# HYDROCHEMICAL AND BACTERIOLOGICAL EVALUATION OF SURFACE WATER AND GROUNDWATER SOURCES IN MPAPE AREA OF ABUJA, NORTH-CENTRAL NIGERIA

**BY**

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# DECLARATION

I hereby declare that this thesis titled: "**Hydrochemical and Bacteriological Evaluation of Surface Water and Groundwater Sources in Mpape Area of Abuja, North Central Nigeria"** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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# CERTIFICATION

The thesis titled: **“Hydrochemical and Bacteriological Evaluation of Surface Water and Groundwater Sources in Mpape Area of Abuja, North-Central Nigeria” by: OGUNTADE, Adebayo Samuel** meets the regulations governing the award of Master of Technology (MTech) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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# ABSTRACT

Access to potable water is a major concern confronting most developing nations particularly with the overwhelming health burden posed by polluted water and its sources. A total of fifteen water samples were collected and analyzed for their chemical and bacteriological parameters to evaluate quality status of surface water and groundwater sources from Mpape area of Federal Capital

Territory, North Central Nigeria. Prior to the analysis, the physical parameters such as pH, Temperature ($^{0}$C), Electrical Conductivity (µS/cm), Total Dissolved Solids (mg/l), Turbidity and Total Suspended Solids were determined in-situ and were observed to be within the recommended limits except Turbidity and Total Suspended Solids while other parameters were analyzed using equipment in accordance with American Public Health Association Standard in a standard laboratory. The result of the laboratory analyses of the water samples showed that the mean concentration of some of the physico-chemical parameters such as sodium, calcium, magnesium, potassium, sulphate, chloride, nitrates, fluoride and phosphate were within the permissible limit recommended by both World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). However, the mean concentration of iron, manganese, turbidity, total suspended solids, lead, cadmium, nickel and chromium were found to be higher than their respective recommended limits. Water Quality Index (WQI) based assessment revealed that over 85% of the samples were contaminated by *E.coli* and *total coliform* with the highest values recorded in surface water and this inferred anthropogenic contamination in almost all the water samples. It is recommended that people should avoid siting wells close to the mining sites, indiscriminate dispose of wastes should cease, grouting of the base and proper covering of hand-dug wells in the area should always be carried out and proper treatment of water before usage is also encouraged.

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# CHAPTER

# INTRODUCTION

## 1.1 Background of the Study

Water is a universal solvent and a natural resource that all living things on earth utilize for their needs. Essential for the sustainability and survival of all life forms on Earth. As such, the demand for water is constantly increasing due to population growth, urbanization and other anthropogenic factors. Water is also essential for humans, who need to drink large amounts of water daily to survive (Nester *et al*., 2004). The Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) and World Health Organization (WHO, 2017) guidelines provide standards for physical parameters of microbiological, chemical and heavy metals in safe drinking water. The United Nations, of which Nigeria is a member, is guided by 17 Sustainable Development Goals (SDGs) to transform our world and ensure a better life for people. The SDGs came into force in January 2016 and include a global agenda through 2030. Goal 6 of the SDGs aims at clean water and sanitation (UN, 2020).

More than 66 million Nigerians in the cities and rural areas lack access to potable water supply, and this has resulted to an increase in the consumption of contaminated or polluted water (WHO, 2015; Ologbushere *et al*., 2016; and Beshiru *et al*., 2018). It is therefore appropriate to intervene urgently to prevent water shortages, especially in developing countries such as Nigeria. In Nigeria, there are serious reports of water-borne infections and illnesses such as diarrhea, cholera and typhoid fever as a result of poor sanitation and poverty (Coleman *et al*., 2013; Igbinosa *et al*., 2017).

## 1.2 Water Sources

Water sources represent water resources (for example; rivers, lakes, streams, springs, reservoirs and groundwater) that provide potable water to the community for various purposes. Most part of the globe surface is covered with liquid water of which 97 % supply of earth water is inside the ocean, that is unhealthy for human utilization and other usages on account of its elevated content of salt, and also out of the residual 3 %, glacial ice caps consists of 2 % while approximately 1 % is obtainable as freshwater in rivers, reservoirs lake, streams and groundwater that is appropriate for consumption by man. Community water systems obtain water from two sources: surface water and groundwater. People use surface and ground water every day for a variety of purposes, including drinking, cooking, and basic hygiene, in addition to recreational, agricultural, and industrial activities (Coleman *et al*., 2013).

### 1.2.1 Surface Water

Surface water is constantly replenished through precipitation and naturally lost through discharge to the oceans, evaporation, evapo-transpiration and groundwater recharge. Although the main natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors such as storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates Igbinosa *et al*., 2017). All of these factors affect the proportions of water loss and the human activities also can have a large and sometimes devastating impact on these factors (Ologbushere *et al*., 2016). Humans often increase storage capacity by constructing reservoirs and decrease it by draining wetlands. Humans often increase runoff quantities and velocities by paving areas and channelizing the stream flow. The total quantity of water available at any given time is an important consideration. Some human water users have an intermittent need for water. For example, many farms require large quantities of water during farming season. To supply such a farm with water, a surface water system may require a large storage capacity to collect water throughout the year and release it in a short period of time. Other users have a continuous need for water, such as a power plant that requires water for cooling. To supply such a power plant with water, a surface water system only needs enough storage capacity to fill in when average stream flow is below the power plant's need. Nevertheless, over the long term the average rate of precipitation within a watershed is the upper bound for average consumption of natural surface water from that watershed. Natural surface water can be augmented by importing surface water from another watershed through a canal or pipeline. Brazil is estimated to have the largest supply of freshwater in the world, followed by Russia and Canada (UN, 2020).

### 1.2.2 Groundwater

Groundwater, which is obtained by drilling wells, is water located below the ground surface in pores and spaces in the rock, and is used by approximately 78 % of community water systems in the Nigeria, supplying drinking water to 32 % of community water system users. It has also been estimated that approximately 15 % of the Nigerian population relies on private ground water wells Igbinosa *et al*., 2017).

Groundwater is fresh water located in the subsurface pore space of soil and rocks. It is also water that is flowing within aquifers below the water table. Groundwater can be thought of in the same terms as surface water: inputs, outputs and storage. The critical difference is that due to its slow rate of turnover, groundwater storage is generally much larger (in volume) compared to inputs than it is for surface water. This difference makes it easy for humans to use groundwater unsustainable for a long time without severe consequences Igbinosa *et al*., 2017). Nevertheless, over the long term the average rate of seepage above a groundwater source is the upper bound for average consumption of water from that source. The natural outputs from groundwater are springs and seepage to the oceans. In coastal areas, human use of a groundwater source may cause the direction of seepage to ocean to reverse which can also cause soil salinization. Humans can also cause groundwater to be "lost" (i.e. become unusable) through pollution. Humans can increase the input to a groundwater source by building reservoirs or detention ponds.

### 1.2.3 Methods of Water Treatment

These are processes that improve the quality of water to make it appropriate for a specific end-use. The end use may be drinking, industrial water supply, irrigation, river flow maintenance, water recreation or many other uses, including being safely returned to the environment. Water treatment removes contaminants and undesirable components, or reduces their concentration so that the water becomes fit for its desired end-use. This treatment is crucial to human health and allows humans to benefit from both drinking and irrigation use. Water is the most crucial compound for life on Earth, and having drinkable water is a key worldwide concern for the twenty-first century. All living things require clean, uncontaminated water as a basic requirement. Water covers more than 71 % of the earth’s surface, but only around 1 % of it is drinkable according to international standards (WHO, 2017) due to various contaminations. Wastewater discharge from industries, agricultural pollution, municipal wastewater, environmental and global changes are the main sources of water contamination. According to a United Nations Sustainable Development Group report in 2021, 2.3 billion people now live in water-stressed countries, and 733 million people live in high and critically water-stressed countries (WHO, 2017. To address water scarcity issues, it is becoming increasingly important to recover water from current wastewater or develop alternate water sources for human consumption. Wastewater is primarily obtained from domestic and industrial sources. Domestic wastewater contains sewage, bacteria, viruses, hazardous and non-toxic organisms, sanitary outputs, detergents, and other solid and liquid discharges from non-manufacturing processes. Water contamination is primarily caused by the discharge of untreated wastewater from enterprises. The effluent from various sources, which contains varying levels of contaminants, is dumped into rivers or other sources of water resources (Beshiru *et al*., 2018). The wastewater may have a high proportion of organic and inorganic contaminants at the initial discharge. Industries generate wastewater as a result of fabrication processes and production of papers, textiles, chemicals, and from various streams such as cooling towers, boilers, and production lines. Treatment for drinking water production involves the removal of contaminants and/or inactivation of any potentially harmful microbes from raw water to produce water that is suitable enough for human consumption without any short term or long term risk of any adverse health effect. In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human or animal (including bird) faeces. Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminthes (Beshiru *et al*., 2018). Water supplied for domestic sources such as for tap water or other uses, may be further treated before use, often using an in-line treatment process. Such treatments can include water softening or ion exchange.

#### 1.2.3.1 Preliminary treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment processes. Preliminary treatment operations typically include coarse screening, grit removal and, in some cases, comminution of large objects. In grit chambers, the velocity of the water through the chamber is maintained sufficiently high, or air is used, so as to prevent the settling of most organic solids. Grit removal is not included as a preliminary treatment step in most small wastewater treatment plants. Comminutors are sometimes adopted to supplement coarse screening and serve to reduce the size of large particles so that they will be removed in form of sludge in subsequent treatment processes. Flow measurement devices, often standing-wave flumes, are always included at the preliminary treatment stage.

#### 1.2.3.2 Primary Treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Approximately 25 to 50 % of the incoming biochemical oxygen demand ($BOD_5$), 50 to 70 % of the total suspended solids (TSS), and 65 % of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation but colloidal and dissolved constituents are not affected (Beshiru *et al*., 2018). The effluent from primary sedimentation units is referred to as primary effluent. In many industrialized countries, primary treatment is the minimum level of pre-application treatment required for wastewater irrigation. It may be considered sufficient treatment if the wastewater is used to irrigate crops that are not consumed by humans or to irrigate orchards, vineyards, and some processed food crops. However, to prevent potential nuisance conditions in storage or flow-equalizing reservoirs, some form of secondary treatment is normally required in these countries, even in the case of non-food crop irrigation. It may be possible to use at least a portion of primary effluent for irrigation if off-line storage is provided (Beshiru *et al*., 2018).

Settled solids (primary sludge) are normally removed from the bottom of tanks by sludge rakes that scrape the sludge to a central well from which it is pumped to sludge processing units. Scum is swept across the tank surface by water jets or mechanical means from which it is also pumped to sludge processing units. In large sewage treatment plants (> 7600 $m^3$/d in the US), primary sludge is most commonly processed biologically by anaerobic digestion. In the digestion process, anaerobic and facultative bacteria metabolize the organic material in sludge, thereby reducing the volume requiring ultimate disposal, making the sludge stable (nonputrescible) and improving its dewatering characteristics. Digestion is carried out in covered tanks (anaerobic digesters), typically 7 to 14 m deep. The residence time in a digester may vary from a minimum of about 10 days for high-rate digesters (well-mixed and heated) to 60 days or more in standard-rate digesters (Nester *et al*., 2004). Gas containing about 60 to 65 % methane is produced during digestion and can be recovered as an energy source. In small sewage treatment plants, sludge is processed in a variety of ways including: aerobic digestion, storage in sludge lagoons, direct application to sludge drying beds, in-process storage (as in stabilization ponds), and land application (Nester *et al*., 2004).

### 1.2.3.3 Secondary Treatment

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes (Deller, 1999). Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally $CO_2$, $NH_3$, and $H_2O$). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter. High-rate biological processes are characterized by relatively small reactor volumes and high concentrations of microorganisms compared with low rate processes. Consequently, the growth rate of new organisms is much greater in high-rate systems because of the well-controlled environment. The microorganisms must be separated from the treated wastewater by sedimentation to produce clarified secondary effluent (Deller, 1999).

The sedimentation tanks used in secondary treatment, often referred to as secondary clarifiers, operate in the same basic manner as the primary clarifiers described previously. The biological solids removed during secondary sedimentation, called secondary or biological sludge, are normally combined with primary sludge for sludge processing. Common high-rate processes include the activated sludge processes, trickling filters or biofilters, oxidation ditches, and rotating biological contactors (RBC). A combination of two of these processes in series (e.g., biofilter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources (Deller, 1999).

