0.00±0.00a | 0.70±0.70$^{a}$ | 2.10±2.10$^{a}$ | <5 NTU | 5 NTU |
| **E. Conductivity** | 366.67±24.04$^{b}$ | 533.67±13.33$^{a}$ | 496.67±201.69$^{a}$ | 386.67±74.24$^{a}$ | 230.00±43.59$^{a}$ | 133.33±23.33$^{a}$ | 236.67±29.63$^{a}$ | 336.67±112.60$^{a}$ | <1000µS/cm | 750 µS/cm |
| **TDS** | 245.67±16.10$^{b}$ | 359.57±8.93$^{a}$ | 332.77±135.13$^{a}$ | 259.07±49.74$^{a}$ | 154.10±29.20$^{a}$ | 89.33±15.63$^{a}$ | 158.57±19.85$^{a}$ | 227.80±74.61$^{a}$ | <500mg/l | 1000mg/l |
| **$Cl^-$** | 87.37±19.25$^{b}$ | 389.95±48.39$^{a}$ | 154.10±21.80$^{a}$ | 291.88±49.35$^{a}$ | 42.13±3.27$^{a}$ | 115.81±38.42$^{a}$ | 80.11±10.77$^{a}$ | 206.79±15.63$^{b}$ | <250mg/l | 250mg/l |
| **$SO_4$** | 6.21±0.13$^{a}$ | 3.28±0.82$^{a}$ | 12.59±0.70$^{a}$ | 16.02±1.31$^{a}$ | 0.64±0.08$^{a}$ | 8.60±2.31$^{a}$ | 9.99±0.31$^{a}$ | 15.66±5.17$^{a}$ | <100mg/l | 250mg/l |
| **$NO_3$** | 6.39±0.10$^{a}$ | 18.8±2.32$^{a}$ | 7.33±0.70$^{a}$ | 26.12±4.58$^{a}$ | 7.99±0.21$^{a}$ | 28.83±7.14$^{a}$ | 11.54±0.45$^{b}$ | 2.62±1.50$^{a}$ | <50mg/l | 50mg/l |
| **Acidity** | 80±21.79$^{a}$ | 81.89±21.22$^{a}$ | 63.07±29.69$^{a}$ | 104.27±36.71$^{a}$ | 46.67±10.93$^{a}$ | 78.15±17.44$^{a}$ | 95.00±22.91$^{a}$ | 92.82±15.88$^{a}$ | - | - |
| **Alkalinity** | 241.25±35.20$^{a}$ | 249.25±19.13$^{a}$ | 75.13±12.59$^{a}$ | 149.76±63.03$^{a}$ | 183.67±75.27$^{a}$ | 187.00±77.89$^{a}$ | 202.07±11.52$^{a}$ | 211.19±25.73$^{a}$ | - | 300mg/l |
| **TH** | 71.77±18.57$^{b}$ | 626.67±174.58$^{a}$ | 355.70±98.25$^{a}$ | 360.00±98.25$^{a}$ | 87.13±14.12$^{a}$ | 156.67±47.02$^{a}$ | 280.98±106.81$^{a}$ | 540.00±255.02$^{a}$ | <150mg/l | 500mg/l |
| **TSS** | 3.67±2.19$^{a}$ | 2.37±0.62$^{a}$ | 3.53±1.51$^{a}$ | 2.96±1.51$^{a}$ | 0.83±0.44$^{a}$ | 2.70±0.40$^{b}$ | 2.57±1.22$^{a}$ | 1.50±0.58$^{a}$ | <500mg/l | |

Values are represented as mean± SEM of triplicate determinations. Values with different superscript between two seasons for each location are significantly different (p>0.05) while superscript that are similar across the row shows no significant difference at (p>0.05). Where MK= Maikunkele, MR= Morris, CH= Chanchaga, MT= Maitumbi, NSDWQ= Nigerian Standard for Drinking Water Quality, WHO= World Health Organization

**Source:** Author's Field Compilation (2019)

6.5-8.5. pH is an important parameter in drinking water as it helps in determining the corrosivity of water (WHO, 2007). It is an important parameter in evaluating the acid–base balance of water and also an indicator of acidic or alkaline state of water status. (Meride and Ayenew 2016). The pH values found in water samples does not have any health implication (NSDWQ, 2007).

The Temperature values obtained from the four locations had no significant difference during both rainy and dry seasons (Table 4.1) and where found to be within the ambient range in temperature giving by NSDWQ and WHO (2011) temperature limit was not given. These findings does not agree with the results of Ojutiku *et al.* (2014) who Assessed water quality parameters and trace metal contents of drinking water sources in Minna Metropolis, reported that there were variation in the mean values of the temperatures obtained in various areas but were significantly different in temperatures and associated it to the weather of the study areas at that specific period. The variation of the present study may be that the seasons probably did not have any profound effect on temperature regardless of different timing in sample collection. Temperature is useful in assessing the quality of drinking water as it influences the overall quality of water (physicochemical and biological characteristics) including the rate of chemical reactions in the water body, decrease in the solubility of gases and improving the tastes and colours of water (Palamuleni and Akoth, 2015).

Turbidity values obtained from the study areas had no significant ($p>0.05$) difference between the two seasons of rainy and dry seasons. However the highest mean value of 3.65±3.15 NTU was recorded during the dry season for MR and was found below the recommended NSDWQ and WHO limits of 5 NTU (Table 4.1). Turbidity should ideally be lower than 5 NTU, since the appearance of drinking water with a turbidity of less than this value is normally acceptable to consumers. Turbidity may be seen as the level of transparency in water. It does not have a health based guideline (WHO, 2011). Amadi *et al.* (2015) who evaluated groundwater quality in shallow aquifers in Minna, reported a mean value of 3.8 NTU and added that turbidity values in some area were recorded higher than the recommended values of 5.0 NTU. The author's finding is not in agreement with the present studies. However, the low values in NTU in the study may be due to some of these wells had fairly well head cover thereby prevented suspended particles and other contaminants to enter into the wells from the surface or through leaching as observed (Mishra *et al.*, 2009).

Electrical conductivity is the ability of water to let electric current pass through it. It is written as micro mhos per centimeter (μ mhos/cm) (Srinivas *et al.*, 2011). When water is clean it does not conduct electricity and therefore conductivity of water is a function of ionic elements existing in that particular water (Amadi, *et al*., 2013).

Electrical conductivity were not significantly ($p>0.05$) different between the two seasons of rainy and dry seasons for all sampled locations. However, it is significantly higher with the mean values of 533.67±13.33 μS/cm during the dry season than the rainy season in well water samples collected from MK as indicated in Table 4.1. This value is found below the recommended standards of 1000 and 750 μS/cm giving by NSDWQ and WHO respectively. However, these studies is in disagreement with the findings of Amadi *et al.* (2015) who evaluated Groundwater Quality in Shallow Aquifers in Minna, North-Central Nigeria. The authors observed that the electrical conductivity ranged between 126 μS/cm to 600 μS/cm with a mean value of 169.4 μS/cm. The variation observed in this present study may be due to different water sampled analysed or increased in the amount of dissolved solids in water samples obtained during the dry seasons in MK which could determine the increase in electrical conductivity in the study area in Table 4.1, as the TDS increases during the dry season. These results however indicates clearly that well water in the study area was not considerably ionized and has the lower level of ionic concentration activity due to small dissolve solids.

The TDS were significantly ($p>0.05$) not different between the two seasons of rainy and dry seasons for all sampled locations. However, TDS is significantly higher having 359.57±8.93 mg/l during the dry season than the rainy season in MK (Table 4.1). The values where found below the standard limit of 500 and 1000 mg/l set by both NSDWQ (2007) and WHO (2011) respectively. These result is similar to the findings of Nazir *et al.* (2016) who classified drinking water quality index and identification of significant factors in lower Quartile (Q1) of Bhakkar district. The authors observed that TDS value was 370 mg/l and were within the WHO recommended limit of 1000 mg/l. Water has the ability to dissolve a wide range of inorganic and some organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulphates etc. These minerals produced unwanted taste and diluted color in appearance of water. This is an important parameter for the use of water. The water with high TDS value indicates that water is highly mineralized (Meride, and Ayenew, 2016).

The concentrations of $Cl^-$ obtained from the sampled well water in MK and MT is significantly ($p<0.05$) higher with a mean value of 389.95±48.39 mg/l and 206.79±15.63 mg/l during the dry season than the rainy season respectively. The $Cl^-$ values were below the NSDWQ and WHO standard limit respectively except the Concentration of well water sample in MK and MR which exceeded the NSDWQ and WHO permissible limit of 250 mg/l during the dry season (Table 4.1). These studies differs from Paul and Salifu (2015) who analysed some anions in well water in Minna Metropolis, Niger State, Nigeria. The authors observed that the mean results of samples of MK and MT were 65.4 and 137.12 mg/l respectively.

These differences in the present studies could be due to the differences in well water samples collected. Where $Cl^-$ concentrations are observed to be high in the environment, it is normally associated with high significant human activities (Frassetto *et al.*, 2008). $Cl^-$ is mainly obtained from the dissolution of salts of hydrochloric acid as table salt (NaCl), NaCO2 and added through industrial waste, sewage. $Cl^-$ is significant in metabolising the human body and other major physiological processes. The significance of $Cl^-$ in drinking water cannot be overstated. It provides a measure of protection against any contamination which may occur (Yisa *et al.*, 2012). Excess $Cl^-$ concentration may damage metallic pipelines and structure, as well as growing floras. (Meride and Ayenew, 2016). This parameter is however, not of health significant (NSDWQ, 2007; WHO, 2011). Nevertheless, according to Elaine (2017) and Frassetto et al. (2008) stated that excess $Cl^-$ level in the human system causes hyperchloremia, a situation evolving from electrolyte imbalance.  Even though $Cl^-$ is an essential electrolyte in the human system, it may become imbalance due to changes in the electrolyte levels in the blood stream of human resulting in dehydration and excessive function of the kidney which is the organ regulating this balance. This can lead to further problems such as vomiting, kidney failure, diarrhea, and even seizures and convulsions.

The results of $SO_4$ where significantly ($p<0.05$) not different between the two seasons of rainy and dry seasons for each location. However, MR had the highest mean of 16.02±1.31 mg/l during the dry season. The result exhibit that the concentration of $SO_4$ was far below the recommended limit of 100 mg/l and 250 mg/l as set by both authorities (Table 4.1). Paul and Salifu (2015) also reported a conflicting $SO_4$ mean value of 84.5

mg/l which was obtained in Minna Central in their analysed study of some anions in well water in Minna Metropolis, Niger State, Nigeria. The variation in the present study might be due to poor dissolution of salts of sulfuric acid which are found abundantly in almost every water bodies and no major negative impact of $SO_4$ on human health is reported (Meride and Ayenew 2016).

The $NO_3$ value obtained were not significantly ($p>0.05$) different between the two seasons of rainy and dry seasons for each location of MK, MR CH and MT. Nevertheless, MT had the highest value of 11.54±0.45 mg/l during the rainy season than the dry season. The values were below the NSDWQ and WHO permissible limit in drinking water of 50 mg/l. This studies is not in agreement with the findings of Paul and salihu (2015) and Amadi *et al.* (2015). The authors reported that the $NO_3$ value of 61.94 mg/l was recorded for MT and 33.2 mg/l was recorded for Minna, North Central respectively. The variation in the present studies could be due to temporal differences in well water samples collected and or very slow bedrock dissolution due to groundwater migration or may be due to pollution from fertilizer blending plant in part of the study area, which could serve as point source pollution to the ground water sources in part of the study area. The $NO_3$ are among the primary nutrients that are mainly responsible for the stimulation of the growth of macrophytes (aquatic plants) and phytoplankton (algae) (Paul and Salifu 2015). Higher level of $NO_3$ in drinking water result to methaemoglobinaemia (blue baby syndrome), goiter, birth malformation, hypertension and gastric cancer (Annapoorna and Janardhana 2015; Dan-Hassan *et al.,* 2012).

Acidity and Alkalinity results of the samples recorded from the study area were not significantly different for both seasons. Acidity permissible limit and health guideline value was not given. Alkalinity results of the samples recorded from the study area were not significantly different between seasons. The values were found lower than the WHO permissible limit of 300 mg/l (Table 4.1). These study is not in consonant with the findings of Amadi *et al.* (2014), who analysed physicochemical parameters of well water, reported that the Alkalinity mean value of 94.90 mg/l recorded in Edati Village, Niger State. The variation in the present study could be principally from carbonate minerals found in limestone dissolving in the aquifer of the study area. Alkalinity is a measure of water's ability to neutralize acids, and so alkalinity and acid are as well related to pH (Chris and Andrews, 2004). It is likely for water to become corrosive when the alkalinity level is lower. Alkalinity in water equal to or greater than 150 mg/L might contribute to scale (lime) formation in plumbing (Chris and Andrews, 2004).

TH showed no significant ($p>0.05$) difference in the well water samples for both rainy and dry seasons of location (MR, CH and MT) except the samples from MK where TH value was significantly higher with a mean value of 626.67±174.58 mg/l during dry season than the rainy season. However, the mean values of TH recorded in the study area between seasons have exceeded the NSDWQ except the TH mean values obtained during the rainy season from well water samples in MK and CH, while MK and MT exceeded the limits of 500 mg/l set by WHO (Table 4.1).

These studies is in agreement with Khwaja and Aggarwal (2014) who Analysed groundwater quality using statistical techniques in a case Study of Aligarh city of India reported that the TH of the water samples ranges between 197 to 608 mg/l. Most of the samples were found above the standard limit of (200 mg/l) set by BIS. TH is a measure of the capacity of water to the concentration of calcium and magnesium in water and is usually expressed as the equivalent of CaCo3 concentration. The degree Hardness of the water in MK and MT could be attributed to the concentration of Calcium and magnesium being the major constituents responsible for water hardness which results in dissolution of carbonate minerals such as calcite and dolomite (Basavarajappa and Manjunatha 2015). Hard water is a nuisance because of mineral buildup on fixtures and poor soap/detergent performance and high level of TH do not pose a health risk (WHO 2011). However, in some instances, where dissolved calcium and magnesium are high, water could be a major contributor of calcium and magnesium to the diet. Hard water is useful in the growth of children, if within the permissible limit (Khwaja and Aggarwal 2014).

TSS concentration was significantly ($p>0.05$) not difference between the two seasons of location (MK, MR and MT) except for the well water sample of CH which was significantly ($p>0.05$) higher with 2.70±0.40 mg/l in the dry season than the rainy season. The values in all locations for both seasons are by far below the NSDWQ recommended maximum permissible limit of 500 mg/l. No permissible standard for TSS established by WHO. A conflicting mean value of TSS up to 22 ± 26 mg/L was observed during the dry season at the urban site by Taiwo *et al.* (2015) in their Comparative Assessment of Groundwater Quality in Rural and Urban Areas of Nigeria. The authors were unable to compare the value with standard limit since it was not given by WHO (2008). The variation in this present studies could be due to very insignificant presence of variety of material including inorganic matter (silt and sediment) and organic matter such as decaying plant, animal matter and waste from sewage (Murphy 2007). TSS are solids in water that can be retained by filter.