#### 1.2.3.4 Tertiary and/or Advanced Treatment

Tertiary and/or advanced wastewater treatment is employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed. Individual treatment processes are necessary to remove nitrogen, phosphorus, additional suspended solids, refractory organics, and heavy metals and dissolved solids (Qiu, 2010). Tertiary treatment is also known as advanced treatment and it is usually follows high-rate secondary treatment. However, advanced treatment processes are sometimes combined with primary or secondary treatment (chemical addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (overland flow treatment of primary effluent). Effluent from primary clarifiers flows to the biological reactor, which is physically divided into five zones by baffles and weirs. In sequence these zones are: (i) anaerobic fermentation zone (characterized by very low dissolved oxygen levels and the absence of nitrates); (ii) anoxic zone (low dissolved oxygen levels but nitrates present); (iii) aerobic zone (aerated); (iv) secondary anoxic zone; and (v) final aeration zone (Qiu, 2010). The function of the first zone is to condition the group of bacteria responsible for phosphorus removal by stressing them under low oxidation-reduction conditions, which results in a release of phosphorus equilibrium in the cells of the bacteria. On subsequent exposure to an adequate supply of oxygen and phosphorus in the aerated zones, these cells rapidly accumulate phosphorus considerably in excess of their normal metabolic requirements. Phosphorus is removed from the system with the waste activated sludge.

Most of the nitrogen in the influent is in the ammonia form, and this passes through the first two zones virtually unaltered. In the third aerobic zone, the sludge age is such that almost complete nitrification takes place, and the ammonia nitrogen is converted to nitrites and then to nitrates. The nitrate-rich mixed liquor is then recycled from the aerobic zone back to the first anoxic zone. Here denitrification occurs, where the recycled nitrates, in the absence of dissolved oxygen, are reduced by facultative bacteria to nitrogen gas, using the influent organic carbon compounds as hydrogen donors (Vetrimurugan *et al*., 2012). The nitrogen gas merely escapes to atmosphere. In the second anoxic zone, those nitrates which were not recycled are reduced by the endogenous respiration of bacteria. In the final re-aeration zone, dissolved oxygen levels are again raised to prevent further denitrification, which would impair settling in the secondary clarifiers to which the mixed liquor then flows. This advanced biological wastewater treatment plant cost only marginally more than a conventional activated sludge plant but nevertheless involved considerable investment. Furthermore, the complexity of the process and the skilled operation required to achieve consistent results make this approach unsuitable for developing countries (Vetrimurugan *et al*., 2012). In many situations, where the risk of public exposure to the reclaimed water or residual constituents is high, the intent of the treatment is to minimize the probability of human exposure to enteric viruses and other pathogens. Effective disinfection of viruses is believed to be inhibited by suspended and colloidal solids in the water, therefore these solids must be removed by advanced treatment before the disinfection step. The sequence of treatment often specified in the United

States is: secondary treatment followed by chemical coagulation, sedimentation, filtration, and disinfection. This level of treatment is assumed to produce an effluent free from detectable viruses. In Near East countries adopting tertiary treatment, the tendency has been to introduce pre-chlorination before rapid-gravity sand filtration and post-chlorination afterwards (Qiu, 2010).

## 1.3 Study Area Description

### 1.3.1 Location and Accessibility

The study area lies between latitudes 09˚7’30”N and 09˚9’30”N and between longitudes 07˚28’0”E and 07˚31’0”E (Figure 1.1). Mpape is one of the main suburbs of Abuja. It is a large, densely populated district in Bwari Area Council and it is approximately ten (10) minutes’ drive from Federal Capital Territory of Abuja. It is a hilly area located opposite Maitama, across the expressway linking Asokoro and Kubwa. The road network is still developing, with one major tarred road that connects the neighbourhood to Maitama via the expressway. The terrain of Mpape is a rugged and hilly type and this serves as the major determinant factor for the localization of quarry sites including notable Julius Berger Quarry Site, Arabs Contractors Quarry Site, Setraco Quarry Site among others. The increasing population of Abuja has made Mpape an important settlement for the middle class and low income earners working and living in the capital city and its satellites towns.

**Figure 1.1**: Topography map of the study area

### 1.3.2 Climate and Vegetation

The area is within a tropical wet and dry climate. It experiences three weather conditions annually. This includes a warm, humid rainy season and a blistering dry season. In between the two, there is a brief interlude of harmattan occasioned by the northeast trade wind, with the main feature of dust haze and dryness. The rainy season begins in April and ends in October, when daytime temperatures reach 28˚ C to 30˚ C and night time lows hover around 22˚ C to 23˚ C. In the dry season which is from November to March, daytime temperatures can soar as high as 23˚ C and night time temperatures can dip to 12˚ C. Even the chilliest nights can be followed by daytime temperatures well above 30˚ C. The high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory (Ogunbanjo, 2004).

Rainfall is the amount of water falling in rain or snow within a given time and area, usually expressed as a hypothetical depth of coverage. Rain is liquid water in the form of droplets that have condensed from atmospheric water vapor and then become heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the Earth (Sekabira *et al*., 2010). It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants and crop irrigation. The major cause of rain production is moisture moving along three-dimensional zones of temperature and moisture contrasts known as weather fronts. If enough moisture and upward motion is present, precipitation falls from convective clouds (those with strong upward vertical motion) such as cumulonimbus (thunder clouds) which can organize into narrow rainbands. In mountainous areas, heavy precipitation is possible where upslope flow is maximized within windward sides of the terrain at elevation which forces moist air to condense and fall out as rainfall along the sides of mountains. On the leeward side of mountains, desert climates can exist due to the dry air caused by downslope flow which causes heating and drying of the air mass (Kim, 2002). The movement of the monsoon trough, or intertropical convergence zone, brings rainy seasons to savannah climes.

The urban heat island effect leads to increased rainfall, both in amounts and intensity, downwind of cities. Global warming is also causing changes in the precipitation pattern globally, including wetter conditions across eastern North America and drier conditions in the tropics. Antarctica is the driest continent. The globally averaged annual precipitation over land is 715 mm (28.1 in), but over the whole Earth it is much higher at 990 mm (39 in). Climate classification systems such as the Köppen classification system use average annual rainfall to help differentiate between differing climate regimes. Rainfall is measured using rain gauges (Kim, 2002). The average annual temperature is 26˚ C in the study area with about 1469 mm of precipitation annually. The driest month is December, with 1 mm of rain. Most of the precipitation falls in August, averaging 326 mm and this makes the coolest month, with temperatures average 22.9˚ C. March is the warmest month of the year. The temperature in March averages 29.6˚ C (Ogunbanjo, 2004).

### 1.3.3 Relief and Drainage

Relief refers to the surface features of the land above the sea level and can be referred specifically to the quantitative measurement of vertical elevation change in a landscape. It is the difference between maximum and minimum elevations within a given area, usually of limited extent. A relief can be described qualitatively, such as a "low relief" or "high relief" plain or upland (Ogunbanjo, 2004). Because it is related to the slope of surfaces within the area of interest and to the gradient of any streams present, the relief of a landscape is a useful metric in the study of the Earth's surface. Relief of Nigeria can be grouped into two main classes which are lowlands and highlands. Lowlands refer to the areas below 300 m above sea level while highlands refer to areas over 300 m above sea level. The study area is categorized as highland because it is a hilly area and the elevation measurement was more than 300 m above the sea level and formed part of North Central highlands that lie in the center of Northern Nigeria (Olobaniyi and Owoyeni, 2004). Drainage refers to water bodies like rivers and lakes while patterns formed by the streams, rivers, and lakes in a particular drainage basin are called drainage systems or river system. They are governed by the topography of land, whether a particular region is dominated by hard or soft rocks, and the gradient of the land (Olobaniyi and Owoyeni, 2004).

### 1.3.4. Geology and Hydrogeology

The study area is almost predominantly underlain by high grade metamorphism and igneous rocks of Precambrian age (Obaje, 2009). Lithologically, the study area consist of the porphyritic granite that vary from coarse porphyritic granite, to medium grained granite, banded gneiss and migmatites belonging to the Pan African older granites of the Nigerian basement complex (Plate I). Texturally, they are differentiated into coarse and fine grained. Mineralogically, they consist predominantly of quartz, feldspars and mica. Offodile, (2002), described the contact between the Pan African granites and the host rock as intrusive gradational and replacive while the contact between the older granite suite are both sharp and also gradational. It has been suggested that the Pan African granites are characterized by distinctive layering which are normally aligned parallel to northwest-southeast lineaments (Obaje, 2009). The major deformational feature across study area is a NW-SE trending fault. These faults have been interpreted as resulting from trans-current movements. All these rocks have been affected and deformed by the Pan-African thermotectonic event. The concealed basement rocks contain highly faulted and folded areas, joints and fracture systems which resulted from multiple tectonic events that serves as aquifers for water system.

**Plate I:** Boulders of porphyritic granite in the study area.

### 1.4 Scope and Limitation of Work

The research area was limited to Mpape, an area within the Federal Capital Territory of Abuja. The entire Mpape is geographically sub-divided into three major areas comprising Eneje, Mashafa, and Katampe 1. Each 1:10,000 topographical sheet covers a superficial area of about 30.80 km$^2$. The geological field mapping and sampling were done on a scale of 1:10,000 aimed to update the geological map of the research area.

### 1.5 Aim and Objectives

The aim of this study is to ascertain the quality status of surface and groundwater resources in Mpape Area of Abuja in order to determine the water potability in the area.

**Objectives:**

i. To produce an updated geological map of the study area on a scale of 1:10,000;

ii. To establish the physical, chemical and bacteriological properties of the water;

iii. To determine the probability of the contaminants in the water sources;

iv. To compare the results of the laboratory analysis with the Nigeria Standard for Drinking Water Quality (NSDWQ, 2015) and World Health Organization (WHO, 2017); and

v. To ascertain the contamination levels of the surface and groundwater through the application of pollution indices on the laboratory results.

### 1.6 Statement of the Research Problem

The poor management of wastes arising from quarrying operations such as dust, sand and rock waste and urbanization caused by rapid population growth due to low cost housing, availability of menial jobs and proximity to city centre has the potential of deteriorating the surface and groundwater system in the area. Available information obtained from interviews carried out during reconnaissance stage revealed prevalence of water borne and water-related diseases which might not be unconnected with poor water quality in the study area.

### 1.7 Significance of Study

Mpape district hosts a lot of quarrying companies and the tendency of anthropogenic activities leading to contamination of surface and groundwater resources of the area cannot be ruled out. In view of this, there is need to analyze the surface and groundwater sources in the area in order to ascertain their quality status, thereby creating awareness aimed at preventing the occurrence or wide spread of water borne diseases such as cholera, typhoid, diarrhea and dysentery.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Geology

The Nigerian Basement Complex is a part of the Pan-African mobile belt. The Nigerian landmass is entirely underlain by the rocks of the crystalline Basement Complex while the sedimentary rocks filled the depressions within it. The deep-seated structural and tectonic setting of the Basement Complex to a large extent exerts a strong influence on the sedimentary basins, thus determining their architecture and evolution (Obaje, 2009). The Basement Complex is exposed in five areas of the country namely Kaduna, Ibadan, Adamawa, Mandara and Obudu. The first two are practically one huge area separated albeit incompletely, by the shallow Bida Basin. The other three areas are also considered practically one continuous northeast – southwest strip of territory shallowly subdivided by the Yola arm and Mamfe Embayment which are offshoots of the Benue Trough, which is considered to be the fundamental demarcation (Ajibade *et al*., 1989). They all form part of a shield – a mobile belt between the West African and the Congo cratons. The belt resulted from the mobilization which took place during Eburnean/Birrimian, the Kibaran/Katangan and the Pan-African events.

According to Ajibade *et al*. (1989), two distinct provinces can be distinguished in the Nigerian Basement namely: the Western Province which is characterized by narrow low-grade schist belts, each belt separated the adjacent ones by migmatites and gneisses or granites and also the Eastern Province comprising mostly of migmatites, gneisses and large volumes of Pan-African granites and intruded by the Mesozoic Younger Granites. Polymetamorphic migmatite-gneiss complex, low-grade metamorphics, syntectonic to late tectonic granitics and volcanics are main four groups of rock types identified in the Nigerian Basement complex areas.

## 2.2 Sources of Water

### 2.2.1 Surface Water

Surface water is any body of water above ground, including streams, rivers, lakes, wetlands, reservoirs, and creeks. The ocean, despite being saltwater, is also considered surface water. Surface water participates in the hydrologic cycle, or water cycle, which involves the movement of water to and from the Earth's surface (Nganje *et al.*, 2010). Precipitation and water runoff feed bodies of surface water. There are three types of surface water: perennial, ephemeral, and man-made. Perennial, or permanent, surface water persists throughout the year and is replenished with groundwater when there is little precipitation. Ephemeral, or semi-permanent, surface water exists for only part of the year. Ephemeral surface water includes small creeks, lagoons, and water holes (Nganje *et al.*, 2010). Man-made surface water is found in artificial structures, such as dams and constructed wetlands.

Since surface water is more easily accessible than groundwater, it is relied on for many human uses. It is an important source of drinking water and is used for the irrigation of farmland. In 2015, almost 80 % of all water used in Nigeria came from surface water (WHO, 2015). Wetlands with surface water are also important habitats for aquatic plants and wildlife. The planet's surface water can be monitored using both surface measurements and satellite imagery. The flow rates of streams are measured by calculating the discharge, that is, the amount of water moving down the stream per unit of time at multiple points along the stream. Monitoring the flow rate of streams is important as it helps determine the impact of human activities and climate change on the availability of surface water. Keeping track of vegetation around bodies of surface water is also important. The removal of vegetation, either through natural means such as fires, or through deforestation, can have a negative impact on surface water. Loss of vegetation can lead to increased surface runoff and erosion, which in turn can increase the risk of flooding.

### 2.2.2 Groundwater

Groundwater is also a major source of freshwater for domestic, agricultural and industrial uses, and approximately 97 % of the earth's useable freshwater is stored as groundwater (Delleur, 1999). Approximately 40 and 70 % of the total global water resources being used for irrigation and domestic purposes are groundwater, and these values could be increased due to the continuous decline in the quantity and quality of available surface water resources which are largely caused by increase in global pollution threats, industrialization and urbanization, as well as the effects of the climate change (Qiu, 2010). Hydrogeochemistry of groundwater is determined by its chemical and biochemical constituents. The suitability of a particular groundwater for certain utilities such as public water supply, irrigation, industrial application, cooling, heating, power generation largely depends on sediments, lithologic content, temperature, possible temporal variations caused by climatic conditions as well as water quality status (Vetrimurugan *et al*., 2012). The chemistry of groundwater is due to several processes like soil/rock-water interaction during recharge and groundwater flow, prolonged storage in the aquifer, dissolution of mineral species (Sekabira *et al*., 2010). These processes are related to weathering of minerals which exerts an important control on groundwater chemistry (Kim, 2002). This process generally dominates the concentration of the major cations (Ca, Mg, Na, K) in groundwater (Kim, 2002; 2003).

The geology has been put as the principal factor controlling the chemistry of groundwater in terms of water types and the processes. The main processes include chloride dissolution for saline and coastal groundwater aquifers and a combination of silicate, carbonate weathering and ion exchange for the different aquifers in the various basins and the basement complex areas. In respect of agricultural uses, groundwater from different areas were put to be of low-salinity and low-alkalinity hazard, good to excellent quality for irrigation on the basis of Na %, sodium absorption ratio (SAR) and Residual Sodium Carbonate (RSC) (Ogunbanjo, 2004; Olobaniyi and Owoyeni, 2004; Adediji and Ajibade, 2005; Ofoma *et al*., 2005 and Nganje *et al*., 2010).

### 2.2.3 Spring Water

A spring is a point at which water flows from an aquifer to the Earth's surface. It may be the result of karst topography where surface water has infiltrated the Earth's surface (recharge area), becoming part of the area groundwater. The groundwater then travels through a network of cracks and fissures openings ranging from inter-granular spaces to large caves (Vetrimurugan *et al*., 2012). The water eventually emerges from below the surface, in the form of a karst spring. The forcing of the spring to the surface can be the result of a confined aquifer in which the recharge area of the spring water table rests at a higher elevation than that of the outlet. Spring water forced to the surface by elevated sources are artesian wells. This is possible even if the outlet is in the form of a 300-foot-deep (91 m) cave. In this case the cave is used like a hose by the higher elevated recharge area of groundwater to exit through the lower elevation opening. Non-artesian springs may simply flow from a higher elevation through the earth to a lower elevation and exit in the form of a spring, using the ground like a drainage pipe. Springs can also be formed as a result of pressure from an underground source in the earth, in the form of volcanic activity. The result can be water at elevated temperature such as a hot spring. Spring discharge, or resurgence, is determined by the spring's recharge basin. Factors that affect the recharge include the size of the area in which groundwater is captured, the amount of precipitation, the size of capture points, and the size of the spring outlet. Water may leak into the underground system from many sources including permeable earth, sinkholes, and losing streams. Human activity may also affect a spring's discharge while the withdrawal of groundwater reduces the water pressure in an aquifer, decreasing the volume of flow (Vetrimurugan *et al*., 2012).

## 2.3 Water Quality

### 2.3.1 Physical Characteristics

Physical contaminants primarily impact the physical appearance or other physical properties of water. The physical parameters usually measured for water quality analysis include pH, temperature, turbidity, electrical conductivity, total dissolved solids and total suspended solids. Examples of physical contaminants are sediment or organic material suspended in the water of lakes, rivers and streams from soil erosion (WHO, 2017). Physical contamination refers to contamination affecting physical properties of water such as coloration, odor, and pH. Such contamination of water does not directly harm people’s bodies, but domestic use of the water is very harmful (WHO, 2017). Problems related to the contamination affecting physical properties are color contamination, offensive odors, corrosiveness (pH), turbidity. Color contamination of water bodies is caused by metals, dye pollution, soil particles, and by the occurrence of water bloom (WHO, 2017). Offensive odor and taste of water are caused by metals and by microorganisms that produce musty odors. Because residents are distressed if their drinking water and other domestic use water is colored or smells badly, water treatment must completely remove colored or malodorous constituents of water. If the pH value of a water body is far from neutral, it affects the growth of living organisms of the ecosystem, and high acidity of soil or agricultural water prevents the growth of plants and agricultural products and pH is, therefore, an important index of environmental contamination. Electrical conductivity is a measure of the amount of dissolved salts in water and an excellent indicator of salinity. Low EC value indicates low concentration of dissolved salts and it implies that salinity of the water samples is low and vice versa. Total dissolved solids represent the total concentration of dissolved substances in water. Turbidity measures relative clarity of a liquid and high concentration of particulate matters affects light penetration. Total suspended solids include anything drifting or floating in the water, from sediment, silt, and sand to plankton and algae. High total suspended solid decreases water's natural dissolved oxygen levels and block sunlight which may halt photosynthesis resulting to death of aquatic organisms.

### 2.3.2 Chemical Characteristics

Exposure of several individuals to unsafe levels of chemical contaminants in drinking water has been reported (WHO, 2017). This lends credence to the important of monitoring the level of metals in surface or groundwater sources in other to determine their potability (UNEP, 2007). Chemicals are among the major contaminants affecting groundwater quality. This is possible through vertical migration of chemical contaminants to the aquifer and extending to the borehole, or by horizontal migration through permeable soils, joints and faults to water supplies that are poorly constructed or have been disrupted by tectonic activities (MacDonald and Calow, 2009). Heavy metals and organics such as polyaromatics hydrocarbon (PAH), polychlorinated biphenyls (PCB), polybrominated diphenyl ethers (PBDE) are also major chemical contaminants of drinking water sources, and of course, a potential threat to public health.

### 2.3.3 Bacteriological Characteristics

Microorganisms are major contaminants of drinking water sources, especially in developing countries like Nigeria, and their presence could have deleterious effect on her citizenry (NSDWQ, 2015). The research has shown that drinking water sources in Nigeria, are frequently contaminated with microorganisms above the permissible limit and are therefore unfit for consumption (Amadi, 2014). Studies have shown that there are fewer functional government water supply to residential homes in Nigeria major cities, with majority of the people, having to depend on borehole as their major source of water supply (Anochie *et al*., 2018). Most of the water obtained from the boreholes are not further subjected to any form of purification, either because of ignorance or the high poverty burden (Anochie *et al*., 2018). The high rate of inequality with respect to water and sanitation is unimaginably high in Nigeria, with a large part of the population also depending on satchet-packed and bottled water as their primary source of drinking water (Amadi *et al*., 2014). Analysis of most of the vended water (satched-packed and bottled) have been reported to be highly contaminated with microorganisms, including *coliform* and *pathogenic bacteria*. Samuel *et al*. (2019) reported *pathogenic bacteria* and *coliform* from borehole samples from Anambra State. Similar outcome was reported in Rivers State (Obioma *et al*., 2017) and Edo State (Foka *et al*., 2018). This is evident in the number of documented outbreaks of water-borne diseases such as cholera, diarrhea, dysentery and typhoid. It is worthy of note that the Nigeria Center for Disease Control (CDC) reported outbreaks of cholera in 20 different states out of 36, between January and October, 2018, with a fatality rate of 1.95 % (Elimian *et al*., 2019; NCDC, 2019).

## 2.4 Water Quality Indices

Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned stakeholders. It has become a useful tool for the assessment and management of water parameters (Amadi, 2014). WQI scale which helps to estimate an overall quality of water based on the values of water quality parameters. It expresses the overall water quality at a certain location and time based on several water quality parameters. The word “Water Quality” is a widely used expression, which has a broad spectrum of meaning depending upon each individual interest of water for an intended use. The objective of WQI is to turn complex water quality data into information that is understandable and usable by public (Amadi, 2014).

Over the years a decision as regards quality of water is made using a series of methods and can be expressed using several scores of parameters obtained from water analysis in the laboratory. In response to the need for a uniform understandable yardstick of water quality, water scientists worked out to compile all the water quality parameters into what is now known as the Water Quality Index (WQI).

## 2.5 Water Sources Contamination

### 2.5.1 Sources of Contaminants

Water can be contaminated by geogenic and by anthropogenic activities such as agriculture, industrial operations, landfills, animal operations, and sewage treatment processes, among many other things. As water runs over the land or infiltrates into the ground, it dissolves material left behind by these potential contaminant sources (Amadi *et al*., 2014). Sources of surface water contamination are generally grouped into two categories based on their origin namely, point and non-point sources. Point source water contamination refers to contaminants that enter a waterway from a single, identifiable source, such as a pipe or ditch. Examples of sources in this category include discharges from a sewage treatment plant, a factory, or a city storm drain. Nonpoint source pollution refers to diffuse contamination that does not originate from a single discrete source. It is often the cumulative effect of small amounts of contaminants gathered from a large area. A common example is the leaching out of nitrogen compounds from fertilized agricultural lands. Nutrients runoff in stormwater from “sheet flow” over an agricultural field or a forest is also cited as examples of NPS pollution.

Interactions between groundwater and surface water are complex. Consequently, groundwater contamination is not easily classified as surface water contamination. By its very nature, groundwater aquifers are susceptible to contamination from sources that may not directly affect surface water bodies, and the distinction of point vs. non-point may be irrelevant. A spill or ongoing release of chemical or radionuclide contaminants into soil (located from a surface water body) may not create point source or non-point source contamination, but can contaminate the aquifer below, defined as a toxin plume. The movement of the plume, called a plume front, may be analyzed through a hydrological transport model or groundwater model. Analysis of groundwater contamination may focus on the soil characteristics and site geology, hydrogeology, hydrology, and the nature of the contaminants. Contaminants in water are derived from different sources (industrial, geological and anthropogenic). The surge in anthropogenic activities and natural processes such as erosion, precipitations, weathering and degradation have made most water sources unsuitable for purpose (Furham *et al.*, 2004). Below are some of the major sources of contaminants of drinking water sources:

**Agricultural Activities**: Chemical contaminants can be released from agricultural run-offs which contain nitrogen compounds and phosphorus from livestock waste, fertilizers and pesticides used during agricultural practices. In Nigeria, agriculture is a major occupation for a large majority of the populace. Lack of good laws guiding indiscriminate disposal of agricultural wastes has led to significant contamination of the water bodies which serve as sources of drinking water to different communities. Livestock production activities and wastes have been identified as major sources of pollution to river bodies, especially when poorly managed (Kato *et al.*, 2009). Additionally, open grazing is still the major mode of raising livestock in Nigeria and these farm animals are usually led in their numbers to the water bodies (rivers, streams, well and boreholes) for drinking at least twice a day (Nur, 2004). In the process, animal faces and urine are released, which contaminate water bodies and thus, render the water body unsafe for consumption by the surrounding communities (Nur, 2004). This problem is aggravated since in many communities in Nigeria, there are no access to treated pipe-borne water for drinking and as well as for other domestic uses. The runoff of animal waste into surface water is reported to pose great risk of pollution (Kwadzah and Iorhemen, 2015).