### 4.1.2 Locational comparison of physicochemical parameters rainy season

The results of physicochemical parameters in Table 4.2 compares parameters across the four sampled locations during the rainy season. From the result MK had the highest pH of 7.13±0.23 while MT has the lowest pH of 6.52±0.09. There was no significant ($p>0.05$)

difference in pH level across all the sampled locations and the values were found within the pH maximum permissible limit of NSDWQ. All the pH values recorded where within the recommended range, therefore making it fit for drinking and domestic purposes. The pH Level across the location has no health implication (WHO, 2011).

MT had the highest temperature of 21.70±2.35 $^{0}$C while CH had the least temperature of 13.20±4.05 $^{0}$C. The mean values of temperature across all the sampled location had no significant ($p>0.05$) difference as compared across the four locations. All the temperature mean values where within the ambient temperature stated by NSDWQ needed for a good drinking water and were significantly not different. This could be as a result of frequent rainfall in the rainy season which brings about ambient temperature across the study area. The temperature level across the study area has no health implication (WHO, 2011).

The Turbidity across the locations was not significantly different in the concentration level. Nevertheless, Turbidity was not detected in MK and CH. The highest turbidity value of 1.30±1.30 NTU was recorded in MR and were within the recommended limit of 5 NTU giving by WHO. This means that the transparency of the sampled well water in the season across the location is good. This could be as a result of increase in the level of well water table due to groundwater recharge from abundant rainfall or absence of or low runoff. No health base guideline giving by WHO and this means the Turbidity has no direct negative impact on health, but can harbour microorganisms protecting them from

**Table 4.2 Comparison of Physicochemical Parameters between Locations of Minna and Environs during the Rainy Season**

| | MK | MR | CH | MT | NSDQW/ *WHO LIMIT |
|---|---|---|---|---|---|
| **Ph** | 7.13±0.23$^{a}$ | 6.64±0.54$^{a}$ | 6.90±0.14$^{a}$ | 6.52±0.09$^{a}$ | 6.5- 8.5 |
| **Temp** | 14.20±4.97$^{a}$ | 15.77±5.38$^{a}$ | 13.20±4.05$^{a}$ | 21.70±2.35$^{a}$ | Ambient |
| **Turbidity** | 0.00±0.00$^{a}$ | 1.30±1.30$^{a}$ | 0.00±0.00$^{a}$ | 0.70±0.70$^{a}$ | <5 NTU |
| **Cond** | 336.67±24.04$^{a}$ | 496.67±201.69$^{a}$ | 230.00±43.59$^{a}$ | 236.67±29.63$^{a}$ | <1000µS/cm |
| **TDS** | 245.67±16.11$^{a}$ | 332.76±135.13$^{a}$ | 154.10±29.21$^{a}$ | 158.57±19.85$^{a}$ | <500 mg/l |
| **$Cl^{-}$** | 87.37±19.25$^{a}$ | 154.10±21.80$^{b}$ | 42.13±3.27$^{a}$ | 80.11±10.77$^{a}$ | <250 mg/l |
| **$SO_4$** | 6.21±0.13$^{b}$ | 12.59±0.70$^{d}$ | 0.64±0.08$^{a}$ | 9.99±0.21$^{c}$ | <100 mg/l |
| **$NO_3$** | 6.39±0.10$^{a}$ | 7.33±0.70$^{a}$ | 7.99±0.21$^{a}$ | 11.54±0.45$^{b}$ | <50 mg/l |
| **AC** | 80.00±21.79$^{a}$ | 63.07±29.69$^{a}$ | 46.67±17.44$^{a}$ | 95.00±22.91$^{a}$ | – |
| **AK** | 241.25±35.20$^{b}$ | 75.13±12.60$^{a}$ | 183.67±75.27$^{ab}$ | 202.07±11.52$^{ab}$ | <*300 mg/l |
| **TH** | 71.77±18.57$^{a}$ | 355.70±98.25$^{b}$ | 87.13±14.12$^{a}$ | 280.98±106.81$^{b}$ | <150 mg/l |
| **TSS** | 3.67±2.19$^{a}$ | 3.53±1.51$^{a}$ | 0.83±0.44$^{a}$ | 2.57±1.22$^{a}$ | <500 mg/l |

Values are represented as mean± SEM of triplicate determination. Values with different superscript across a row are significantly different ($p>0.05$) while superscript that are similar across the row shows no significant difference at ($p>0.05$). Where * = WHO limit, MK= Maikunkele, MR= Morris, CH= Chanchaga, MT= Maitumbi, NSDWQ= Nigerian Standard for Drinking Water Quality, WHO= World Health Organization, $Cl^{-}$= Chloride, AC= Acidity, AK= Alkalinity

**Source**: Author's Field Compilation (2018)

disinfection. This can create difficulty in water treatment process and can also be a possible risk of bacterial in treated water (NSDWQ, 2007). There was no significant difference in the concentration level of electrical conductivity across the sampled locations and were found much below the standard limit of 1000 µS/cm NSDWQ (Table

4.2). However MR had the highest electrical conductivity this means that MR water sample had more ionic elements than other areas which makes it to be more conductive to electric than others.

TDS was not significantly different among the sampled locations during the rainy season. The highest values 245.67±16.11 mg/l of TDS have not exceeded the recommended standard value of 500 mg/l as stated by NSDQW (Table 4.2). The values acquired during the rainy season ranging from 154.10±29.21 to 245.67±16.11 mg/l across the study locations implies that the water is not mineralised as TDS is a function of organic and inorganic minerals (Meride and Ayenew, 2016). These findings on TDS does not have any health implications (NSDWQ, 2007) The $Cl^-$ concentration obtained from the water sample in MR was significantly higher with the mean value of 154.10±21.80 mg/l than levels obtained from other three locations. However, the values were found to be within the range of 250 mg/l as obtained from NSDWQ. The variation could be as a result of high significant human activities in the area than other locations (Frassetto *et al.,* 2008).

$SO_4$ concentration is significantly different across the areas having MR with the highest significant mean value of 12.59±0.70 mg/l while CH has the lowest $SO_4$ mean of 0.64±0.08 mg/l. The mean values of $SO_4$ are found to be less than the maximum permissible limit of 100 mg/l as given by NSDWQ (Table 4.2). The mean values reveals have no health implications (WHO, 2011). High $SO_4$ concentration in MR could be due to high level of dissolution of salt of sulphuric acid available in the aquifer of the well water sampled which might be less concentrated across other areas.

MT is significantly higher in $NO_3$ concentration with a value of 11.54±0.45 mg/l when compared across other areas in the rainy season (Table 4.2). However all the nitrate values were much lower than the recommended standard of 50 mg/l. The significant increase of nitrate in MT might be due to runoff and vegetation around the wells.

Acidity concentration of water samples across the locations shows no significant difference and acidity permissible limit was not giving by both NSDWQ and WHO. This parameter has no health consequences (WHO, 2011). The Alkalinity level is significantly different from across the study locations, having the highest significant value of 241.25±35.20 mg/l recorded for MK. The alkalinity level did not exceeds the recommended value of 300 mg/l as given by WHO. The high Alkalinity in MK indicates it abundance of carbonate minerals in limestone around the hand dug wells than across other locations of the study area. Therefore the level of alkalinity found in MK means that the hand dug well water could contribute to lime formation in plumbing (Chris and Andrews 2004).

According to Table 4.2, TH concentration shows that there was significant ($p<0.05$) difference in the hand dug well water samples in all four locations. MR has the highest significant ($p<0.05$) value of 355.70±98.25 mg/l and the least value of 71.77±18.57mg/l was recorded in MK. However, these values have exceeded the maximum permissible limit of 150 mg/l as given by NSDWQ and found below the WHO standard. The high level of hardness in these areas indicates higher dissolution of carbonate minerals than in other areas of lower TH. There is no any health implication for this parameter but since the level is found above the NSDWQ standard these areas are likely to experience excessive use of soap in water to get desired foam if used for washing. The TSS level found in the study area were not significantly different across the four locations and where far below the given standard of 500 mg/l by NSDWQ. There is no health implication for TSS.

### 4.1.3 Locational comparison of physicochemical parameters dry season

On the other hand, Table 4.3 compares the physicochemical result obtained across the study location during the dry season. The pH in MK had the highest value of 7.67±0.18 while CH had the lowest value of 7.67±0.18 according to the result in Table 4.3. The mean values of pH was significantly not different across the sampled locations and were found to be within the NSDWQ pH permissible limit of 6.5-8.5. The pH is neither Acidic nor Alkaline during the dry season across the study locations. The level is found suitable for drinking water

The mean values of Temperature was significantly not different across the sampled locations and the highest mean value of 25.46 ± 0.44 $^{0}$C was recorded for CH while MR had the least mean temperature of 22.73 ± 1.37 $^{0}$C. However, this value were within the ambient temperature which has no negative effect on drinking water or health (NSDWQ). The high temperature of well water sample recorded in CH could be due to the shallowness of the wells in that location, CH had the lowest well mean depth of 3.43 metres which is close to the subsurface and could have the impact of temperature than other areas of the study.

The mean values of Turbidity was significantly not different across the sampled locations. However, there was no Turbidity detected in CH while the highest mean value of 3.65±3.15 NTU was recorded for MR (Table 4.3) and all values were found below the permissible limit of 5 NTU as given by NSDWQ. The mean values obtained across the study area has no health implication and it is aesthetically acceptable by the consumers (WHO, 2011).

**Table 4.3 Comparison of Physicochemical Parameters between Locations of Minna and Environs during Dry Season**

| Parameters | MK | MR | CH | MT | NSDQW/ *WHO LIMIT |
|---|---|---|---|---|---|
| **pH** | 7.67±0.18$^{a}$ | 7.40 ± 0.10$^{a}$ | 6.98 ± 0.30$^{a}$ | 7.29 ± 0.17$^{a}$ | 6.5- 8.5 |
| **Temp** | 22.87 ± 1.27$^{a}$ | 22.73 ± 1.37$^{a}$ | 25.46 ± 0.44$^{a}$ | 25.00 ± 2.05$^{a}$ | Ambient |
| **Turbidity** | 2.31 ± 1.65$^{a}$ | 3.65 ± 3.15$^{a}$ | 0.00 ± 0.00$^{a}$ | 2.10 ± 2.01$^{a}$ | <5 NTU |
| **E. Cond** | 536.67 ± 13.33$^{b}$ | 386.67 ± 74.24$^{b}$ | 133.33 ± 23.33$^{a}$ | 336.67 ± 112.60$^{ab}$ | <1000µS/cm |
| **TDS** | 359.57 ± 8.93$^{b}$ | 259.07 ± 49.74$^{b}$ | 89.33 ± 15.63$^{a}$ | 227.80 ± 74.61$^{ab}$ | <500 mg/l |
| **$Cl^-$** | 389.95 ± 48.39$^{c}$ | 291.88 ± 49.35$^{bc}$ | 115.81 ± 38.42$^{a}$ | 206.79 ± 15.63$^{ab}$ | <250 mg/l |
| **$SO_4$** | 3.28 ± 0.82$^{a}$ | 16.02 ± 1.31$^{b}$ | 8.60 ± 2.31$^{ab}$ | 15.66 ± 5.17$^{b}$ | <100 mg/l |
| **NO3** | 18.80 ± 2.32$^{b}$ | 26.12 ± 4.58$^{b}$ | 28.83 ± 7.14$^{b}$ | 2.62 ± 1.50$^{a}$ | <50 mg/l |
| **AC** | 81.89±21.22$^{a}$ | 104.27±36.71$^{a}$ | 78.15±17.44$^{a}$ | 92.82±15.88$^{a}$ | – |
| **AK** | 249.25±19.14$^{a}$ | 149.76±63.03$^{a}$ | 187.00±77.89$^{a}$ | 211.19±25.73$^{a}$ | <*300 mg/l |
| **TH** | 626.67±174.57$^{a}$ | 360.00±200.33$^{a}$ | 156.67±47.02$^{a}$ | 540.00±255.02$^{a}$ | <150 mg/l |
| **TSS** | 2.37±0.6$^{a}$ | 2.96±0.91$^{a}$ | 2.70±0.40$^{a}$ | 1.50±0.58$^{a}$ | <500 mg/l |

Values are represented as mean± SEM of triplicate determination. Values with different superscript across a row are significantly different (p>0.05) while superscript that are similar across the row shows no significant difference at (p>0.05). E. cond. = electrical conductivity, * = WHO limit, MK= Maikunkele, MR= Morris, CH= Chanchaga, MT= Maitumbi, NSDWQ= Nigerian Standard for Drinking Water Quality, WHO= World Health Organization

**Source**: Author’s Field Compilation (2019)

The electrical conductivity was significantly the lowest in CH with the mean value of 133.33±23.33 µS/cm as compared across the location during the dry season. The electrical conductivity mean values of the study areas were found below the permissible limit of 1000 µS/cm. The low value obtained in CH indicates low mineralisation (dissolved solid) during the dry season than in other areas. This fact can be seen in Table 4.3 as TDS level dropped to 89.33±15.63 mg/l during the dry season than the rainy season which had influence on conductivity.

Across the locations TDS was sampled and analysed and the mean values obtained showed that CH was significantly different from other location as having the lowest value of 89.33±15.63 mg/l. All mean values were found below the permissible limit of 500 mg/l. The low values in CH as compared across other location could be due to low dissolution of organic and inorganic minerals in the dry season (Maride and Ayenew, 2016). There is no health implication at levels found in the sample (NSDWQ, 2007).

The highest $Cl^-$ concentration of the hand dug well water samples was recorded in MK with a value of 389.95±48.39 mg/l and MR had the lowest value of 115.81±38.42 mg/l. $Cl^-$ concentration across the sampled location were significantly different. The $Cl^-$ in MK and MR exceeded the permissible limit of 250 mg/l as giving by NSDWQ (Table 4.3). The highest concentration as obtained in Mk could be due to more dissolution of salts of hydrochloric acid as table salt (Yisa *et al.*, 2012) than obtained in other locations of the study area. $Cl^-$ has no health implication at level found in the drinking water and no health base guideline is giving. However, the inhabitant of MK and MR might experience change of taste in drinking water due to excessive chloride of more than 250 mg/l concentrations and could increase the rates of corrosion of metals in the distribution system if any (WHO, 2011) than other locations.

The concentration of $SO_4$ in MK was significantly different and had the lowest mean value recorded while the highest was recorded in MR with the value of 16.02±1.31 mg/l. SO4 is found far below the standard limit of 100 mg/l set by NSDWQ as given in Table

4.3. This finding in MK could be as a result of very low dissolution of salts of sulphuric acid as compared to other locations of study. The concentrate of $SO_4$ found in the samples across the location of the study does not have negative health implications.