Rim-Rukeh *et al*. (2006) evaluated how agricultural activities impacted on the quality of Orogodo River in Delta State, Nigeria. This was carried out in a research study that involved 100 farmers' from Agbor and Owa communities. These farmers were asked questions on the frequency and method of irrigation practices they have adopted during different farm practices, most especially the use of fertilizers which normally result in water pollution. The sampling of the river was carried out at five different sampling stations along the river selected by testing the physicochemical properties of the river. The authors reported that the method adopted by the farmers constituted a major reason why the selected river was highly polluted. The difference in the selected parameters tested was linked to the runoff from farmlands and the capability of the river to undertake self-purification. The study also suggested that the contamination of Jakara River at both upstream and downstream and its use for irrigation purposes on vegetables could lead to the bioaccumulation of such heavy metals along the food chain (Rim-Rukeh *et al*., 2006).

Orheruata and Omoyakhi (2008) also reported agricultural waste from poultry as an important source of pollution affecting the quality of drinking water in Nigeria. Adegbola *et al*. (2012) assessed the effect of some sources of pollution on groundwater quality in wells from Gambari community in Ogbomosho, Nigeria. They reported that the most polluted wells that shown minimal satisfactory level were linked to their proximity to cassava processing and milling industry.

**Industrial effluents:** Industrial effluent is another major source of chemical contaminants of drinking water sources in Nigeria. Industrial effluents mostly contain heavy metals, hydrocarbons, and atmospheric deposition (Alam *et al*., 2007). Industrial effluents loaded with heavy metals and harmful microbes can be hazardous when it gets into the food chain through the soil and water bodies and can affect plants, animals and humans adversely (Deshmukh *et al*., 2011; Bai *et al*., 2012). Wastewaters from most industries in Nigeria are disposed into water bodies (Kanu and Achi, 2011). Interestingly, many of these industrial effluents are discharged untreated into water bodies, partly because of weak regulations, thereby contaminating the receiving surface and ground waters. Reports have shown that effluents from pharmaceutical industry (Bakare *et al*., 2009; 2011), hospitals (Iyekhoetin *et al*., 2011), universities (Alabi *et al*., 2012), tobacco industry (Alabi *et al*., 2014), automobile workshops (Alabi *et al*., 2016) and cocoa industry (Alabi *et al*., 2017) contained heavy metals such as lead, zinc, cobalt and other chemical constituents in high concentrations capable of contaminating drinking water sources and lead to public health detrimental effects.

**Leachates:** Dumpsites and landfills are major sources of leachate which contributes to chemical contaminants of surface and ground waters. Leachates are known to contain contaminants such as organic matters, ammonium, magnesium calcium, sodium, sulphate, potassium, iron, heavy metals (e.g. Cr, Cd, Cu, Pb, Ni, Zn) etc. These contaminants not only have the potential to penetrate and pollute soils but can significantly impact surface and ground water. The magnitude of the threat posed by leachates is a function of the concentration and toxicity of the constituents, depth of water table, and direction of groundwater flow. Phthalate esters (PAEs) from landfill have been reported to significantly contribute to the contamination of groundwater (Liu *et al*., 2010). Also, groundwater around a municipal landfill site has been reported to contain inorganic contaminants to the extent that shallow ground water near landfill sites are considered unsuitable for drinking (Han *et al*., 2014). Porowska (2015) used stable carbon isotopes to determine the source of inorganic carbon in groundwater near a reclaimed landfill and found 47-80 % of dissolved inorganic carbon reportedly from the biodegradation of organic matter in the landfill and then positioned that the surrounding groundwater was contaminated by leachate from the landfill.

**Oil spill:** Crude oil is a mixture of many different hydrocarbons which is known to be highly toxic, causing damage to natural and semi natural ecosystems including aquatic systems (Dawes, 1998). During oil spill, pollutants such as benzene, polyaromatic hydrocarbon (PAHs), grease, oil and heavy metals are introduced into aquatic ecosystems. In southern Nigeria, Ifelebuegu *et al*. (2017) showed alteration of the physicochemical parameters of drinking water sources due to pollution by petroleum hydrocarbon. The findings indicated significant alteration of water quality in some rivers due to oil exploration and other related activities. The values obtained for turbidity, total suspended solid, total dissolved solid, dissolved oxygen, electrical conductivity and heavy metals (e.g. Cu, Pb, Ni, Cd, Cr and Zn) were found to be higher than the recommended limits for drinking water. Many rivers and streams have been chemically polluted and rendered unsuitable for drinking, cooking and other domestic uses because of the constant oil spillage in Nigeria. Many aquatic lives have been lost and human consumption of organisms from these contaminated waters pose serious health problems due to bioaccumulation of chemical contaminants in the food chain. Due to the persistent nature of oil spillage, contamination of water sources remains a serious problem which would persist for a long period of time, thereby causing quality water shortage.

In the Niger Delta region, many studies have documented the effects of oil spillage on water sources (UNEP, 2011; Linden and Palsson, 2013; Alinnor *et al*., 2014; Onyegeme-Okerenta *et al*., 2017). A study by Lindén and Pålsson (2013) reported high level of petroleum hydrocarbon contamination of rivers, creeks, and ground waters in Ogoni land. This is of serious negative impact on human health and the ecosystem. It is not uncommon that a plethora of petroleum hydrocarbon spills sometimes occur due to leaks from decrepit infrastructure, aged facilities and pipelines as well as oil spillage during transportation, and other man-made causes (Ite *et al*., 2013; Lindén and Pålsson, 2013). A recent study by Onyegeme-Okerenta *et al*., (2017) showed that water quality of some rivers and streams in Uzere, a community in Niger Delta, is impaired following the incidence of crude oil spillage in the community.

Similarly, Ifelebuegu *et al*., (2017) investigated the impact of crude oil spills on the physicochemical, microbial and hydro biological properties of the Nun River and reported that the physicochemical parameters and heavy metals (e.g. Cr, Cd Pb, Cu, Ni and Zn), total dissolved solid, turbidity, total suspended solid, dissolved oxygen, electrical conductivity, of the river failed to meet the adequate and recommended limits for drinking water. Also, the water quality parameters were seriously compromised due to oil exploration and other related activities. In another study, Tongo *et al*. (2017) showed that acenaphthylene, naphthalene, and fluoranthene were common pollutants in Ovia River in Edo State, Nigeria. Furthermore, the concentrations of individual PAHs recorded in Ovia River were significantly higher than the recommended or permissible concentration.

Due to contamination of drinking water sources, especially in the southern parts of Nigeria, most locals resort to drilling borehole as their drinking water source. However, discharged petroleum hydrocarbons often sink into groundwater thereby polluting these ground waters (Frynas, 2000; Yakubu, 2017). Alinnor *et al*. (2014) collected and analysed groundwater from five communities in the Niger Delta region and reported that the water samples from varying depth were contaminated with petroleum hydrocarbons. Following an analyses of some drinking water samples from wells, also in the oil rich Niger Delta region, the United Nations Environment Programme detected high levels of benzene concentrations. The benzene levels were about 1800 times higher than the drinking water allowable limit set by the United States Environmental Protection Agency (USEPA) (UNEP, 2011; Kponee *et al*., 2015) and over 900 times higher than the acceptable limit set by the WHO for drinking water (UNEP, 2011).

**Municipal waste:** Kayode *et al*. (2018) evaluated the effects of municipal waste dumpsite on the quality of drinking water obtained from groundwater around Oke-Afa, Oshodi/Isolo area of Lagos state, Nigeria. They assayed water samples from two boreholes and eighth hand-dug wells using standard procedures. The results showed high levels of heavy metals especially barium (Ba) and aluminum (Al) which occurred in high values when compared to the stipulated limits for potable drinking water by World Health Organization. Aboyeji *et al*. (2016) also evaluated the effect of leachates generated from municipal solid waste dumpsites on the water qualities from fifteen boreholes and five wells along downslopes of the dumpsite around Olusosun in Lagos metropolis. The quality of the water sources were evaluated using water quality index rating and geospatial techniques. The results obtained from the heavy metal and physicochemical parameters revealed that the water quality were unfit for human consumption because the values obtained fell below the range recommended by WHO for potable drinking water.

The findings of Aboyeji (2016) further showed that there are no impervious soil structures that could prevent the seepage of the leachates into the aquifer that are close to the dumpsite. In another study conducted by Usman *et al*. (2016) on the influence of liquid and solid wastes on groundwater quality, they obtained water samples from different boreholes at some specific distances from dumpsites and analyzed its physicochemical and heavy metals concentrations. The results obtained indicated the absence of lead (Pb) from all the samples while chromium (Cr) and manganese (Mn) were above the WHO (2015) standard limit for drinking water sources. The microbiological analyses showed the presence of *E. coli* and other *coliform bacteria* in the tested samples.

Olagunju *et al*. (2018) reported on the environmental impact assessment of soil and groundwater around Ilokun waste dumpsite. Seven (7) samples each for soil and water analyses around the dumpsite were collected out of which five (5) water samples were obtained from hand dug well while two (2) other water samples were obtained from borehole. In all the samples investigated, the results obtained exceeded the permissible limits of World Health Organization (2017) and Nigerian Standard for Drinking Water Quality (2015). The study by Karshima (2016) detailed more on the consequence of poor municipal waste management on human health. In the report, sources of potential hazards which included flooding from drain obstructions, water pollution by feces and discharge of heavy metal constituents from municipal solid waste are highlighted.

**Scrap Yards:** Scrap yards contain unwanted, dumped metal parts from different sources. In most of the scrap yards in Nigeria, car parts and electronic wastes are the major constituents. Different informal recycling activities are very common at the scrap yards with scavengers picking different metal parts for repair or sale. The scrap yards contaminate the soil due to leaching and can contaminate water bodies during raining season especially as run-offs. Also, acid bath used by scavengers during informal recycling at the scrap yards can cause the release of chemical contaminants. The study of Ojekunle *et al.* (2016) revealed that there could be significant discharge of hazardous heavy metals in the water bodies as a result of seepage and uncontrolled activities in Ikorodu, Lagos State and Lafenwa scrap yards in Abeokuta, Ogun State respectively. High concentrations were reported in the physicochemical parameters and heavy metals analyzed in the surface water from most of sampling locations. On comparison of the results to the limits set by the

Nigerian Standard for Drinking Water Quality (NSDWQ, 2015), their results exceeded the permissible limits.

**Abattoir Activities:** Indiscriminate discharge of untreated abattoir effluents is another source of water contamination when it is directly transported into ground or surface water bodies, resulting in serious surface and ground water contamination. Abattoirs are located indiscriminately in Nigeria and usually near water sources since the process requires a lot of water and for ease disposal of wastes (Omoruyi *et al.*, 2011). Abattoirs effluents have been reported to markedly increase the amounts of nitrogen, phosphorus and total solids in contiguous water bodies (Bello-Osagie and Omoruyi, 2012). The high biochemical oxygen demand (BOD), nutrients and pathogen content in abattoir waste poses pollution risk to water bodies (Matsumura and Mierzwa, 2008; Keskes *et al.*, 2012). In Nigeria, study of Omole and Longe (2008) showed that the quality of a surface water was impacted negatively by the activities of abattoir, with water quality parameters including total suspended solid (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and heavy metals including cadmium (Cd), lead (Pb), and copper (Cu) above the permissible limits by regulatory authorities. Kwadzah and Iorhemen (2015) reported that animal processing and trading activities at Tudun Wada abattoir River Kaduna water quality. The study found higher concentrations of BOD, COD, nitrate-nitrogen, ammonia-nitrogen, total nitrogen and total phosphorus in the river water. In addition, higher concentrations of these parameters were found downstream than upstream, an indication of the negative impact of the abattoir wastewater discharge into the river.

### 2.5.2 Effects of Water Contaminants

The consequences of contaminated groundwater or degraded surface water are often serious. Contamination of groundwater can result in poor drinking water quality, loss of water supply, degraded surface water systems, high cleanup costs, and high costs for alternative water supplies, and/or potential health problems. For example, estuaries that have been impacted by high nitrogen from ground water sources have lost critical shellfish habitats (Amadi *et al*., 2014). In terms of water supply, in some instances, ground water contamination is so severe that the water supply must be abandoned as a source of drinking water. In other cases, the ground water can be cleaned up and used again, if the contamination is not too severe and if the municipality is willing to spend for the water treatment though subsequent follow-up water quality monitoring is often required for many years for sustainable of good water quality (Amadi *et al*., 2014).

Contamination of the groundwater may remain undetected for long periods of time because of its slow movement and often time this makes cleanup of a contaminated water supply difficult, if not impossible. If a cleanup is to be undertaken, it can cost thousands to millions of dollars. Once the contaminant source has been controlled or removed, the contaminated groundwater can be treated in one of several ways such as containing the contaminant to prevent migration, pumping the water, treating it, and returning it to the aquifer, leaving the ground water in place and treating either the water or the contaminant and allowing the contaminant to attenuate (reduce) naturally (with monitoring), following the implementation of an appropriate source control (Amadi *et al*., 2014).