The concentration of $NO_3$ was significantly lower with the value of 2.62±1.50 mg/ in MT as compared to other locations during the dry season. However, the $NO_3$ concentration across all locations were below the permissible limit as given by NSDWQ (Table 4.3) and does not pose any health risk to the consumer. The concentration of Acidity was significantly not different across all locations of the study area. However MR had the highest mean value of Acidity recorded. Acidity in water is known not to have health implication to the consumer, though the limit was not given by any of the organisation in Table 4.3.

The concentration of Alkalinity was significantly not different across all locations of the study area. However, MK had the highest concentration of Alkalinity during this period and was found below the recommended limit of 300 mg/l given by WHO. This findings indicates that MK could be dissolving more carbonate minerals available in limestones of the area than other sampled locations. There is no health guideline given by WHO as alkalinity does not pose health risk. The highest concentration of TH was recorded for MK. However, the mean values of TH obtained within the dry season across all the locations has exceeded the permissible standard limit of 150 mg/l as given by NSDQW. This indicate that the water samples obtained in these areas are loaded with calcium and magnesium which might cause the water of the area to be hard for drinking, as a consequence it will lead individuals to drink more water as it has lose the ability to quench taste for a long time. Hardness in water does not pose health risk (WHO, 2011).

MR had the highest concentration of TSS with the value of 2.96±0.91 mg/l while MT had the lowest value of 1.50±0.58 mg/l. There were no significant difference in the mean values across the locations of the study area. All the mean values were found far below the permissible limit of 500 mg/l and does not pose health risk. The result obtained in MR clearly showed that the water samples contains low organic and inorganic matter than other sampled areas resulting to lower TSS within the dry season.

## 4.2 Analysis of the Microbiological Parameters of the Sampled Hand Dug Well Water

The microbial analysis of the collected sample water from hand dug wells generally showed that the water were contaminated with one form of coliform bacteria or the other, which needs careful treatment before consumption.

### 4.2.1 Seasonal variability of the microbiological parameters

The counts of microbiological parameters of hand-dug well water samples for dry and rainy seasons and their comparison with NESREA (2011) microbial Standards for drinking water are presented in Table 4.4 which presents the seasonal variations of microbiological parameters within each location of MK, MR, CH and MT.

The occurrence of a set of bacteria known as coliforms in water samples serve as indicators of pollution (Azuonwu *et al.,* 2017). The main coliform among them is Escherichia coli (*E. coli*), which was isolated from the hand dug well water samples used in the present study and whose existence indicates the possible existence of other intestinal pathogens or pathogenic bacteria (Azuonwu *et al.,* 2017).

From the result in Table 4.4, *S. aureus* coliform was too numerous to count (TNTC) during the rainy season in MR while coliform count was not detected during the dry

**Table 4.4 Seasonal Variability of Microbiological Parameters of Minna and Environs**

| PARA-METERS | MK | | MR | | CH | | MT | | NESREA LIMIT |
|---|---|---|---|---|---|---|---|---|---|
| | RAINY | DRY | RAINY | DRY | RAINY | DRY | RAINY | DRY | |
| *S. aureus* | 40.00±10.00[a] | 460.00±277.37[a] | TNTC | ND | 86.67±29.63[a] | 26.67±14.53[a] | 90.00±5.77[a] | 23.33±14.53[a] | 0 |
| *P. aeruginosa* | 120.00±11.55[a] | 40.00±30.55[a] | 10.00±0.01[b] | 66.67±6.67[a] | ND | ND | ND | . ND | 0 |
| *E. coli* | 143.33±53.64[a] | 190.00±66.58[a] | 316.67±158.99[a] | 31.67±4.41[a] | 206.67±96.84[a] | 260.00±20.82[a] | 130.00±35.12[a] | 33.33±33.33[a] | 0 |
| *S. typhi* | TNTC | 336.67±173.24[a] | 16.67±8.82[a] | 10.00±10.00[a] | 43.33±29.63[a] | TNTC | 10.00±10.00[a] | 30.00±30.00[a] | 0 |

Values are represented as mean± SEM of triplicate determinations. Values with different superscript between two seasons for each location are significantly different ($p>0.05$) while superscript that are similar across the row shows no significant difference at ($p>0.05$). Where ND = Not Detected; TNTC = Too Numerous to Count, MK= Maikunkele, MR= Morris, CH= Chanchaga, MT= Maitumbi, NESREA= National Environmental Standard and Regulations Enforcement Agency,

**Source:** Author's Field Compilation (2019) season. There were no significant ($p>0.05$) difference in *S. aureus* mean coliform count between seasons from MK, CH and MT in all the well water samples. *S. aureus* coliform count in both seasons exceeded the NESREA (2011) microbiological limit for groundwater of 0 cfu/ml. These studies is not in consonant with Onyango et al. (2018) who examined the microbiological quality and contamination level of water sources in Isiolo County in Kenya, the authors observed that S. aureus were not detected in 35.29% of the ground water sources and *S.aureus* counts were significantly ($p\leq0.05$) different among the ground water sources. The variation in the present study which account for the high load of coliform count may be as a result of the shallowness of the wells to the earth surface which ranges from 2.5 to 15 meters deep as measured. These wells are shallow and could easily be contaminated from the surface of unhealthy and poor sanitised environment, (Plate II). As a consequence *S. aureus* is a gram-positive microorganism that is often associated with nosocomial infections (Azuonwu *et al.,* 2017) which are caused by nosocomial pathogens (bacteria, viruses and fungal) parasites (Hassan *et al.,* 2016).

**Plate II. A Typical Poorly Constructed and badly Managed Hand Dug Wells Environment Sampled at Maitumbi, MT3**

Bacteria are the most common pathogens responsible for nosocomial infections which are embedded in soil and water (Suresh and Joshi 2013). When people consume water contaminated with *S. aureus* they may come down with infections such as bloodstream infections, urinary tract infections and pneumonia. The problem with *S. aureus* infection is the issue of its resistance to beta-lactamase antibiotics including penicillin and methicillin-a derivative of penicillin. The presence of this coliform in drinking water thus calls for public health concern (Azuonwu *et al.,* 2017).

*P. aeruginosa* is significantly higher with the coliform count of 66.67±6.67 Cfu/ml during the dry season in MR than the rainy season while *P. aeruginosa* was not detected in CH and MT during both seasons. These result is far above the permissible limit of 0 cfu/ml given by NESREA (2011). These studies is similar with the findings of Okunye and Odeleye (2015) who investigated the bacteriology of well water samples from selected market locations in Ibadan Nigeria. The authors observed that *P. aeruginosa* count in Bodiga, Oje, Gbagi, Sango, and Molet-Bode Markets ranges from 14-16; 12-14; 22-16; 8-16 and 8-14 cfu/ml respectively except Oja Oba market where *P. aeruginosa* was not detected. In the present study this coliform isolates has similar contaminant source with S. aureus.

*P.aeroginosa* is a gram negative bacteria that is normally found within (water, soil and moist areas) environment belonging to the group referred to as Enterobacteriaceae. As a consequence they can cause illness such as watery and bloody diarrhoea, dysentery, urinary tract infections and when introduced into the bloodstream, they can lead to bacteremia (Azuonwu *et al.*, 2017) and if water used by such persons for drinking or bathing contains sufficient numbers of these organisms, they can produce various infections of the skin and the mucous membranes of the eye, ear, nose and throat (WHO 2011).

*E. coli* coliform count were detected in all the samples and were significantly ($p>0.05$) not different between the two seasons in each location respectively (Table 4.4). The *E.coli* count in both seasons far exceeded the NESREA (2011) permissible limit of 0 cfu/100ml. *E.coli* had been investigated by other researchers notably (Amadi *et al.* (2015); Onyango, *et al.,* (2018)). These result oppose the findings of Amadi *et al.* (2015) and Onyango *et al.* (2018). Amadi *et al.* (2015) evaluated groundwater quality in shallow aquifers in Minna, North-Central Nigeria and reported that the mean concentration of *E.coli* in Minna central were 0.20 cfu/100ml. Onyango *et al.* (2018) also reported from his findings that the mean *E-coli* counts were 22.9 % of the ground water samples. BH2A had the highest mean *E-coli* count of 205 cfu/ml while SW2A had the lowest mean *E. coli* count of 9 cfu/ml. The *E. coli* counts were significantly ($p \leq 0.05$) different among the ground water sources.

The presence of *E-coli* in the samples of the present study is an indication of faecal contamination of the hand dug wells and may be due to the inflow of sewage from the septic tanks into the close by hand dug wells and/or due to the proximity to the hand dug wells, as the distances between Wells and the septic tanks did not conform with the NESREA (Sanitation and Waste Control) regulations 2009 minimum recommended distance of 15metres. These group of bacteria are gram-negative organism and are usually found in the intestines of human beings and other warm blooded animals. Consumed contaminated water by *E. coli* results to disease such as typhoid, cholera, diarrhea and dysentery (Azuonwu *et al.,* 2017).

The *S.typhi* count is significantly TNTC during the dry and rainy seasons in MK and CH respectively, see Table 4.4. The result of *S.typhi* count is more than the NESREA (2011) permissible limit of 0 cfl/ml. These findings is in agreement with Ekelozie *et al*. (2018). According to their findings, *S.typhi* had the most occurrences in hand dug well water than other sources of water samples analysed and had the highest frequency of five (38.5%) compared to other salmonella isolates in different water sources. The variation in the present study could be attributed to poor environmental sanitation and hygiene around majority of the wells in the study area (Plate III) and possible runoff into the wells which could lead to faecal contamination as some of the local's children defecate in the open space around the well environment as observed.

**Plate III. A Typical Poorly Constructed and badly Managed Hand Dug Wells Environment Sampled at Maikunkele, MK1**

The *S.typhi* species is the principal cause of typhoid fever which can be spread through the consumption of the contaminated water (Ekelozie *et al.*, 2018) and also a common cause of gastroenteritis such as diarrhoea, vomiting, nausea and abdominal pain. Untreated cases could become chronic or fatal. The portal of entry for *S. typhi* is through ingestion of contaminated food and/or water contaminated with animal or human faeces. The infection is commonly treated with antibiotics such as Ampicillin, Chloramphenicol, Trimethoprim, Sulpha-methaxazole, and Cephalosporin (Ohalete *et al.,* 2011).

### 4.2.2 Locational comparison of microbial counts rainy season

The microbial result in Table 4.5 compares each microbial counts across the four sampled locations of MK, MR, CH and MT during the rainy season October, 2018. According to table 4.5 Staphylococcus aureus (S. aureus) detected in MR was significantly TNTC while the lowest coliform count of 40.00±10.00 Cfu/ml was recorded in MK when compared to other locations of the study area. This count has far exceeded the permissible microbial count of 0 Cfu/ml given by NESREA (Table 4.5). The high contamination by S. aureus in MR could be as a result of heavy anthropogenic activities around these hand dug wells and unkept hand dug well environment and lack of protective head cover for the hand dug Well could receive contaminants from the surface.

P. aeruginosa was significantly higher with the Microbial count of 120.00±11.55 Cfu/ml in MK during the rainy season than other as compared to other locations of the study. This microbial count has exceeded the limit of 0 Cfu/ml given by NESREA. The abundance of P. aeruginosa in MK could be as a result of poor sanitised environment and open wells.

The coliform count of E. coli was higher in MR than any other location of the study area during the rainy season, this has indeed exceeded the E. coli microbial count of 0 Cfu/ml as given by NESREA (2011). This high microbial count in MR may be due to nearness of the Hand dug wells to the septic tanks as observed than other wells in other areas of the study.

**Table 4.5: Comparison of Microbial Contamination between Locations during Rainy Season**

| PARAMETERS | MK | MR | CH | MT | NESREA LIMIT (Cfu/ml) |
|---|---|---|---|---|---|
| *S. aureus* | 40.00±10.00[a] | TNTC | 86.67±29.63[a] | 90.00±5.77[a] | 0 |
| *P. aeruginosa* | 120.00±11.55[b] | 10.00±10.00[a] | 0.00±0.00[a] | 0.00±0.00[a] | 0 |
| *E. coli* | 143.33±53.64[a] | 316.67±158.99[a] | 206.67±96.84[a] | 130.00±35.12[a] | 0 |
| *S. typhi* | TNTC | 16.67±8.82[a] | 43.33±29.63[a] | 10.00±0.001[a] | 0 |

Values are represented as mean± SEM of triplicate determination. Values with different superscript across the row are significantly different (p>0.05) while values with similar superscript across the row shows no significant difference at (p>0.05). ND = Not Detected; TNTC = Too Numerous To Count, MK= Maikunkele, MR= Morris, CH= Chanchaga, MT= Maitumbi, NESREA= National Environmental Standard and Regulations Enforcement Agency,

**Source:** Author's Field Compilation (2018)

The result in Table 4.5 shows that S. typhi was significantly TNTC in MK while MT had the lowest S. typhi coliform count of 10.00±0.001 cfu/ml in the rainy season. This microbial count has exceeded the 0 Cfu/ml limit giving by NESREA for this type of bacteria. This could be due open defecation around the well associated with high runoff into the wells (plate II) which was less as observed in other areas

### 4.2.3 Locational comparison of microbial counts dry season

The Microbial result in Table 4.6 compares each microbial counts across the four sampled locations of MK, MR, CH and MT during the dry season March, 2019. From the Table 4.6 MK had the highest *S. aureus* coliform count of 460.00±277.37 cfu/ml and the least coliform count was not detected in MR. The coliform count of *S. aureus* were not significantly (p<0.05) different across the four sampled locations. These coliform counts has exceeded the 0 Cfu/ml as given by NESREA (Table 4.6). The high microbial count of *S. aureus* in MR location than other location of the study area may be due to reduction in the volume of hand-dug well water as groundwater recharge is low associated with unhealthy hand dug Well environments as observed. *P. aeruginosa* was significantly higher in MR with the coliform count of 66.67±6.67 cfu/ml which has exceeded the NESREA limit of 0 Cfu/ml/. The cause for the high *P. aeruginosa* count in MR during the dry season than other locations of the study could be due to external contamination by wind erosion as the hand dug wells lack well head cover and also associated with different human activities.

**Table 4.6 Comparison of Microbial Contamination between Locations during Dry Season**

| PARAMETERS | MK | MR | CH | MT | NESREA LIMIT (Cfu/ml) |
|---|---|---|---|---|---|
| *S. aureus* | $460.00\pm277.37^{a}$ | $0.00\pm0.00^{a}$ | $26.67\pm14.53^{a}$ | $23.33\pm14.53^{a}$ | 0 |
| *P. aeruginosa* | $40.00\pm30.55^{a}$ | $66.67\pm6.67^{b}$ | $0.00\pm0.00^{a}$ | $0.00\pm0.00^{a}$ | 0 |
| *E. coli* | $190.00\pm66.58^{b}$ | $31.67\pm4.41^{a}$ | $260.00\pm20.82^{b}$ | $33.33\pm33.33^{a}$ | 0 |
| *S. typhi* | $336.67\pm173.24^{a}$ | $10.00\pm10.00^{a}$ | TNTC | $30.00\pm30.00^{a}$ | 0 |

Values are represented as mean± SEM of triplicate determination. Values with different superscript across the row are significantly different (p>0.05) while values with similar superscript across the row shows no significant difference at (p>0.05). ND = Not Detected; TNTNC = Too Numerous to Count, MK= Maikunkele, MR= Morris, CH= Chanchaga, MT= Maitumbi, NESREA= National Environmental Standard and Regulations Enforcement Agency,

**Source:** Author's field compilation (2019)

The coliform count *E. coli* and *S. typhi* was significantly higher significantly in CH during the dry season than other locations of the study area. This microbial counts has cross the limit of 0 Cfu/ml set by NESREA (2011). The high *E. coli* and *S. typhy* in CH could be due to leakages from latrines and sewages near the hand dug wells since most of the houses in CH where the samples were collected are clustered (built close together), which does not allow standard distance between the hand dug wells and latrines as observed.

## 4.3 Mapping the Distribution of Groundwater Pollutants

### 4.3.1 WQI of the groundwater samples

The results of WQI of the physicochemical parameters are presented in table 4.7. The seasonal variation of WQI values ranged from 27.6 to 67.2 and 34.5 to 110 for rainy and dry seasons, respectively. During the rainy season, nine (75%) of groundwater sample were in 'Excellent' water class and three (25%) were in 'Good' water class while in the dry season three (25%), eight (67%) and 1 (8%) of groundwater samples were in excellent good and poor water class respectively.

**Table 4.7 Water Quality Index for Rainy and Dry Season**

| Sample Points | WQI Rainy Season | Water Class | Sample Points | WQI Dry Season | Water Class |
|---|---|---|---|---|---|
| MK1 | 36 | Excellent | MK13 | 75.4 | Good |
| MK2 | 36 | Excellent | MK14 | 110 | Poor |
| MK3 | 40.3 | Excellent | MK15 | 82.2 | Good |
| MR4 | 64.2 | Good | MR16 | 67.7 | Good |
| MR5 | 67.2 | Good | MR17 | 92.2 | Good |
| MR6 | 41.2 | Excellent | MR18 | 53.2 | Good |
| CH7 | 34.2 | Excellent | CH19 | 54.7 | Good |
| CH8 | 29.4 | Excellent | CH20 | 34.5 | Excellent |
| CH9 | 27.6 | Excellent | CH21 | 37.9 | Excellent |
| MT10 | 42.9 | Excellent | MT22 | 44.2 | Excellent |
| MT11 | 54.4 | Good | MT23 | 99.8 | Good |
| MT12 | 35.1 | Excellent | MT24 | 52 | Good |

**Source**: Author's Field Compilation (2019)

The WQI of the present study revealed excellent, good and poor quality. The WQI indicates that the well water of the study area is good for human health and fit for human consumption except the well water sample from MK14 which indicated 'poor' water class during the dry season. Due to the fact that the values of the physicochemical parameters all fell within the recommended standards except TH led to the Excellent and good water class obtained in the WQI which is <100 according to Table 3.3.

The WQI maps are presented in figure 4.2a and 4.2b The groundwater sample points in the study area is shaded blue and green in Figure 4.2 indicating that the wells were in 'excellent' and 'good' quality classes. The dry season WQI map (Figure 4.2b) displays well water quality in blue, green, and red colour for excellent, good and poor water quality class respectively.

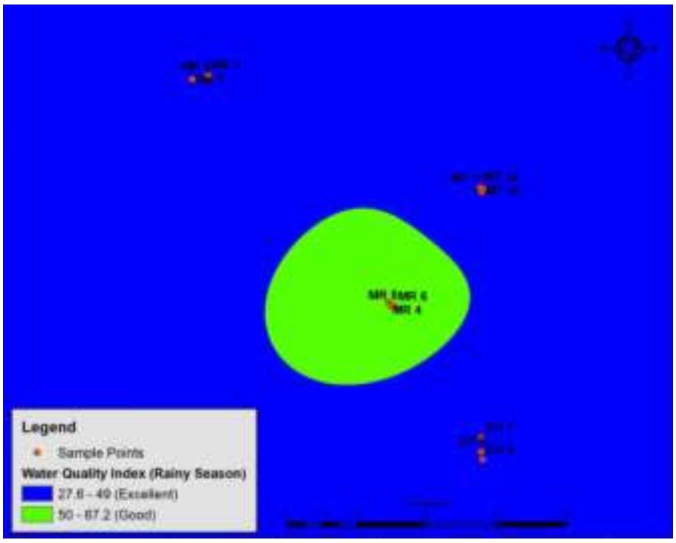


**Figure 4.2A Spatial Distribution of WQI for Rainy Season**

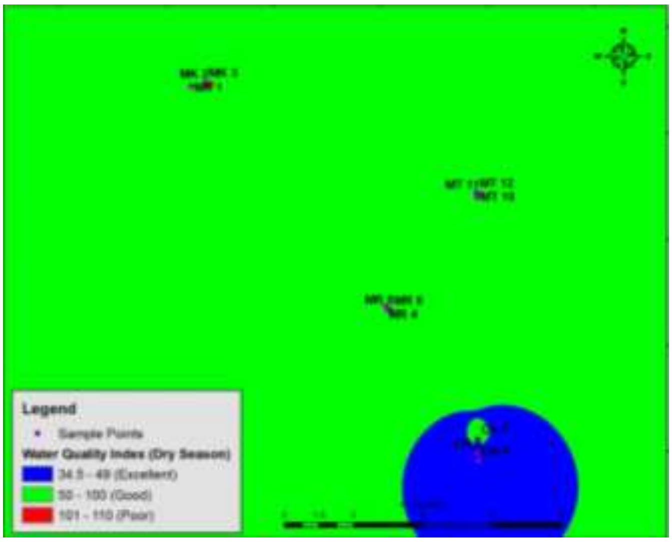


**Figure 4.2B Spatial Distribution of WQI for Dry Season**

The spatial distribution of WQI for rainy season in Figure 4.2A indicates that the groundwater samples in the northwest (MK), northeast (MT) and southeast (CH) are within the blue area of 'excellent' water class while the green area indicates groundwater samples from the Central area (MR) to be of 'good' water class quality. While the spatial distribution of WQI for dry season in Figure 4.2B indicates that the groundwater samples in the southeast (CH) and one sample point (MT10) in the eastern area (MT) shows groundwater sample were found within the blue area that are of 'excellent' water class. Second, in the central area (MR), northwest (MK) Northeast (MT) and part of (CH) in the southeast of the study area are within the green area of 'good' water class. Third, one hand dug well water sample (MK2) in northwest (MK) show 'poor' water quality which means the water is not in good condition as classify in Table 3.3.

There is a variation between the seasons of the WQI maps. During the rainy season (Figure 4.2A) the samples collected in the study area were all of 'excellent' quality class except two groundwater samples from the Central area (MR) in green colour and one from the western area (MT) which is not clearly shown in green colour on the printed map. The changes can be visually appreciated in the dry season's map of Figure 4.2B as all the areas initially of 'excellent' quality class reduced in quality to 'Good' water class in exception of southeast (CH) of the study area remained in excellent water category including one groundwater sample in the eastern area (MT) while in the northwest (MK) had one sample Point (MK2) categorised as 'poor' water. These spatial distributions of WQI seasonal variation from 'excellent' to 'good' water class is attributed to the general increase in concentration of parameters during the dry season across the study areas.

The presented WQI may be compared with initial work carried out in the same study area and with works carried out by researchers in different parts of the world (Amadi *et al.*, 2015; Srinivas and Nageswararao, 2013; Vasan-thavigar *et al.*, 2010). Amadi *et al.* (2015) used the WQI to evaluate groundwater quality in shallow aquifers in Minna, Nigeria. The WQI of their study area revealed that 33% of the total sample were excellent and good for drinking and 67% were poor to unsuitable water (unfit for domestic purposes).

### 4.3.2 Spatial distribution of groundwater parameters

The spatial distribution of groundwater physicochemical parameters can be appreciated as displayed in different thematic maps of Minna and environs. The concentration of different parameter can be viewed visually providing an understanding of the distribution across the study area. The laboratory analysis of hand dug well samples for pH revealed the highest values for rainy season to be 7.38 and were found to be highly concentrated in northern part of the study area (MK) and southeast (CH) (Figure 4.3A). While during the dry season groundwater samples revealed the maximum value for pH to be 7.87 and the spatial distribution of pH across the study area were found to be highly concentrated in MK (Figure 4.3B).

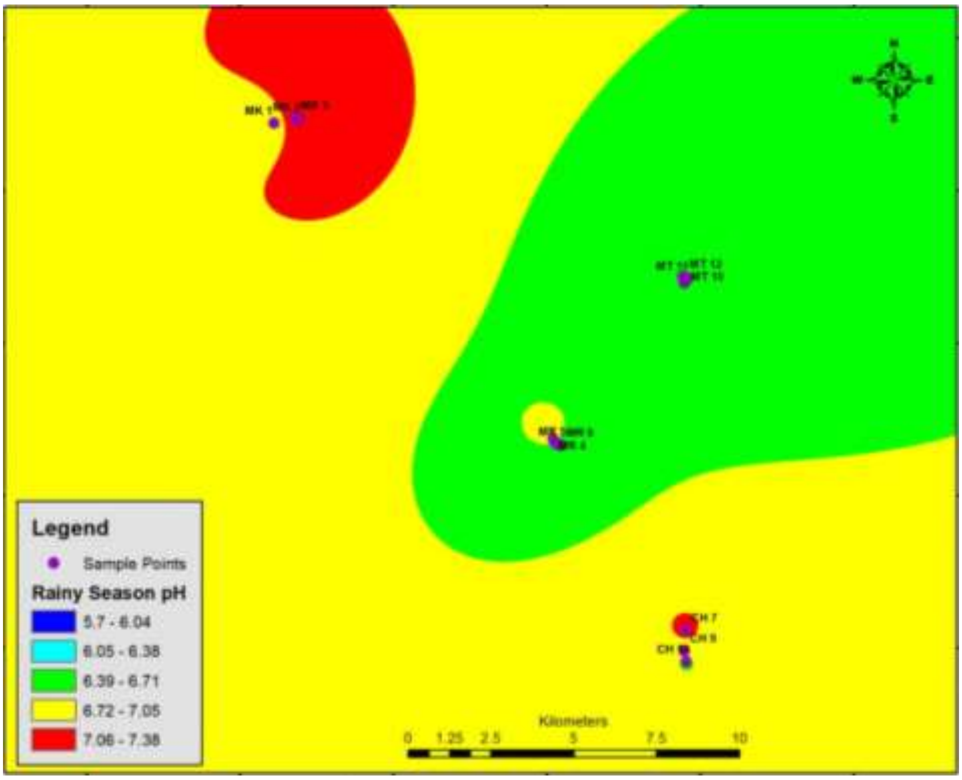


**Figure 4.3A Rainy Season Spatial Distribution of pH**

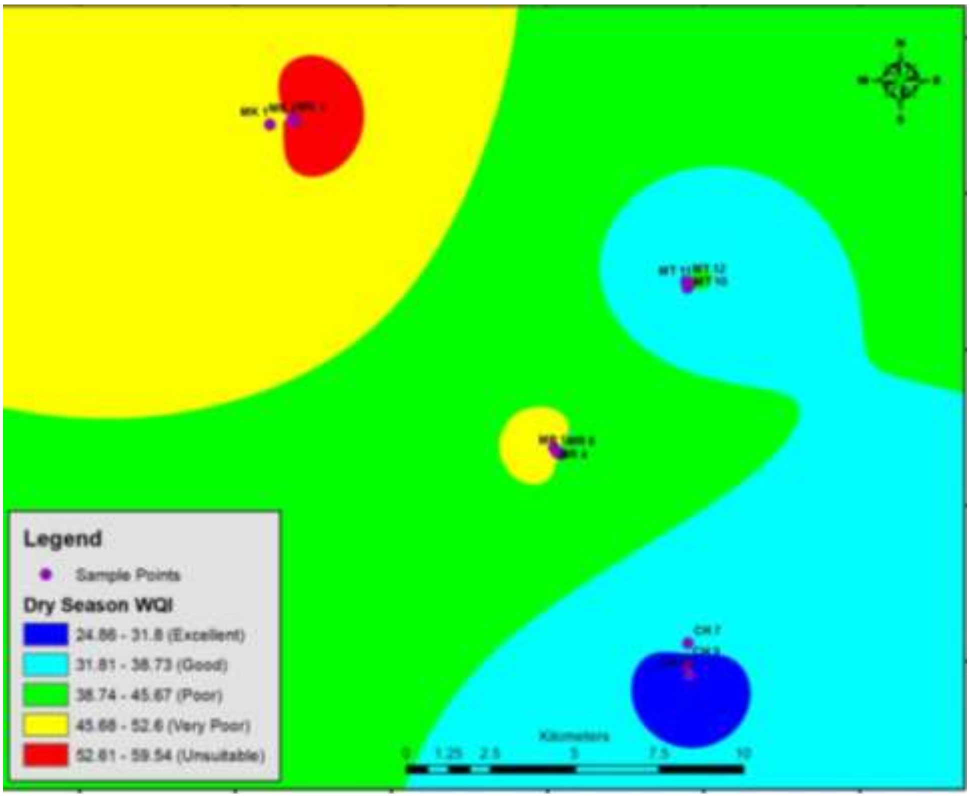


**Figure 4.3B Dry Season Spatial Distribution of pH**

The laboratory analysis of groundwater samples revealed the maximum value for Temperature during rainy season to be 25.08$^0$C and the distribution of the temperature across the area were found to be highly concentrated in MT (Figure 4.4A). While during the dry season the maximum value revealed for Temperature was found to be 28.78$^0$C and the temperature were majorly distributed in the northwest (MT) and CH in the southern part (Figure 4.4B).