Selection of the appropriate remedial technology is based on site-specific factors and often takes into account cleanup goals based on potential risk that are protective of human health and the environment. The technology selected is one that will achieve those cleanup goals. Different technologies are effective for different types of contaminants (Amadi *et al*., 2014), and several technologies are often combined to achieve effective treatment. The effectiveness of treatment depends in part on local hydrogeological conditions, which must be evaluated prior to selecting a treatment option.

Given the difficulty and high costs of cleaning up a contaminated aquifer, some communities choose to abandon existing wells and use other water sources, if available. A community might decide to install new wells in a different area of the aquifer. In this case, appropriate siting and monitoring of the new wells are critical to ensure that contaminants do not move into the new water supplies.

A number of microorganisms and thousands of synthetic chemicals have the potential to contaminate ground water (Nur *et al*., 2014). Drinking water containing bacteria and viruses can result in illnesses such as hepatitis, cholera, or giardiasis. Methemoglobinemia or “blue baby syndrome,” an illness affecting infants, can be caused by drinking water that is high in nitrates. Benzene, a component of gasoline, is a known human carcinogen. The serious health effects of lead are well known—learning disabilities in children; nerve, kidney, and liver problems; and pregnancy risks. Concentrations in drinking water of these and other substances are regulated by federal and state laws. Hundreds of other chemicals, however, are not yet regulated, and many of their health effects are unknown or not well understood. Preventing contaminants from reaching the ground water is the best way to reduce the health risks associated with poor drinking water quality.

### 2.5.3 Mitigation of Water Contamination

Water sources contamination is a serious problem that is growing in the world, but its true extent is not known and it is difficult to determine because of the complexities of contaminants, their transformation, and fate in groundwater systems. It is also difficult to predict their movement in groundwater. Since we know that the problem is serious and that our needs for groundwater will grow, the mitigation of groundwater contamination, despite the high cost, is necessary (Sekabira *et al*., 2010). Successful mitigation requires that we determine which microbial and chemical contaminants are the most serious threats to human health, develop the technology to biologically, chemically, and physically transform hazardous waste into nonhazardous materials; develop the technology to properly contain hazardous materials and to remediate contamination, and determine the effects of those hazardous materials on soils and water microorganisms and macro-organisms (Vetrimurugan *et al*., 2012). Water sources contamination can be mitigated through regulation, bioremediation, and watershed management.

**Regulation:** During the early1900s, rapid industrialization in the U.S. resulted in widespread water pollution due to free discharge of waste into surface waters. The Cuyahoga River in northeast Ohio caught fire numerous times, including a famous fire in 1969 that caught the nation's attention (WHO, 2017). In 1972 Congress passed one of the most important environmental laws in U.S. history, the Federal Water Pollution Control Act, which is more commonly called the **Clean Water Act** (CWA). The purpose of the Clean Water Act and later amendments is to maintain and restore water quality, or in simpler terms to make our water swimmable and fishable. It became illegal to dump pollution into surface water unless there was formal permission. The CWA regulates pollution from a single source such as that from industry or sewage treatment plants by setting pollution standards (maximum levels of each pollutant that can be in bodies of water or released at a time). United States water quality improved significantly as a result but there is still more work to be done (Vetrimurugan *et al*., 2012).

**Remediation:** Remediation is the act of cleaning contamination in the environment and it can be categorized into bioremediation, chemical remediation and physical remediation. Biological remediation (**bioremediation**) is a waste management technique that involves the use of organisms such as plants, bacteria, and fungi to remove or neutralize pollutants from a contaminated site (Vetrimurugan *et al*., 2012). According to the United States EPA, bioremediation is a "treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or nontoxic substances" (USGS, 2009). This type of remediation is usually used on organic chemicals but also works on reducing or oxidizing inorganic chemicals like nitrate. Phytoremediation is a type of bioremediation that uses plants to absorb the chemicals over time (Vetrimurugan *et al*., 2012).

Bioremediation is widely used to treat human sewage and has also been used to remove agricultural chemicals (pesticides and fertilizers) that leach from soil into groundwater. Certain toxic metals, such as selenium and arsenic compounds, can also be removed from water by bioremediation (WHO, 2017). Mercury is an example of a toxic metal that can be removed from an environment by bioremediation. Several species of bacteria can carry out the biotransformation of toxic mercury into non-toxic forms. These bacteria, such as *Pseudomonas aeruginosa*, can convert a charged form of mercury ($Hg^{2+}$) to an uncharged form (Hg), which is less toxic to humans (WHO, 2017).

Probably one of the most useful and interesting examples of the use of prokaryotes for bioremediation purposes is the cleanup of oil spills. To clean up these spills, bioremediation is promoted by adding inorganic nutrients that help bacteria already present in the environment to grow. Hydrocarbon-degrading bacteria feed on the hydrocarbons in the oil droplet, breaking them into inorganic compounds. Some species, such as *Alcanivorax borkumensis*, produce surfactants that break the oil into droplets, making it more accessible to the bacteria that degrade the oil

(MacDonald and Calow, 2009). In the case of oil spills in the ocean, ongoing, natural bioremediation tends to occur, inasmuch as there are oil-consuming bacteria in the ocean prior to the spill. Under ideal conditions, it has been reported that up to 80% of the non-volatile components (those that do not readily evaporate) in oil can be degraded within one year of the spill. Researchers have genetically engineered other bacteria to consume petroleum products; indeed, the first patent application for a bioremediation application in the U.S. was for a genetically modified oil-eating bacterium (MacDonald and Calow, 2009).

There are a number of cost/efficiency advantages to bioremediation, which can be employed in areas that are inaccessible without excavation. For example, hydrocarbon spills (specifically, oil spills) or certain chlorinated solvents may contaminate groundwater, which can be easier to treat using bioremediation than more conventional approaches (MacDonald and Calow, 2009). This is typically much less expensive than excavation followed by disposal elsewhere, incineration, or other off-site treatment strategies. It also reduces or eliminates the need for “pump and treat”, a practice common at sites where hydrocarbons have contaminated clean groundwater. Using microorganisms for bioremediation of hydrocarbons also has the advantage of breaking down contaminants at the molecular level, as opposed to simply chemically dispersing the contaminant (Nester *et al*., 2004).

Chemical remediation uses the introduction of chemicals to remove the contaminant or make it less harmful. One example is reactive barriers, a permeable wall in the ground or at a discharge point that chemically reacts with contaminants in the water. Reactive barriers made of limestone can increase the pH of acid mine drainage, making the water less acidic and more basic, which removes dissolved contaminants by precipitation into a solid form. Physical remediation consists of removing the contaminated water and either treating it pump and treat with filtration or disposing of it. All of these options are technically complex, expensive, and difficult, with physical remediation typically being the most costly (Nester *et al*., 2004).

**Watershed Management:** It involves reducing chemicals applied to land in the watershed (which will drain into a body of water) and runoff of those chemicals. This strategy is more effective for non-point source pollution than setting pollution standards (as the CWA does) because it does not require each source of pollution be identified (Gizaw *et al*., 2018). A watershed is the geographical area drained by a watercourse. The concept applies at various scales – from, for example, a farm drained by a creek (a "micro-watershed") to a large river basin (or a lake basin). A river basin usually comprises a complex system of watersheds and micro-watersheds crossed by and draining into a major river and its tributaries, from the beginning of the river (its "source") to its mouth and a lake basin may be defined as a geographic land area draining into a lake). Because soils and vegetation are intimately linked to the water cycle, watersheds are the most useful planning unit for integrated water and land resource management (Gizaw *et al*., 2018).

Forests and trees play crucial roles in hydrological processes in watersheds. Forested mountain and upland watersheds supply an estimated (70 %) of the world's accessible freshwater resources for domestic, agricultural, industrial and ecological needs (UNEP, 2011). Watershed services and functions may be threatened by deforestation, uncontrolled timber harvesting, changes in farming systems, overgrazing, roads and road construction, pollution, and the invasion of alien plants. They may also be affected by natural disturbances such as wildfires, windstorms and disease. The deterioration of watershed functions has significant negative impacts, potentially leading to erosion and the depletion of soil productivity; the sedimentation of watercourses, reservoirs and coasts; increased runoff and flash flooding; reduced infiltration to groundwater; reduced water quality; and the loss of aquatic habitat and biodiversity (UNEP, 2011).

Watershed management considers the management and conservation of all available natural resources in a comprehensive way. It provides a framework for integrating different land-use and livelihood systems forestry, pasture and agriculture, using water as the "entry point" in the design of interventions. Watershed management aims to preserve the range of environmental services especially hydrological services provided by a watershed and to reduce or avoid negative downstream impacts while, at the same time, enhancing resource productivity and improving local livelihoods (UNEP, 2011).

## 2.6 Previous Studies

In Nigeria, less than one-third of urban and rural dwellers have access to piped water supply (WHO/UNICEF, 2014) for drinking, and those with piped water still experience unreliable, poor quality service (Kumpel *et al*., 2016). Most households rely on public standpipes and non-piped water supplies, such as hand-dug wells, boreholes, springs and water vendors (WHO/UNICEF, 2014). These sources of drinking water are classified as "improved drinking water sources" (WHO, 2011). Improved drinking water source can be defined as a source that is adequately constructed in such a way that the source is protected especially from faecal matters and other contaminations from outside (WHO/JMPR, 2013). Other sources like rivers, streams, lakes and ponds from surface are classified as "unimproved drinking water sources (WHO, 2011)". Streams and rivers which have become important sources of water for cooking and drinking in remote villages and slums are faced with environmental contaminations from discharges or effluents from abattoirs or sewage especially downstream (Omole and Longe, 2008) and from industrial wastewater (Bello-Osagie and Omoruyi, 2012) remains of major public health concern. Drinking water contamination by different microorganisms such as Escherichia coli, coliforms (Kumpel *et al*., 2016), *Staphylococcus aureus* and *Pseudomonas species* have been reported in Nigeria. Also, the presence of metals like iron, calcium, chromium and aluminium have been found in surface water (Titilawo *et al*., 2018) and sachet-packed water (Emenike *et al*., 2018), including cadmium, lead, manganese and nickel in groundwater (Ayedun *et al*., 2015) above permissible levels for drinking water. Other contaminants such as fluoride (Emenike *et al*., 2018) and light polycyclic aromatic hydrocarbons have also been reported to be present in groundwater in levels above permissible limits in some locations in Nigeria (Adekunle *et al*., 2017).

It is estimated that there are about 1.1 billion people with limited access to adequate water supplies, which resulted in the outbreak of diarrhea (about 4 billion cases) and death (about 5 million per annum) worldwide (WHO, 2015). Bacterial contamination of drinking water is a major contributor to water-borne diseases in rural areas of most developing countries where water sources are communally shared (Nguendo-Yongsi, 2011; Delaire *et al*., 2017) and exposed to multiple faecal-oral transmission pathways in their neighbourhood boundaries (Theveron *et al*., 2012; Jung *et al*., 2017). *Escherichia coli* (*E. coli*) infections associated with drinking contaminated water remain a major public health concern as its presence signifies fatal illnesses such as diarrhoea (Theveron *et al*., 2012; Martinez-Santos *et al*., 2017). The World Health Organization (WHO) estimates that diarrhoeal disease due to exposure to unsafe drinking water, inadequate sanitation and hygiene practices contribute to more than 25 % of reported global environmental burden of the disease (Harris *et al*., 2017).

In sub-Saharan Africa, with deteriorating environments attributed to high levels of open defecation, drinking water sources remain vulnerable to faecal contamination (Harris *et al*., 2017; Njuguna, 2016). Approximately 215 million people practice open defecation (Njuguna, 2016), a major source of transmission mode of pathogens that cause diarrhoeal diseases. *E. coli* is the most common cause of diarrhoeal diseases infections as well as human gastro- intestinal tract infections caused by ingestion of unsafe drinking water in children in low-income countries (Gizaw *et al*., 2018). According to Gizaw *et al*. (2018), a greater proportion of intestinal parasitic infections in sub-Saharan African countries is associated with poor water, sanitation and hygiene conditions and most of the infections are faecal-oral. Harris *et al*. (2017) also characterized the relationship between sanitation and the risk of water contamination in rural Mali, concluding that *E. coli* concentrations in communal water sources were significantly associated with poor neighbourhood sanitation practices. Poor socio-economic status of communities enhances and/or increases open defecation rates and unhygienic practices increasing the transmission of bacterial pathogens into water sources (Berendes *et al*., 2017).