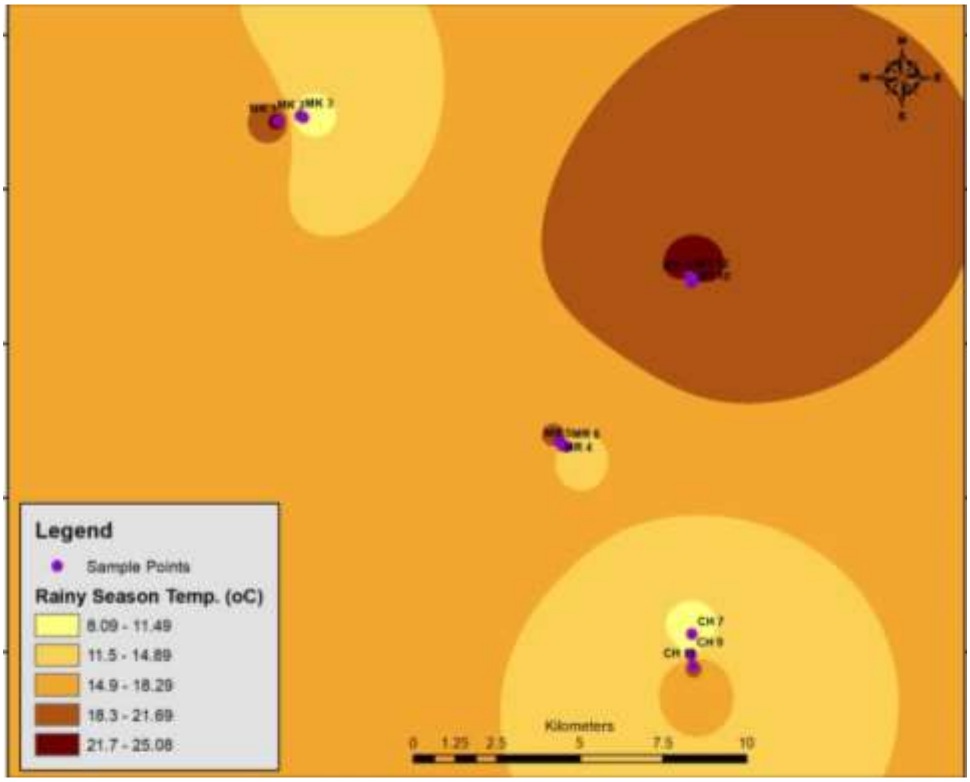


**Figure 4.4A. Rainy Season Spatial Distribution of Temperature**

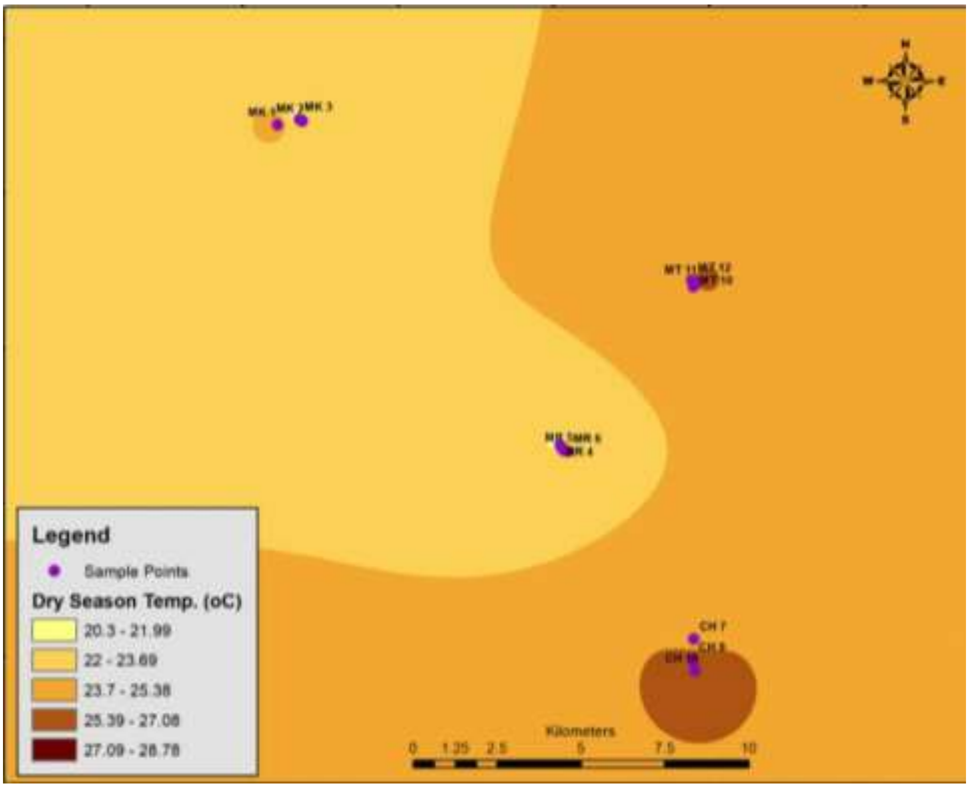


**Figure 4.4B. Dry Seasons Spatial Distribution of Temperature**

The laboratory analysis of groundwater samples revealed the maximum value for Turbidity to be 3.62 NTU. Turbidity was found to be concentrated in the central area (MR) during rainy (Figure 4.5A). While the dry season laboratory results of groundwater samples revealed the maximum value of 3.33 NTU for Turbidity and was also found to be concentrated in the central area (MR) during dry season (Figure 4.5B)

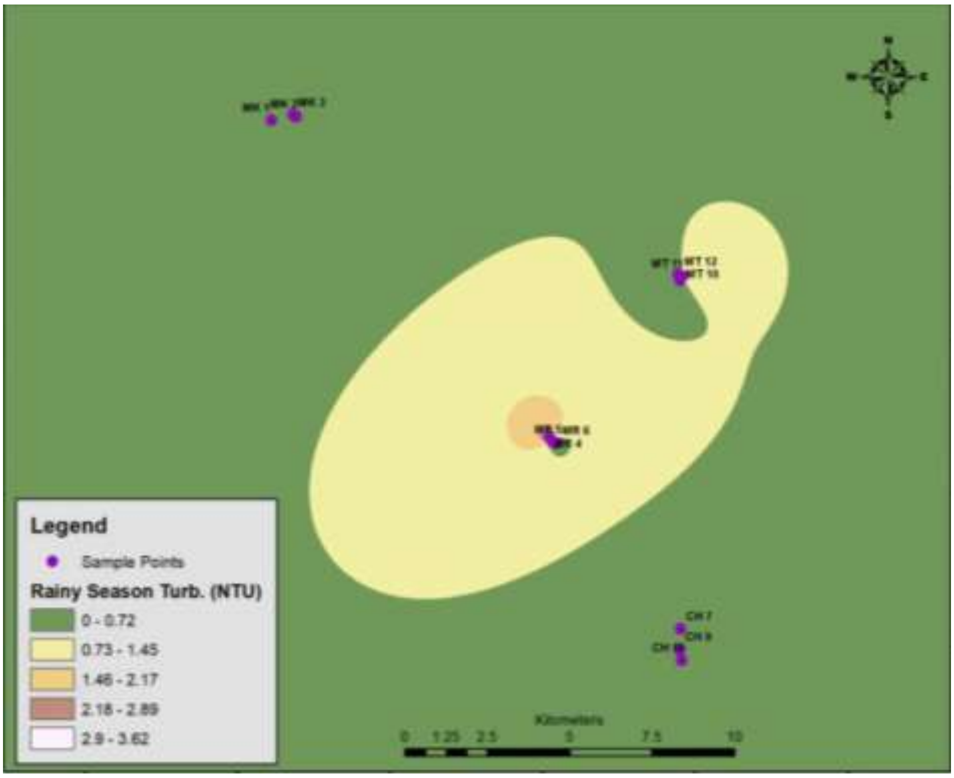


**Figure 4.5A. Rainy Season Spatial Distribution of Turbidity**

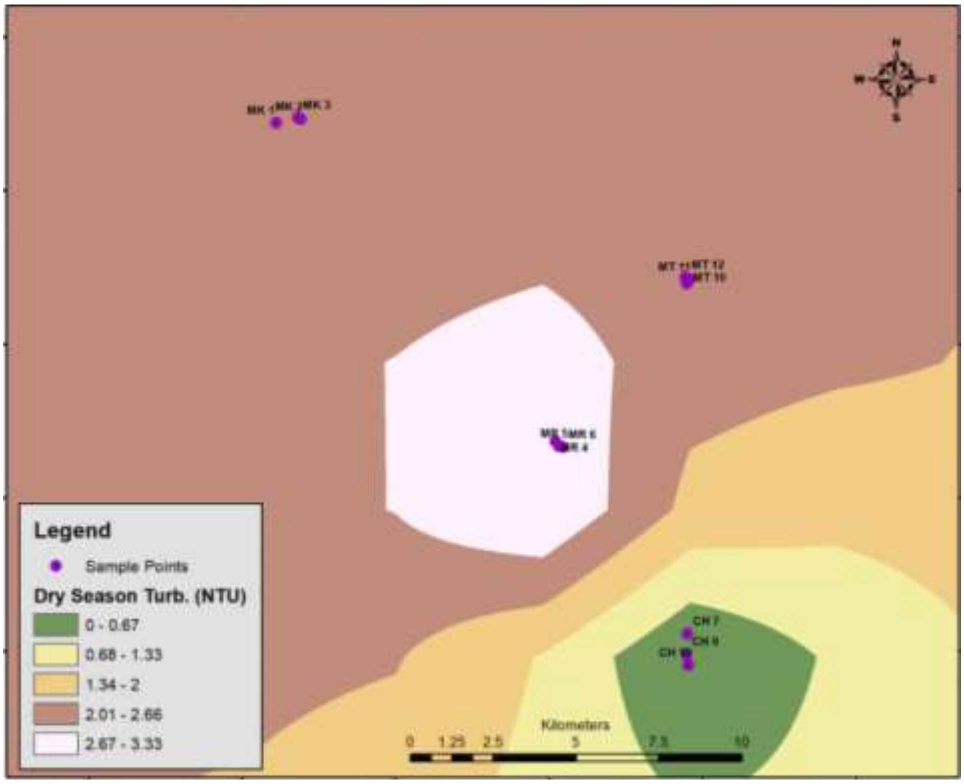


**Figure 4.5B. Dry Season Spatial Distribution of Turbidity**

The groundwater samples of the study area revealed the maximum value of 784.7 µS/cm for conductivity. High conductivity was found to be concentrated in the central part of the study area (MR) during the rainy season (Figure 4.6A), while the laboratory analysis of groundwater samples revealed the maximum value of 549.74 µS/cm during dry season and Conductivity concentration was found to be highly concentrated in the northern area (MK) (Figure 4.6B).

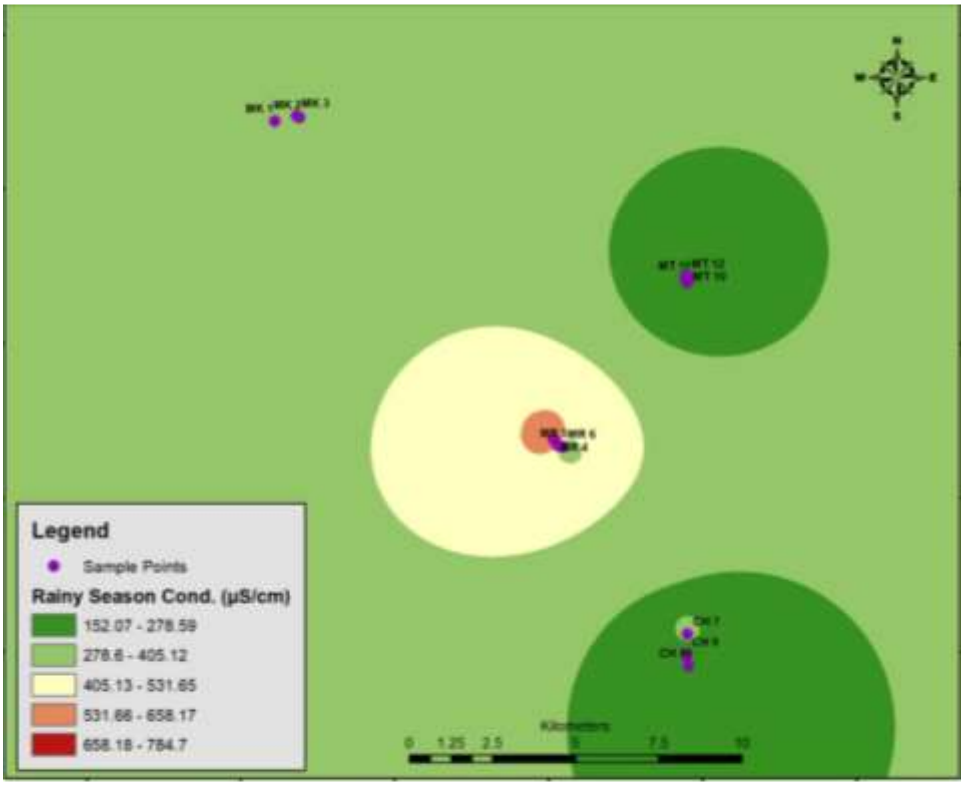


**Figure 4.6A. Rainy Season Spatial Distribution of Electrical Conductivity**

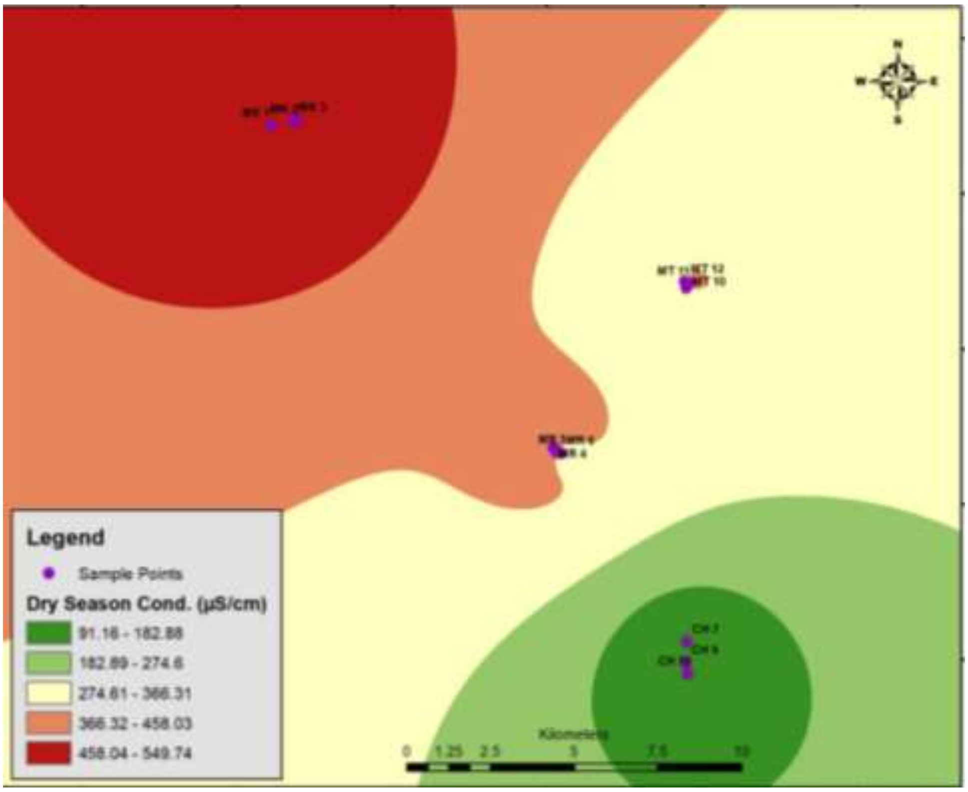


**Figure 4.6B. Dry Season Spatial Distribution of Electrical Conductivity**

The groundwater samples show the maximum value of 525.75 mg/l for TDS. The TDS is highly concentrated in the Central area (MR) during the rainy season as depicted in Figure 4.7A, while for the dry season samples show the maximum value of 368.33 mg/l and TDS is highly concentrated in the North (MK) during the dry season as depicted in Figure 4.7B

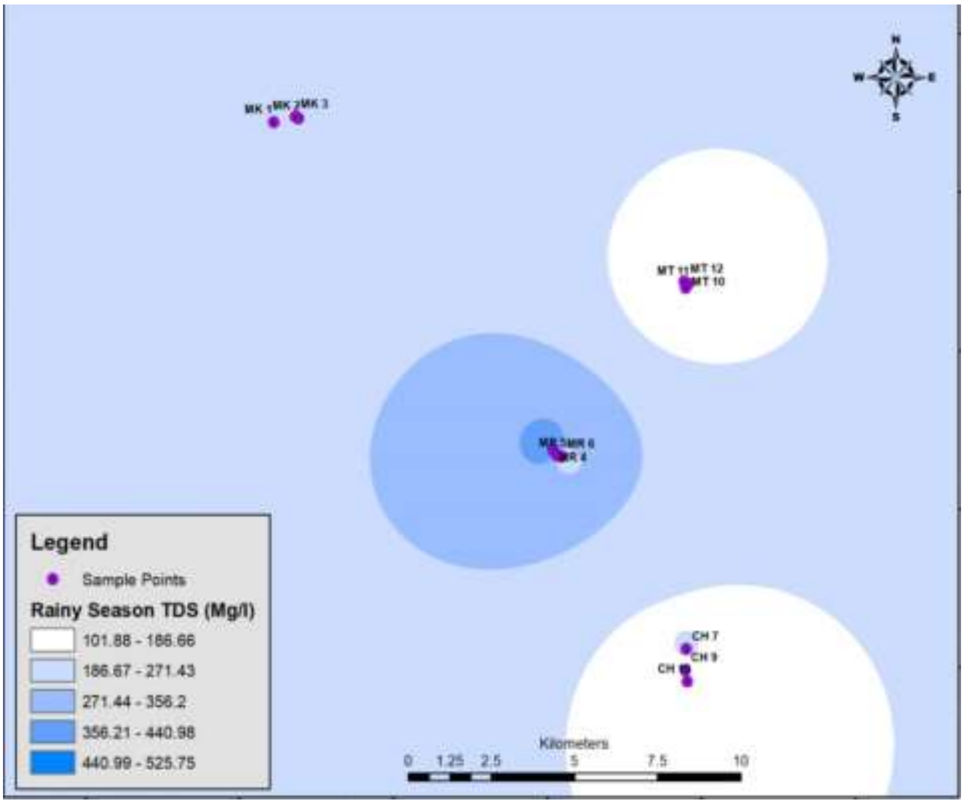


**Figure 4.7A. Rainy Season Spatial Distribution of TDS**

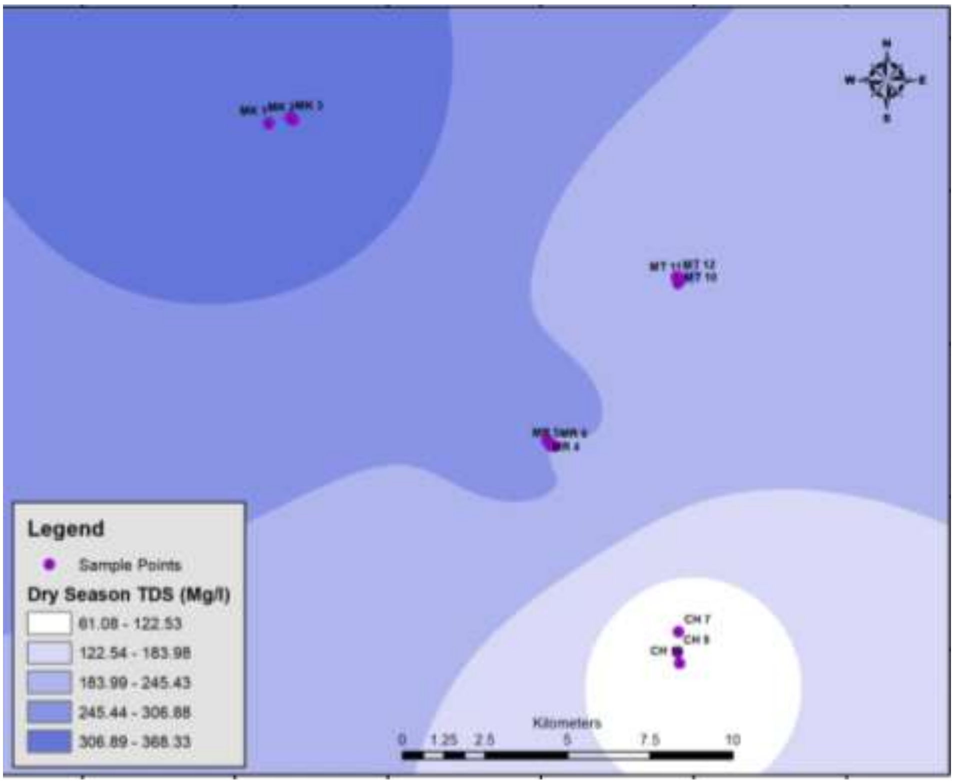


**Figure 4.7B. Dry Season Spatial Distribution of TDS**

The groundwater samples show the maximum value of 191.6 mg/l for Chloride which is seen to be more concentrated in central area (MR) of the study area during the rainy season (Figure 4.8A) while for the dry season the groundwater samples revealed the maximum value of 476.03 mg/l. The distribution of Chloride is seen to be more concentrated in Northern part (MK) of the study area (Figure 4.8B).

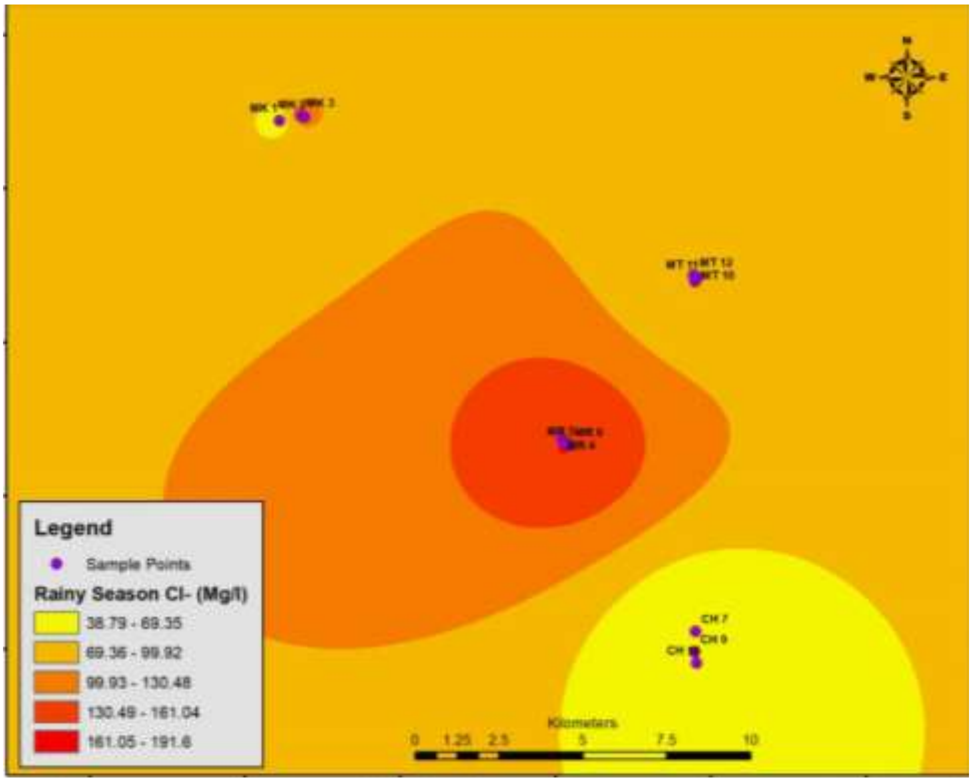


**Figure 4.8A Rainy Season Spatial Distribution of Chloride**

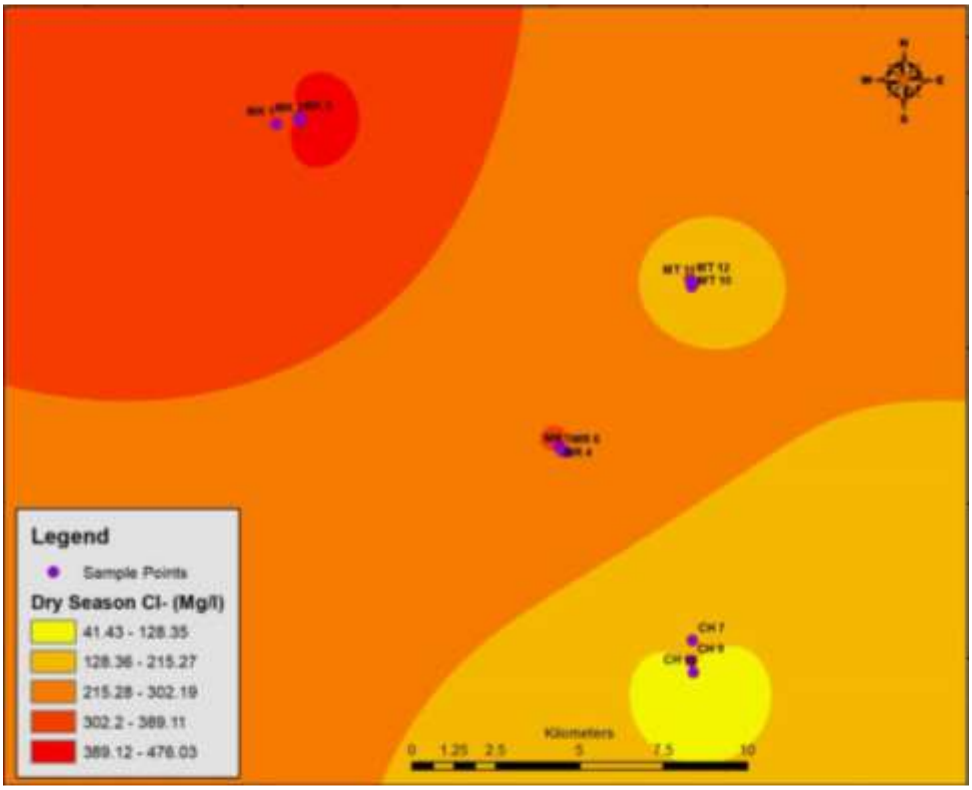


**Figure 4.8B. Dry Season Spatial Distribution of Chloride**

The groundwater samples show the maximum value of 13.8 mg/l of $SO_4$. The distribution of $SO_4$ were found to be high during the rainy season in the central (MR) area of the study (Figure 4.9A), while the analysed groundwater samples for the dry season showed the maximum value of $SO_4$ to be 23.54 mg/ and the distribution was high in Northeast (MT) of the study area (Figure 4.9B)

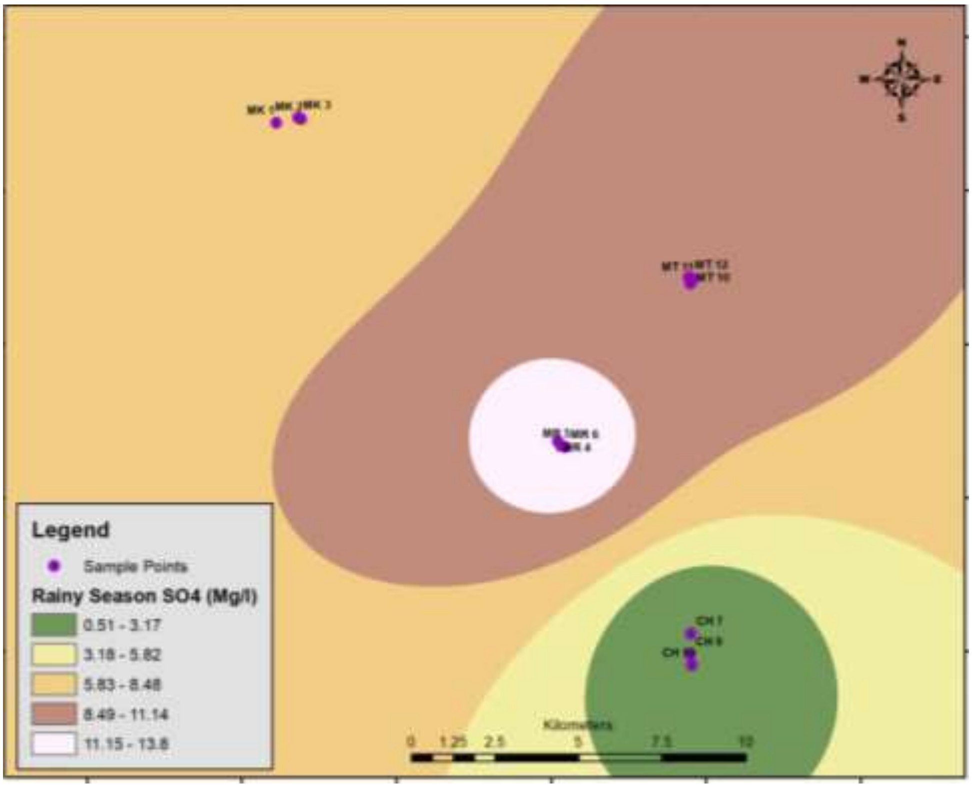


**Figure 4.9A. Rainy Season Spatial Distribution of Sulphate**

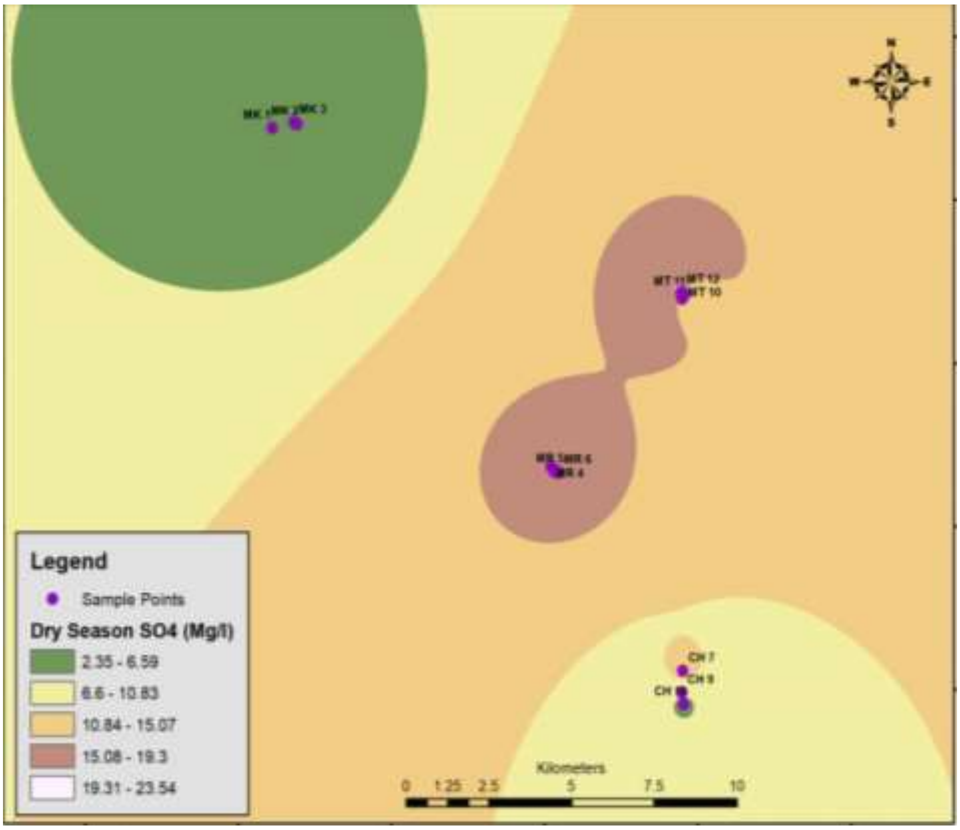


**Figure 4.9B. Dry Season Spatial Distribution of Sulphate ($SO_4$)**

The laboratory analysis of groundwater samples show the maximum value of 12.2 mg/l of $NO_3$. High $NO_3$ concentration during the rainy season were found in Northwest (MT) of the study area (Figure 4.10A), while the analysed groundwater samples for dry season show the maximum value of $NO_3$ to be 37.65 mg/l, the southern area (CH) had the highest concentration of $NO_3$ (Figure 4.10B),