In Lesotho's rural areas, diarrhoea illnesses are a severe public health problem and a major cause of morbidity and mortality in infants and young children and most of it is related to faecal pollution of water sources from poor environmental hygiene and sanitation (Ramaili, 2006). Approximately 70 % of the population practice open defecation, and it is estimated that the child mortality rate was 85.9 deaths per 1000 live births in 2017 (UNICEF Data, 2018; Motsima, 2016). Exposures to faecal contamination occur at the community-scale via contaminated public water sources originating from within the community. Over the years, studies have shown that shortages of clean water are associated with improper management, alarming population growth, unfavourable policy implementation of water-related projects and upsurge in industrial activities (Sibanda *et al*., 2014; Kora *et al*., 2017). These dynamics are also known to unpleasantly affect the access, availability, distribution, provision and quality of water and associated resources (Igbinosa and Okoh, 2009; Liang *et al*., 2013). There is need for urgent interventions to prevent water shortages, particularly in developing countries like Nigeria where significant reports of waterborne infections and diseases such as diarrhea, cholera and typhoid occur as a consequence of poor sanitation and poverty (Coleman *et al*., 2013; Igbinosa and Aighewi, 2017). Over 66 million Nigerians in the cities and rural areas lack access to portable drinking water supply, and this has resulted to an increase in the consumption of contaminated or polluted water (WHO, 2015; Ologbushere *et al*., 2016; Beshiru *et al*., 2018) with potential detrimental public health effects.

Increase in demand for water resources globally occurs essentially due to population growth and modern developments. Thus the welfare of every society is tied to the sustainable exploitation of water resources (Bear, 2000). The surface water resources cannot adequately satisfy the astronomical increasing demand for potable water in both developing and developed countries. Therefore, surface and groundwater serve as the main sources of water for domestic and industrial use but groundwater accounts for about 98 % of the world's fresh water and it is fairly well distributed throughout the world (Buchanan, 1983). Both surface and groundwater continue to serve as reliable sources of water supply in most rural and urban communities in Nigeria. They are renewable resources and their availability and use of which are influenced by many factors such as the lithology of the area, climatic patterns and water quality. However, human activities and seepage of hazardous materials into groundwater have affected its quality (Olasehinde, 1998; Ajibade *et al.*, 1982).

In Nigeria, surface and groundwater are important resources both in the rural and urban areas and are susceptible to quality degradation from poor effluent management anthropogenic activities. For instance, research carried out by Etu-Efeotor (1998) on the hydrochemical analysis of surface and groundwater at Gwagwalada area of Federal Capital Territory, Abuja revealed that there is high concentration of nitrates, phosphates and sulphates in surface water and this is believed to have resulted from the human and agricultural activities in the area. Adakole *et al*. (2010) studied the quality characteristics of water in Samaru area of Zaria showed that all the physical parameters considered conformed with the (WHO, 2011) standards, while some of the chemicals parameters like total hardness, nitrate, chloride and sulphate of the samples do not conform to the standard. Aremu *et al*., (2011) evaluated the physiochemical properties of groundwater from hand-dug wells, boreholes and stream water in Bwari and its environs. The result showed that the water is slightly acidic, soft, and fresh, have low to moderate chemical ions values and are classified as Ca-Na-$HCO_3$, Ca-K-$HCO_3$, Mg-Ca-$HCO_3$, and Na-K-$HCO_3$ water types.

Karshima, (2016) reported that over 90 % of the water samples analyzed from parts of Kaduna Metropolis is in conformity with the Nigerian Standard for Drinking Water Quality (NSDWQ, 2010) standard in term of physico-chemical quality. However, over 65 % of the samples were contaminated by coliform. This inferred anthropogenic contamination of some of the groundwater in the study area. It also indicated that the borehole water is more potable than the shallow hand dug wells. Nur *et al*. (2014) investigated on the water quality characteristics of groundwater in Jalingo metropolis showed that some of the water samples do not conform to WHO (2011) permissible standard in terms of pH, iron, magnesium and coliform count. It further stated that the water samples have generally low concentration of anions and cations and classified the dominant water type in the area as $Na^+$-$K^-$-$Cl^-$-$SO_4$ water type.

Adesida *et al*. (2005) analyzed groundwater chemistry of weathered zone aquifers of an area underlain by basement complex rocks, Akure, Nigeria. The results showed that there is a human activity imprint on the groundwater chemistry, which overshadows the normal expected influence of weathering and bedrock geology. Ako (1996) carried out the chemical quality of shallow groundwater from a metamorphic terrain of part of Southwest, Nigeria. The study concluded that the pattern of nutrient concentration between surface and groundwater investigated show that the chemistry of groundwater is dependent to a large extent on the host bedrock. Adekunle *et al*., (2017) evaluated the physico-chemical and biological quality of water sources in Southwestern, Nigeria. They attributed the contamination/pollution to some of the water analyzed to both geogenic and anthropogenic factors.

Offodile (2002) determined the impact of human activities on groundwater quality of shallow aquifers in Jimeta-Yola. The study revealed elevated concentration for contamination/pollution tracers ($NO_3$, Cl, $SO_4^{2-}$) and electrical conductivity. They suggested that the contamination is due to human activities. Olobaniyi and Owoyemi (2004) determined the groundwater quality in the deltaic plain sand aquifer of Warri area. They reported saltwater contamination in some of the samples based on high chloride content, low Ca/Mg and Na/Cl ratio. They stated that the water is suitable for domestic and industrial purposes in terms of its physico-chemical attributes. However, the presence of heterotrophic and coliform bacteria compromises this quality. Edet *et al*. (1997) assessed the contamination risk of coastal plain aquifers in Calabar by some potentially toxic elements. They concluded that the small scale mining activities, low concentration of elements, immobility of mineral species under prevailing Eh-pH conditions, dilution and precipitation of mineral phases make contamination risk of the coastal plain sand very low.

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Preliminary Studies

This process was undertaken to collect adequate data and prepare plan for an area to be studied. It included desk review which was done to collate and review published works and gather all other relevant information regarding a site's geology, hydrogeology and environmental setting and reconnaissance survey. It was also carried out to confirming the findings from the desk study in the field. Additional information relevant for the research was collected to explore site conditions and availability of needed resources.

## 3.2 Field Work

This entailed geological mapping and water sample collection. The following steps were taken during geological mapping: visual observation of lithologic units, geological features such as rivers, mountains/hills and geological structures such as faults and fractures present in the study area were identified. Water samples which were taken from different sources were properly labelled according to the location where they were sourced and obtained from. $HNO_3$ was added to the water samples labelled for cations' analysis to conserve the samples and also to prevent unwanted reactions.

**Some tools and equipment used in geological field mapping included:**

Map, geographic positioning system (GPS), compass clinometer, geological hammer, hand held lens, glass containers, plastic containers, sample bags, measuring tape, field notebook, masking tape, marker pens, field camera, safety clothing and first aid kit. The measurement of the following physical parameters such as $_P$H, temperature, electrical conductivity and total dissolved solids of both surface and groundwater samples were determined and carried out in-situ (on site) using Multi-Meter device following the standard protocols and methods of American Public Health Organization (APHA) and American Society for Testing and Materials (ASTM) (Plate II). For laboratory analysis, glass and plastic containers were used to collect sample in each location. Two drops of $HNO_3$ concentration were added to the water samples in the glass container for the determination of major cations and heavy metals to curtail chemical reaction. Glass containers were used because they are non-reactive while acid was added to prevent adsorption of heavy metals through walls of containers and microbial degradation. The samples in the plastic container were used for the determination of anion and bacteriological analysis. Samples were stored in cool boxes for transportation to the lab.

**Plate II:** Measurement of physical parameters on-site

### 3.3 Laboratory Analysis

The samples were analyzed for twenty-eight parameters which include: pH, temperature, electrical conductivity, total dissolved solids, turbidity, total suspended solids, sodium, calcium, magnesium, potassium, iron, manganese, copper, zinc, lead, nickel, chromium, cobalt, sulphate, chloride, bicarbonate, carbonate, nitrate, flouride, phosphate, Total E-coli and total coliform. The analytical methods adopted were based on International acceptable methods and analytical application principles. Even though, various kinds of instrument by different manufacturers were used in the course of carrying out the sample analyses, the principles employed were all based on approved standard methods and were strictly adhered to for the testing of each parameter (APHA-AWWA-WEF 2017).

### Determination of Turbidity

**Method: APHA 2130B** (Eletrometric using Palintest Turbimeter Plus). The Turbimeter Plus operates according to ISO 7027 method of turbidity, utilizing two NIR light sources at 860 mm. Turbidity measurements were carried out by analysis of light scattered to the incident light (nephlometric measurements) with technology allowing multiple validation of all results for greater accuracy (APHA-AWWA-WEF, 2017).

**Materials:**

Palintest Turbimeter Plus

20 NTU, 100 NTU and 800 NTU Turbidity standards

Turbidity sample cells

Glass beakers

Water samples (Borehole, Surface water and Hand dug well sources)

Distilled water

Soft tissue

**Procedure:**

The Palintest Turbimeter Plus was placed on a flat surface.

The turbidity meter was switched ON and allowed to warm for 5 minutes.

Meter was then calibrated using 20 NTU, 100 NTU and 800 NTU turbidity standards.

Cleaned turbidity sample cell was rinsed with sample to be measured and filled to mark.

The sample cell was then inserted in the sample well and covered with light shield cap and switched to turbidity mode and pressed “READ”.

All above steps 1-6 were repeated for each sample turbidity measurement.

### Determination of Total Suspended Solids

**Method:** APHA 2130B (Eletrometric using Palintest Turbimeter Plus). The Turbimeter Plus operates according to ISO 7027 method for measurement of turbidity, utilizing two NIR light sources at 860 mm. The relationship between turbidity and Total Suspended Solids (TSS) was automatically correlated and TSS value was determined based on calculated factors (slope and offset) for turbidity versus TSS to give rapid qualitative reliable data (APHA-AWWA-WEF, 2017.

Palintest Turbimeter Plus

20 NTU, 100 NTU and 800 NTU Turbidity standards

Turbidity sample cells

Glass beakers

Water samples (Borehole, Surface water and Hand dug well sources)

Distilled water

Soft tissue

**Procedure:**

The Palintest Turbimeter Plus was placed on a flat surface.

The turbidity meter was switched ON and allowed to warm for 5 minutes.

Meter was then calibrated using 20 NTU, 100 NTU and 800 NTU turbidity standards and stored.

Slope and intercept for the straight line relationship were entered directly with the slope factor range from 0.1 - 50.0 and intercept set at -50.0 - +50.0 and pressed “DONE”.

Cleaned turbidity sample cell and rinsed with sample to be measured and filled to mark.

The sample cell was then inserted in the sample well and covered with light shield cap and switched to TSS mode and pressed “READ”.

Displayed TSS reading in mg/l was recorded as the sample TSS.

Steps 1-7 were repeated for each sample TSS measurement.

### Determination of Major and Heavy Metals

**Method:** Absorbance Air/Acetylene Atomic Absorption Spectrophotometric. Direct aspiration of sample into an air-acetylene flame using atomic absorption spectrophotometer (ASS) was designed to measure elemental (ionic) metals in solution (APHA-AWWA-WEF, 2017). It performed integrated measurements in absorbance or emission intensity, as well as sample concentration in comparison to standard solution. The concentration of each metallic ion in a sample was determined at specific wavelength by using appropriate hollow cathode lamp and freshly prepared standards solution of the metallic ion. Each metal has its own characteristic absorption wavelength and a source of energy (hollow cathode lamp) composed of that metallic ion. The amount of energy at characteristics wavelength absorbed in the flame when a sample was aspirated, is directly proportional to the concentration of analyte metal in the water sample over a concentration range of the metal standard solutions.

**Materials:**

Pipettes (1 ml, 2 ml, 5 ml, 10 ml, 50 ml)

Measuring cylinders (10 ml, 50 ml, 100 ml)

Glass beakers (50 ml, 100 ml, 250 ml)

Volumetric flasks (50 ml, 100 ml, 250 ml, 500 ml, 1000 ml)

Air compressor

Acetylene

Buck 230AA Atomic Absorption Spectrophotometer and Accessories

Computer set

Water samples (Borehole, Surface water and Hand dug well sources)

Analyte Metal free water (deionized water). The deionized water was always checked to determine the presence or otherwise of the analyte metal

Series of metal standard solution in the optimum concentration range were prepared.

**Procedure:**

100 ml of the metal standard solution in the optimum concentration range were prepared.

Hollow cathode lamp for the desired metal was appropriately installed in the AAS instrument.

The ASS instrument was turned ON and allowed to warm until energy source stabilized.

Current was adjusted as necessary after warming.

Wavelength characteristic for analyte metal was set and optimized until optimum energy gain was observed.

Burner head position was aligned both vertically and horizontally to obtain maximum response.

Acetylene tank was turned ON, flow rate adjusted and set to 12 – 15psi.

Air compressor was turned ON, flow rate adjusted and set to 50 – 90 psi for maximum sensitivity for the metal being measured.

Oxidant selector was switched to air at flow indicator between 4.5 – 6.5.

Fuel valve was turned ON and flow adjusted to 4 on the red scale.

Burner was lighted with spark striker and flame allowed to stabilize.

A blank (deionized water) was aspirated to zero the AAS instrument.

The analyte metal standard solutions were aspirated, starting with the lowest concentration and ends with the highest concentration.

Deionized water was aspirated to read zero on the AAS instrument after aspiration of each standard.

Calibration curve of the analyte metal was appropriately ensured before digested sample runs.

After precise and accurate calibration curve was obtained, the AAS instrument was then operated with the water samples (with intermittent aspiration of deionized water after each sample run).

Actual concentration of the analyte metallic ion obtained was saved and recorded.

Above steps 1-17 were repeated for each metal measurement.

### Determination of Sulphate

**Method:** APHA 4500$SO_4^{2-}$E (Colorimetric using Sulfate Reagent Tablet and Wagtech PTW10010XA Potalab +). Sulphate was determined by modified turbidimetric method using barium chloride in SULFATE TURB PHOT tablet. Sulphate ions in the sample reacted with barium in the SULFATE TURB PHOT reagent tablet to form insoluble barium sulphate precipitate according to equation 3 (APHA-AWWA-WEF, 2017). The amount of whitish turbidity formed was directly proportional to the sulphate concentration. Detection limit of the method is 0 – 70 mg/l

$M(SO_4)_n + BaCl = M^{n+} + nBaSO_4$

**Materials:**

ZI PTW 10010C XA Advanced Potable Water Quality Laboratory (Physico-Chemical) Test Kit

SULFATE TURB PHOT tablets

10 ml cells

Timer

Pipettes

Measuring cylinder

Glass beakers

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT

Water samples (Borehole, Surface water and Hand dug well sources)

Deionized water

**Procedure:**

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT was switched to sulphate detection mode and calibrated with the water sample to be tested.

SULFATE TURB PHOT tablet was added to 10 ml water sample and crushed to dissolve in a clean 10 ml cells.

The aliquot was mixed and allowed to stand for 5 minutes contact time, to allow full colour development. Colour developed is directly proportional to the sulphate concentration.

Intensity of colour developed was measured using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT and sulphate concentration displayed was recorded.

The above steps 1- 4 were repeated for each sample sulphate measurement.

### Determination of Chlorine

**Method:** APHA 4500$Cl^-$B (Argentometric titration). Chloride was determined by argentometric titration method using silver nitrate ($AgNO_3$) and potassium chromate ($K_2CrO_4$) indicator at pH of 7 – 10. Chloride in the sample reacted with silver to form insoluble silver chloride precipitate (APHA-AWWA-WEF, 2017).

$M(Cl)n + AgNO_3 = M^{n+} + nAgCl$

**Materials:**

0.014 mol/dm$^3$ $AgNO_3$ solution was obtained by dissolving 2.396 g $AgNO_3$ in deionized water. Standard against 0.014 mol/dm$^3$ NaCl using 1 ml $K_2CrO_4$ as indicator at pH of 7.5.

Potassium Chromate indicator: 5 g of $K_2CrO_4$ was dissolved in a little deionized water. $AgNO_3$ solution was added till a definite red precipitate was formed. The aliquot was left to stand for 12 hours, filtered and diluted to 100 ml with deionized water.

Aluminium hydroxide ($Al(OH)_3$) suspension: 125 g of $Al(SO_4)_3.12H_2O$ was dissolved in 1 litre of deionized water, warmed to 60 $^0$C and 55 ml of Conc. $NH_4OH$ was added slowly with stirring. The aliquot was allowed to stand for 1 hour, transferred into a large bottle and washed with deionized water till it was free of chloride.

1 mol/dm$^3$ NaOH

0.5 mol/dm$^3$ $H_2SO_4$

Burette

Pipettes

Measuring cylinder

Filter funnel

Conical flasks

Glass beakers

Filter paper

Retort stand

Analytical balance

Water sample

Distilled water

**Procedure**

100 ml of the water sample was measured and transferred to a clean 250 ml conical flask.

3 ml $Al(OH)_3$ suspension was added to sample that was turbid, mixed and allowed to settle. Then filtered, washed and combined filtrate and washing.

10 ml $K_2CrO_4$ indicator was added to the 100 ml of sample at $_PH$ 7.5 (where necessary $_PH$ was adjusted with 0.5 mol/dm$^3$ $H_2SO_4$ or 1mol/dm$^3$ NaOH solution).

The aliquot was titrated with 0.01411 mol/dm$^3$ $AgNO_3$ solution to a pinkish yellow end point.

At the endpoint, titration colour changes from yellow to pinkish-yellow and the chloride concentration was computed as shown below.

Reagent blank titre value was established using 100 ml deionized water.

Steps 1 – 6 were repeated for each water sample, but step 2 was only used for samples where necessary.

$$\text{Chloride (mg/l)} = \frac{(A-B)^{x}N}{\text{Vol of sample}}$$

Where, ‘A’ is the sample titre value, ‘B’ is the blank titre value and N = 0.0141

**Determination of Bicarbonate**

**Method:** APHA 2320B (Colorimetric using Alkaphot M Reagent Tablet and Wagtech PTW10010XA Potalab +). Total alkalinity is the quantitative capacity to neutralize a strong acid by sample to be measured. The alkalinity of water sample is basically a metallic function of carbonate, bicarbonate and hydroxide content and is an indicator of the concentration of these constituents. Bicarbonate was measured by colorimetric method using Alkaphot M (APHA-AWWA-WEF, 2017).

$M(HCO_3)_n = M^{n+} + {}_nHCO_3^-$

**Materials:**

ZI PTW 10010C XA Advanced Potable Water Quality Laboratory (Physico-Chemical) Test Kit

Alkaphot M tablets

10 ml cells

Timer

Pipettes

Measuring cylinder

Glass beakers

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT

Water samples (Borehole, Surface water and Hand dug well sources)

Deionized water

**Procedure:**

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT was switched to bicarbonate detection mode and calibrated with the water sample to be tested.

Alkaphot M Bicarbonate reagent tablet was added to 10ml digested water sample and crushed to dissolve in a clean 10 ml cell.

The aliquot was mixed and allowed to stand for 1minute contact time, to allow full colour development. Colour developed is directly proportional to the bicarbonate concentration.

Intensity of colour developed was measured using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT and bicarbonate concentration displayed was recorded.

The above steps 1- 4 were repeated for each sample biocarbonate measurement.

### Determination of Carbonate

**Method:** APHA 2320B (Colorimetric using Alkaphot R Reagent Tablet and Wagtech PTW10010XA Potalab +). Total alkalinity is the quantitative capacity to neutralize a strong acid by sample to be measured. The alkalinity of water sample is basically a metallic function of carbonate, bicarbonate and hydroxide content and is indicator of the concentration of these constituents. Carbonate was measured by colorimetric method using Alkaphot P (APHA-AWWA-WEF, 2017).

$M(CO_3)_n = M^{n+} + {}_nCO_3^{2-}$

**Materials:**

ZI PTW 10010C XA Advanced Potable Water Quality Laboratory (Physico-Chemical) Test Kit
Alkaphot P tablets
10 ml cells
Timer
Pipettes
Measuring cylinder
Glass beakers
Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT
Water samples (Borehole, Surface water and Hand dug well sources)
Deionized water

**Procedure:**

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT was switched to bicarbonate detection mode and calibrated with the water sample to be tested.

Alkaphot P Carbonate reagent tablet was added to 10ml digested water sample and crushed to dissolve in a clean 10 ml cell.

The aliquot was mixed and allowed to stand for 1minute contact time, to allow full colour development. Colour developed is directly proportional to the bicarbonate concentration.

Intensity of colour developed was measured using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT and bicarbonate concentration displayed was recorded.

The above steps 1- 4 were repeated for each sample carbonate measurement.

### Determination of Nitrate

**Method:** APHA 4500$NO_3^-$ E (Cadmium Reduction Colorimetric Using Test Reagent Power, Tablet and Wagtech PTW10010XA Potalab +). Nitrate was determined by colorimetric method via reduction and the resulting nitrite determined by reaction with sulphanilic acid in the presence of N- (1-naphathyl)-ethylene diamine to form reddish dye (APHA-AWWA-WEF, 2017). Detection limit of the method is 0 – 20 mg/l.

**Materials:**

ZI PTW 10010C XA Advanced Potable Water Quality Laboratory (Physico-Chemical) Test Kit
Zinc-based Nitrates Powder
Nitricol tablets
20 ml Nitratest Tube
10 ml cells
Timer
Pipettes
Measuring cylinder
Glass beakers
Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT
Water samples (Borehole, Surface water and Hand dug well sources)
Deionized water

**Procedure:**

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT was switched to nitrate detection mode and calibrated with the water sample to be tested.

A spoonful Zinc-based Nitratest Powder was added to 20 ml of the water sample to be tested in a clean 20 ml Nitratest Tube.

Nitratest tablet containing ammonium chloride was then added to aids rapid flocculation.

The aliquot was allowed to stand for 1minute contact period and then tube content was inverted 4 times.

After clarification 10 ml of the clear solution was carefully decanted in a clean 10 ml cell and Nitricol was tablet added, crushed and mixed to dissolve.

The content to stand for 10 minutes contact time, to allow full colour development. Colour developed was directly proportional to the nitrate concentration.

Intensity of colour developed was measured using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT and mg/l $NO_3$ value displayed was recorded.

The above steps 1- 7 were repeated for each sample nitrate measurement.

**Determination of Fluoride**

**Method:** APHA 4500-$F^-$ D (Colorimetric Using Zirconyl Chloride, Eriochrome Cyanine and Wagtech PTW10010XA Potalab +). Fluoride was analysed by adding Zirconyl Chloride, Eriochrome Cyanine reagents tablets to a 10 ml sample of the water in acid solution to form a red coloured complex (APHA-AWWA-WEF,2017). This colour is destroyed by fluoride ion to give a pale yellow. The detection limit of the method is 0 – 1.5 mg/l.

**Materials:**

ZI PTW 10010C XA Advanced Potable Water Quality Laboratory (Physico-Chemical) Test Kit

Fluoride No. 1 (Zirconyl Chloride) tablets

Fluoride No. 2 (Eriochrome Cyanine) tablets

10 ml cells

Timer

Pipettes

Measuring cylinder

Glass beakers

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT

Water samples (Borehole, Surface water and Hand dug well sources)

Deionized water

**Procedure:**

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT was switched to fluoride detection mode and calibrated with the water sample to be tested.

Zirconyl Chloride in Fluoride 1 tablet was added and crushed to dissolve and followed by addition of Eriochrome Cyanine in Fluoride 2 tablet were separately added and crushed in 10 ml of the water sample in a clean 10 ml cell.

The aliquot was mixed and allowed to stand for 5 minutes contact time, to allow full colour development. Colour developed was directly proportional to the fluoride concentration.

Intensity of colour developed was measured using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT and fluoride concentration displayed was recorded.

The above steps 1- 4 were repeated for each sample fluoride measurement.

**Determination of Phosphate**

**Method:** APHA 4500P C (Calorimetric Using Ammonium Molydbate and Stannous Chloride in Reagent Tablet and Wagtech PTW10010XA Potalab +). Phosphate content was determined by using ammonium molybdate and stannous chloride. A modification of molybdenum blue (Phosphate Reagent Tablet) was used after sample pre-treatment with all reagents combined in a single tablet (APHA-AWWA-WEF, 2017). The acidic ammonium molybdate react to produce yellow phosphomolybdate complex. The stannous chloride reduces the complex giving rise to intense molybdenum blue colour as shown below.

$PO4^{3-} + 12(NH_4)_2\ MoO_4\quad 24H^+(NH_4)_3PO_412MoO_3 + 21NH^{4+}12H_2$

$(NH_4)_3PO_412MoO_3{+}Sn^{2+}$ Molybdenum blue + $Sn^{2+}$

**Materials:**

ZI PTW 10010C XA Advanced Potable Water Quality Laboratory (Physico-Chemical) Test Kit

Phosphate reagent tablets

10 ml cells

Timer

Pipettes

Measuring cylinder

Glass beakers

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT

Water samples (Borehole, Surface water and Hand dug well sources)

Deionized water

**Procedure:**

Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT was switched to fluoride detection mode and calibrated with the water sample to be tested.

Phosphate reagent tablet was added to 10ml digested water sample and crushed to dissolve in a clean 10 ml cell.