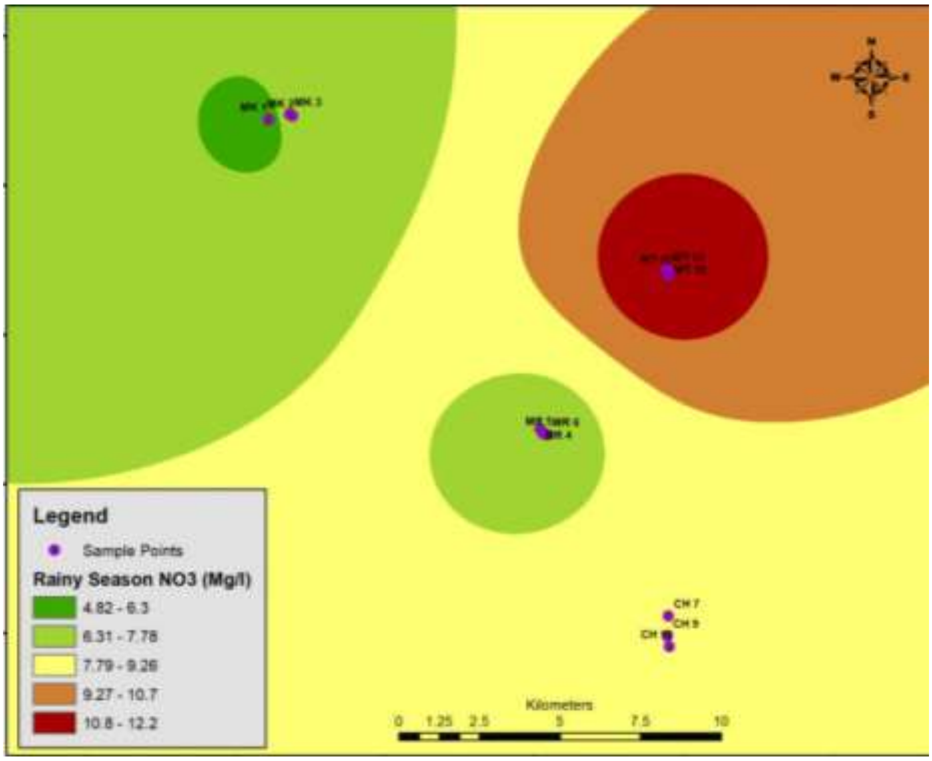


**Figure 4.10A. Rainy Season Spatial Distribution of Nitrate**

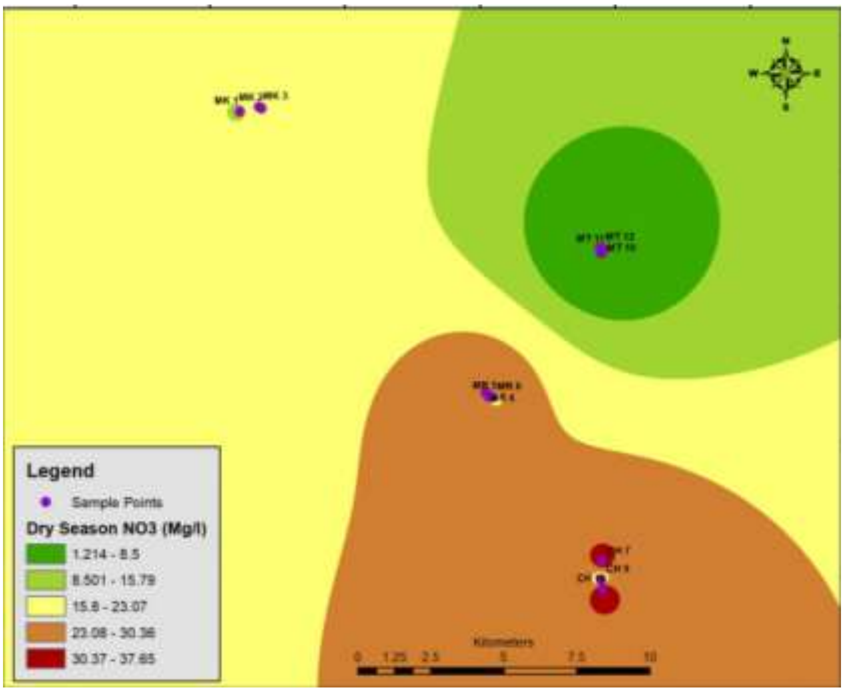


**Figure 4.10B Dry Season Spatial Distribution of Nitrate**

The laboratory analysis of groundwater samples show the maximum value of 136.48 mg/l and Acidity concentration were highest in the Northwest (MT) during the rainy season as indicated in Figure 4.11A while for the dry season laboratory analysis of groundwater samples show the maximum value of 151.44 mg/l, and Acidity concentration were highest in the central (MR) area during the dry season as indicated in Figure 4.11B

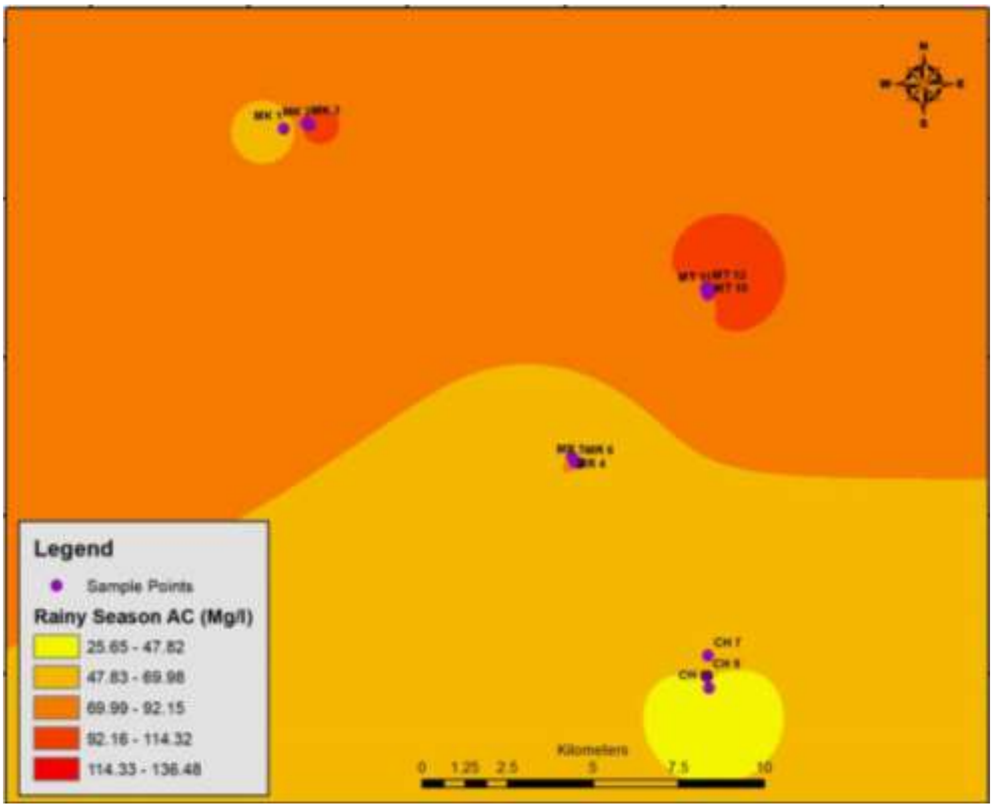


**Figure 4.11A. Rainy Season Spatial Distribution of Acidity**

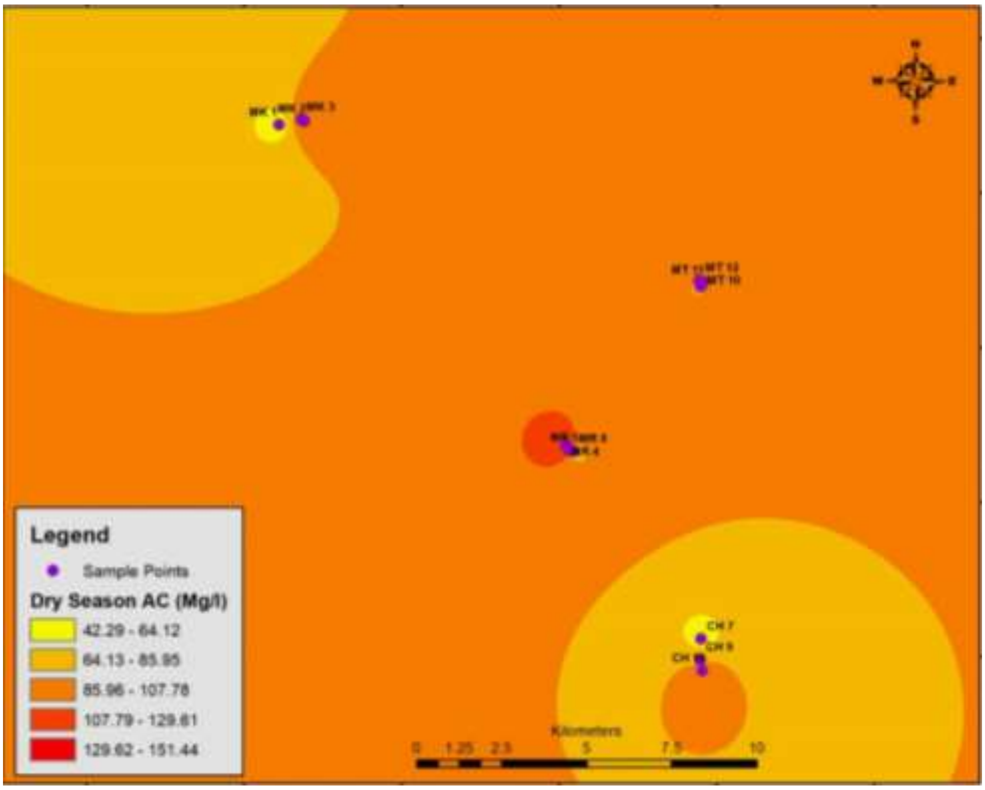


**Figure 4.11B Dry Season Spatial Distribution of Acidity**

The laboratory analysis of groundwater samples show the maximum value of 333.71 mg/l and high concentration of Alkalinity were found in the Southern area (CH) during the rainy season as indicated in Figure 4.12A, while for the dry season laboratory analysis of groundwater samples revealed the maximum value of 342.13 mg/l and high concentration of Alkalinity were found in the Southern area (CH) as indicated in Figure 4.12B