The aliquot was mixed and allowed to stand for 10 minutes contact time, to allow full colour development. Colour developed is directly proportional to the phosphate concentration.

Intensity of colour developed was measured using Wagtech PTW10010 Potalab + (C) XA Photometer 7500 BT and phosphate concentration displayed was recorded.

The above steps 1- 4 were repeated for each sample phosphate measurement.

### Determination of ***Escherichia Coli*** **(*E.Coli*)** and ***Total Coliform***

**Method:**

APHA 9222 (Membrane Filtration). The number of indicator organisms of microbial pathogens (*Escherichia Coli* and *Total Coliforms*) in water sample were aseptically determined by filtering a measured volume of the sample through membrane filter (APHA-AWWA-WEF, 2017;). Microbial organisms in the sample were retained on or near the surface of the membrane filter, which was then incubated face upward on a suitable selective medium containing lactose. Colonies were counted and the results expressed in term of colony forming unit present in 100 ml (cfu/100 ml) of water sample.

**Materials:**

ZI PTW 10010 Potalab + (M) Advanced Portable Water Quality Laboratory (Microbiological) Test Kit

Membrane filtration unit

Membrane filter

Petri dishes

Dispenser

Colony counter

Spatula

Analar grade absolute ethanol

Cotton wool

Aluminium foil

Incubator

Thermometer

Water bath

Analytical balance

Oven

Hand gloves

Forceps

Conical flasks

Measuring cylinder

Pipettes

Glass beakers

Sterile deionized water

Soft tissue

Detergent

Water samples (Borehole, Surface water and Hand dug well sources)

Lauryl sulphate broth: 37.5 g sterilized lauryl sulphate broth was weighed using analytical balance and dissolved in 1,000 ml sterile deionized water. The content was covered with aluminium foil in a conical flask and heated on steam bath for 15minutes, then allowed to cool at room temperature.

**Procedure**

All the needed test facilities (membrane filtration unit, forceps, measuring cylinder, pipettes, glass beakers, spatula, petri dishes, etc.).

Room temperature cooled prepared media was carefully poured into each sterile petri dish and allowed to solidify.

Filter funnel of membrane filtration unit was loosed and the base support removed.

Using sterilized forceps, a sterile membrane filters was placed onto the sterile membrane support, with the grid side up.

The membrane support was locked by pushing the filter funnel firmly down into position.

Sample to be measured was poured into the sterile filter funnel up to the 100 ml graduation.

The filtration vacuum pump was connected to the filtration unit base and pumped to suck the sample to be measured through the membrane filter.

When all the 100 ml water has been filtered, the vacuum pump was released.

Using sterile forceps, the membrane filter was carefully taken from the filtration unit (with caution to avoid any tear).

The membrane filter was carefully placed on top of the prepared plate.

The petri dish lid was placed and appropriately labelled from the bottom with the sample ID and indicator organism to be measured (either *E.coli* or *total coliforms*).

All the above steps 1 – 11 were repeated twice for each water sample to enable measurement of both the *E.coli* and *total coliforms* content of the sample.

When the last sample was processed, 4 hours resuscitation period was observed before incubation.

This allows any physiologically stressed *E.coli* and *total coliform* to recover before culturing.

Samples for E.coli were placed inside the incubator and incubated at temperature of 44˚ C for 20 hours.

Samples for total coliform analysis were placed inside another incubator and incubated temperature of 37° C for 20 hours.

Numbers of colonies produced were recorded after period is 20 hours incubation following 4 hour resuscitation.

After the 24 hours period, each of the incubator was switched OFF.

Petri dishes were separately removed from incubator.

The petri dishes were placed on a flat surface, the lids removed.

Plates which had characteristic pink colonies after 24 hours resuscitation and incubation were selected.

Number of colonies present in each water sample were counted within a few minutes (as the colours are liable to change on cooling and standing) with the aid of colony counter.

$$\textit{E.Coli} \text{ or } \textit{Total Coliform} \text{ (cfu/100 ml)} = \frac{\text{Number of colonies*100}}{\text{Volume of sample filtered}} \ldots\ldots\ldots.(3.2)$$

### 3.4 Water Quality Indices

Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the different users and regulatory agencies. It has become a useful tool for the assessment and management of water parameters. WQI scale helps to estimate an overall quality of water based on the values of water quality parameters. It expresses the overall water quality at a certain location and time based on several factors. The main objective of WQI is to turn complex water quality data into information that is understood and usable by the public. Over the years a decision of as regards quality of water is made using a series of methods and can be expressed using several scores of parameters obtained from water analysis in the laboratory. In response to the need for a uniform understandable standard of water quality, water scientists worked out to compile all the water quality parameters into what is known as the Water Quality Index (Amadi, 2014).

**Calculation of WQI:**

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter $q_i$ was calculated using this expression (Amadi, 2014):

$$Qi = (Ci/Si) * 100 \ldots\ldots\ldots\ldots..(3.3)$$

A quality rating scale ($q_i$) for each parameter is assigned by dividing its concentration (Ci) in each water sample by its respective standard (Si) and the result multiplied by 100. Relative weight (Wi) was calculated by a value inversely proportional to the recommended standard (Si) of the corresponding parameter:

$$Wi = 1/Si \ldots\ldots\ldots\ldots..(3.4)$$

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating (Qi) with unit weight (Wi) linearly as shown below

$$WQI = (\sum_{n=i}^{i=n} w_i q_i) \ldots\ldots\ldots\ldots..(3.5)$$

Where:

$q_{i:}$ the quality of the ith parameter

$w_{i:}$ the unit weight of the ith parameter and,

n: the number of the parameter considered

Generally, WQI were discussed for a specific and intended use of water. In this study, the WQI for drinking purpose is considered and permissible WQI for the drinking water is taken from the overall WQI given as:

$$\text{Overall WQI} = \frac{\sum q_i w_i}{\sum w_i} \quad \ldots\ldots\ldots\ldots\text{(3.6)}$$

### 3.5 Data Analysis and Reporting

Water samples were collected and analysed to determine the physical, chemical and bacteriological composition of water body, and its suitability for domestic, industrial, and agricultural uses. They were also analysed to aid in understanding hydrochemical and hydrologic relationships in natural systems and to evaluate the influence of man's activities on these systems. Interpretation of the analytical reports from a systematic sampling and analysis was also done to indicate the nature, source, and variability of both dissolved and suspended matter present in the water body. Different water sources in the area were randomly sampled and were truly representatives of the entire water body. The extent to which a single small sample was considered representative of the large water mass depends on several factors such as: (1) The homogeneity of the water body being sampled, (2) the number of points sampled, (3) the size of the individual samples, and (4) the manner in which the samples were collected.

Most water bodies are not completely homogeneous, and obtaining a truly representative sample would depend on the sampling technique employed, as well as the size and number of samples collected. A more representative sample was obtained by collecting several small samples from different parts of the water body, than by collecting one large sample at a single point. Most natural-water bodies are subject to forces which promote homogeneity, such as turbulence and wind action, but they are also affected by chemical, physical, and biological processes which promote nonhomogeneous conditions.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Geology and Hydrogeology

The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex, Younger Granite and Sedimentary Basins. The Basement Complex, which is Precambrian in age is made up of the Migmatite-Gneiss Complex, the schist Belts, the Older Granites and undeformed Acid and Basic Dykes. The Younger Granites comprise several Jurassic magmatic ring complexes centered around Jos and other parts of north-central Nigeria, They are structurally and petrologically distinct from the Older Granites. Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra basin, the lower, middle and upper Benue trough, the Chad basin, the Sokoto basin, the Mid-Niger (Bida-Nupe) basin and the Dahomey basin. The present study area is Mpape, a suburb in the Federal Capital Territory of Abuja. The area is geologically underlain by migmatite, banded gneiss, medium-grained granite and coarse porphyritic granite belonging to the Pan African older granites of the Nigerian basement complex (Figure 4.1). Texturally, they are divided into coarse-grained and fine grained granites. Mineralogically, they consist predominantly of quartz, feldspars and mica. The contact between the Pan African granites and the host rock can be described as intrusive gradational and replacive while the contact between the older granite and suite are both sharp and also gradational. These granites are characterized by distinctive layering which are normally aligned parallel to northwest-southeast lineaments.

Traditionally, people in Mpape depend on available surface water resources, such as rivers, streams, and water from the abandoned quarry pit in the area as shown in Plate III, IV, V and VI. However, rapid population growth coupled with climate variability/change and prolonged dry seasons has led to increasing demands for water and the depletion and pollution of surface water sources in this area. This makes it very difficult to ensure sustainable supply of potable water for various uses. This has resulted in the need for alternative water sources of which groundwater is the prime option. Groundwater has the potential of being potable and has long been regarded as mostly a safe source of water for domestic, industrial and agricultural purposes as compared to surface water. The quality of some sources of groundwater has also been found unacceptable due to the introduction of a range of pollutants into the aquifers.

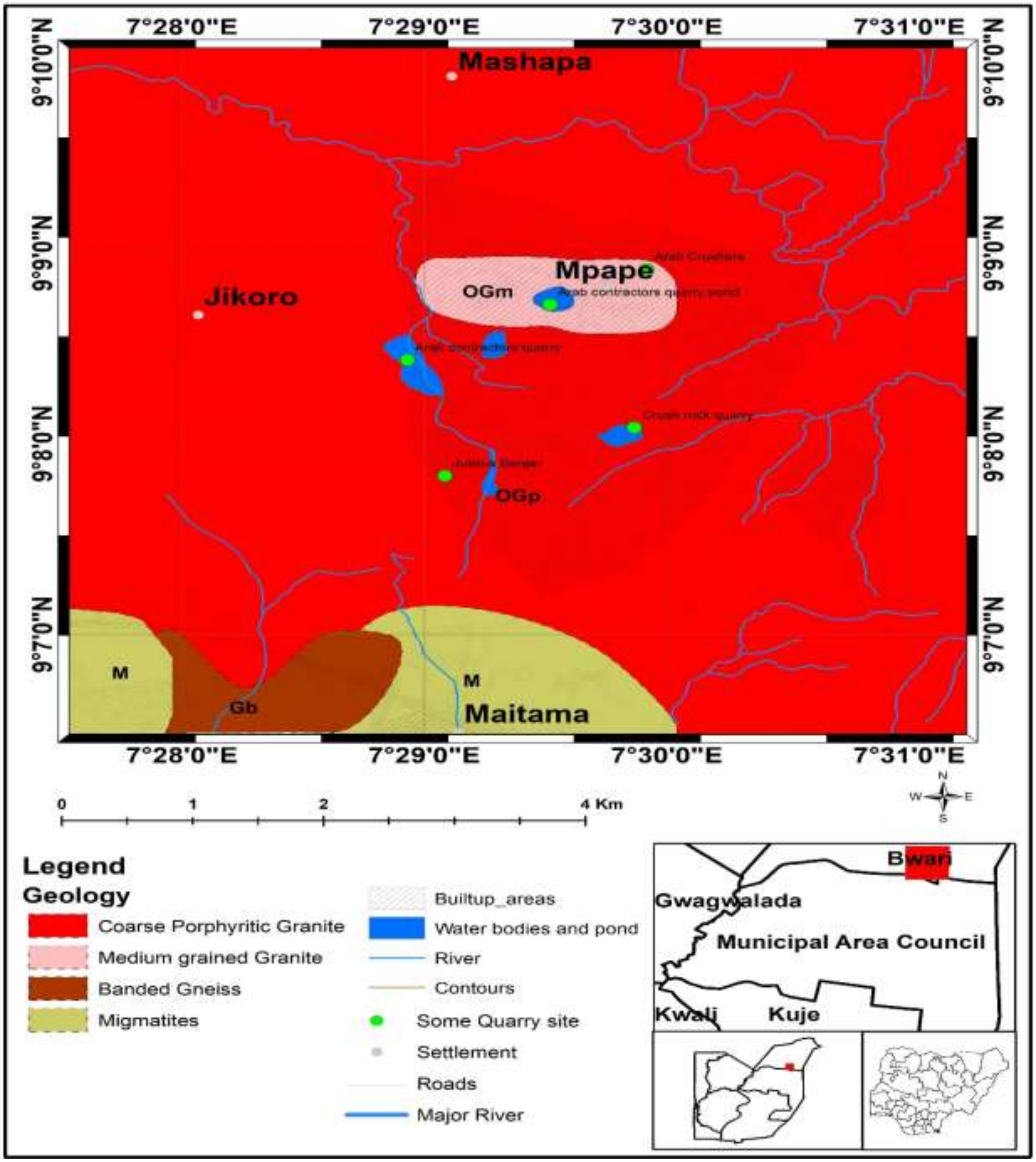

**Figure 4.1:** The geological map of the study area