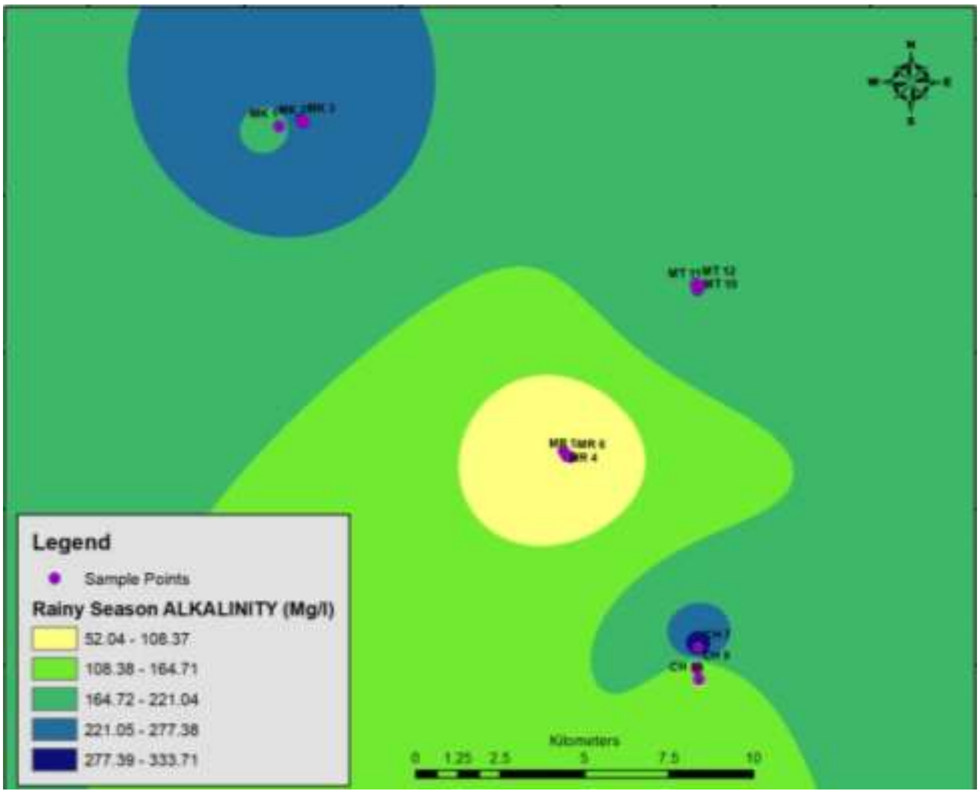


**Figure 4.12A Rainy Season Spatial Distribution of Alkalinity**

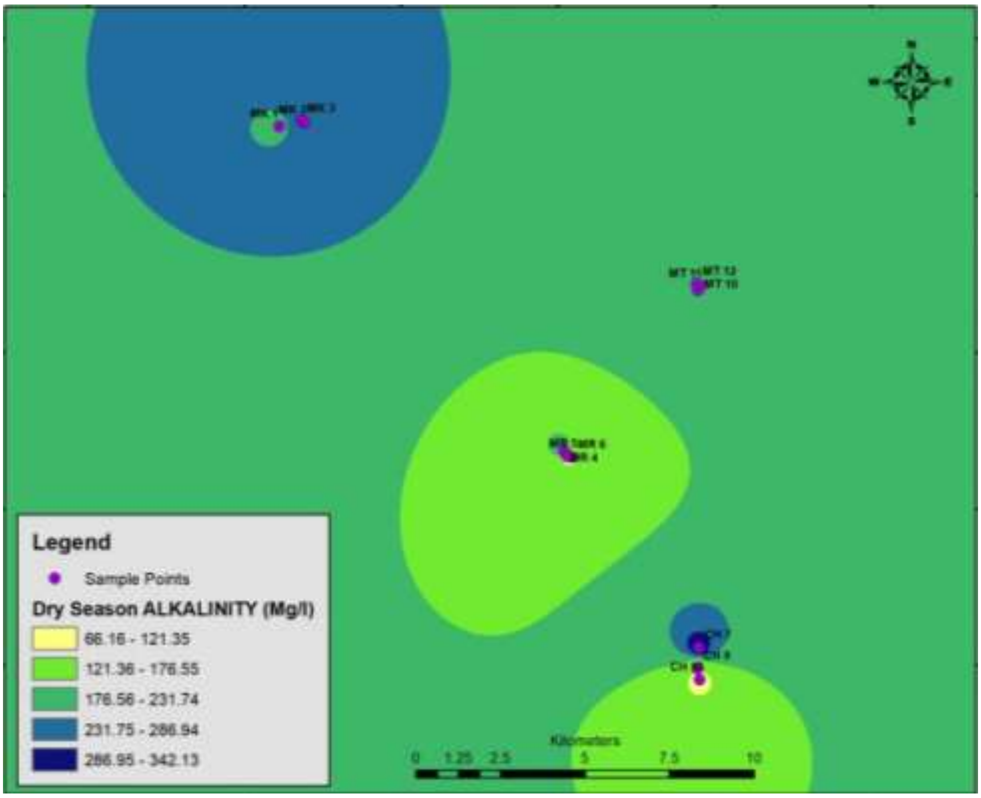


**Figure 4.12B. Dry Season Spatial Distribution of Alkalinity**

The laboratory analysis of groundwater samples show the maximum value of TH to be 534.21 mg/l. highest volume of TH during the rainy season were found in central area (MR) (Figure 4.13A). However, during the dry season the laboratory analysis of groundwater samples show the maximum value of TH to be 1009.76 mg/l. TH were found to be highest in northern (MK) and northwest (MT) during the dry season (Figure 4.13B). The colour assigned to the highest values in both Figures 4.13 A and B was red but does not show on the map because of the sample point colour overlying the highest colour value, but when both figures were zoomed on the computer screen the highest colour values were seen in these areas mentioned.

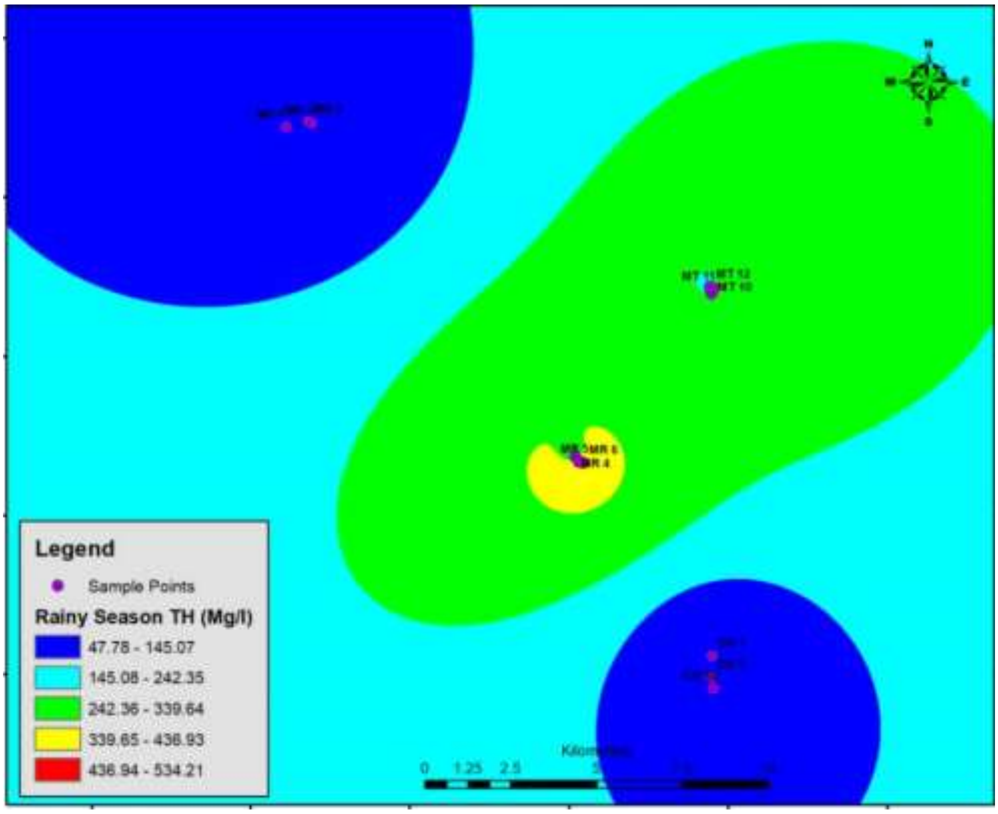


**Figure 4.13A Rainy Season Spatial Distribution of Total Hardness**

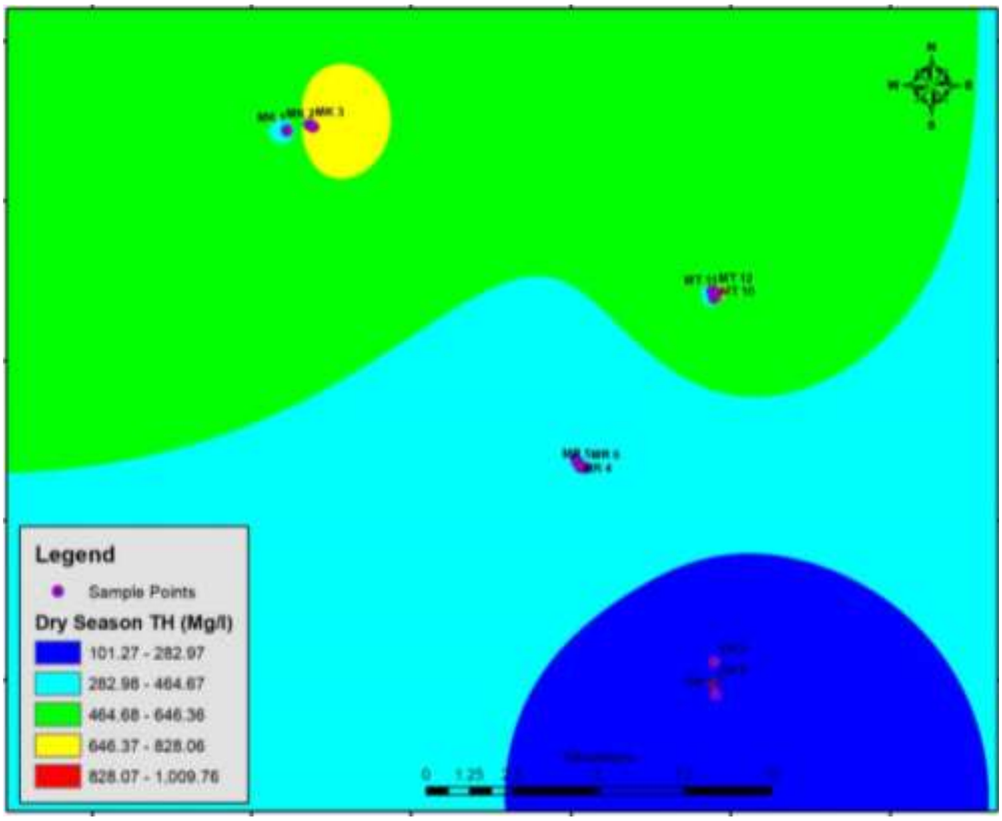


**Figure 4.13B Dry Season Spatial Distribution of Total Hardness**

The general findings of the physicochemical parameters interpolated reveals that the parameters were not concentrated in one particular part of the study area but reasonable variation in concentration exist between the two seasons where MR in the central area had higher concentration of physicochemical parameters than other locations in the rainy season while Mk and MT had higher concentrations of physicochemical parameters during the dry season.

The spatial distribution of groundwater pollutant on maps using interpolation techniques found in GIS in the present study may be the first because none of the published journals, theses, or articles reviewed have utilised the use of GIS to map the groundwater pollutant. Base on the spatial distribution of groundwater pollutant of the study area, there is no similar study to be compared with. However, it can be compared with other research carried out around the world. Among them is Adnan and Iqbal (2014), who did similar studies on Spatial Analysis of the Groundwater Quality in the Peshawar district of Pakistan. The findings of the present studies is not in agreement with the findings of Adnan and Iqbal (2014). According to their findings all the parameters selected for the spatial distribution were found to be concentrated in the main city. However, the implications of the interpolated physicochemical parameters is that other hand dug wells that have not been analysed within the study area could have the same water quality status as revealed by the water quality maps which are generally good for drinking purposes.

# CHAPTER FIVE

# 5.0 CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusions

The study conducted on variability in the quality of hand dug well water Minna and Environs during rainy and dry seasons in October 2018 and March 2019 revealed that the physicochemical parameters of the hand dug well studied showed that they are generally suitable for drinking and all parameters where within the recommended standard limits during both seasons, except TH and $Cl^-$ found to exceed the recommended permissible limits of NSDQW (2007) and WHO (2011) during both rainy and dry seasons. Seasonal variations indicated higher concentration of Total Hardness, Chloride ($Cl^-$), Electrical conductivity (µS/cm), and nitrate ($NO_3$) during the dry season than the rainy season.

The findings of the microbiological parameters has shown that all the well sampled where contaminated with pathogenic bacteria. However the seasonal variation shows that *S. aureus* was not detected during dry season in MR and *P. aeruginosa* was not detected in CH and MT during rainy and dry seasons respectively.

The study revealed that the presence of pathogenic bacteria in the groundwater sampled indicates faecal contamination which result to gastrointestinal diseases such as cholera, typhoid, diarrhoea dysentery and various skin infections.

The findings of the Water Quality Index (WQI) of the physicochemical parameters indicated that the well water of the study area is fit for human consumption. The visual interpretation of spatially distributed physiochemical parameters shows that most of the parameters used for the thematic mapping were found to be concentrated in the Central area (MR) during the rainy season and in the northwest (MK) and eastern area (MT) during the dry season. In addition, the interpolation reveals that the water quality of the surrounding environment are generally safe for consumption.

## 5.2 Recommendations

Recommendations here are provided base on the problems unveiled within the study areas. Individual and government responsibilities are highlighted to ensure safe and healthy drinking water in Minna and Environs.

i. Nitrate is seen to be rapidly increasing during the dry season than the rainy season in Morris (MR) which could be pollution arising from Morris blending fertilizer plant. Relevant authorities such as the state Ministry of Urban and regional planning should ensure with might that the facility is moved and relocated to appropriate location (industrial layout) to curtail and avoid any future pollution which might occur, since this facility is situated within the residential area of Morris Phase II developmental area and also ensure the facility is adopting best environmental practices to manage the waste appropriately to sustain the environment.

ii. The Hardness of water observed in Maitumbi (MT) for drinking and domestic purposes could be remedied through the following methods:

   a. Respective well owners should boil the hard water on a high temperature to remedy the unpleasant taste resulting from high calcium concentration and filter the water to remove sediment.

   b. Second, soften the hard water for laundry use with baking soda and white vinegar. Mix 118 ml with detergent into bucket of hard water or into washing machine and wash. This process will not filter the minerals out of the water but will soften the water and rinses much better. Add 118 ml of distilled white vinegar to the laundry just before the last rinse. This helps to neutralise hard water containing much calcium.

iii. The contaminated wells with pathogenic bacteria should be chlorinated with the help of a professional using at least unscented household liquid bleach of 1 gallon (3.79 litres) for a shallow or dug well of about 5.45 metres deep. This will help eliminate pathogenic bacteria causing diseases such as cholera, typhoid and dysentery.

iv. The water from these biologically contaminated hand dug wells should always be boiled on high heat to kill pathogenic bacteria and filter the water before consumption.

v. Poorly constructed wells should be rebuilt and maintained according to standard.

vi. A good Well head cover should be provided to prevent surface contaminants from contaminating the water via runoff and wind erosion depositing sediments.

vii. The individual well owners should ensure proper hygiene and sanitation around the well water environment to secure and prevent contaminants into the well and also provide a healthy guideline of water collection from the well by the public as most of the wells are accessed by the public.

viii. Massive sensitization, environmental education and awareness campaign on hygiene, sanitation and waste control should be carried out by relevant authorities such as NESREA and NISEPA through various media and target population in market and schools.

ix. All well water sources provided by the government or other water sources for the public should be monitored for quality and maintained for public health and safety.

x. There should be collaboration among Stakeholders on key issues related to water born disease, causes and solutions affecting public health, in order to encourage personal and collective responsibility in building an environmentally healthy society for achievement of sustainable development and to ensure a cleaner and healthier environment in Minna and Nigeria at large.

xi. Treated water/boreholes should be made for all residence in Minna and environs.

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# APPENDICES

## APPENDIX A

**FIELD SAMPLING FORM.**

**DEPARTMENT OF GEOGRAPHY**

**FEDERAL UNIVERSITY OF TECHNOLOGY MINNA**

**WELL SAMPLING DATA FORM**

**WELL NO: __________**

Project:
__________________________________________________________________________

Location Descript. __________________________________________________________

Sampling Area: _____________________________

Sample no.:________________________________

GPS Lat.:______________GPS Long.:_______________

Sampling date: ________________________________

Sampling time: _______________________________

Sampling method: _____________________________

Weather Condition: _____________________________________

Amb. Temp. °C________________________________

Sampled by: __________________________________

**WATER ELEVATION DATA**

Method of measurement: ___________________

Water Level [in Metres]: ___________________________

Depth of Well ________________

Elevation around the Well (in Metres): ______________________________

Colour/Sediment/Odour: ______________________________

Water Temp. ($^0$C). ________________

Date: _____________________________________

Comments: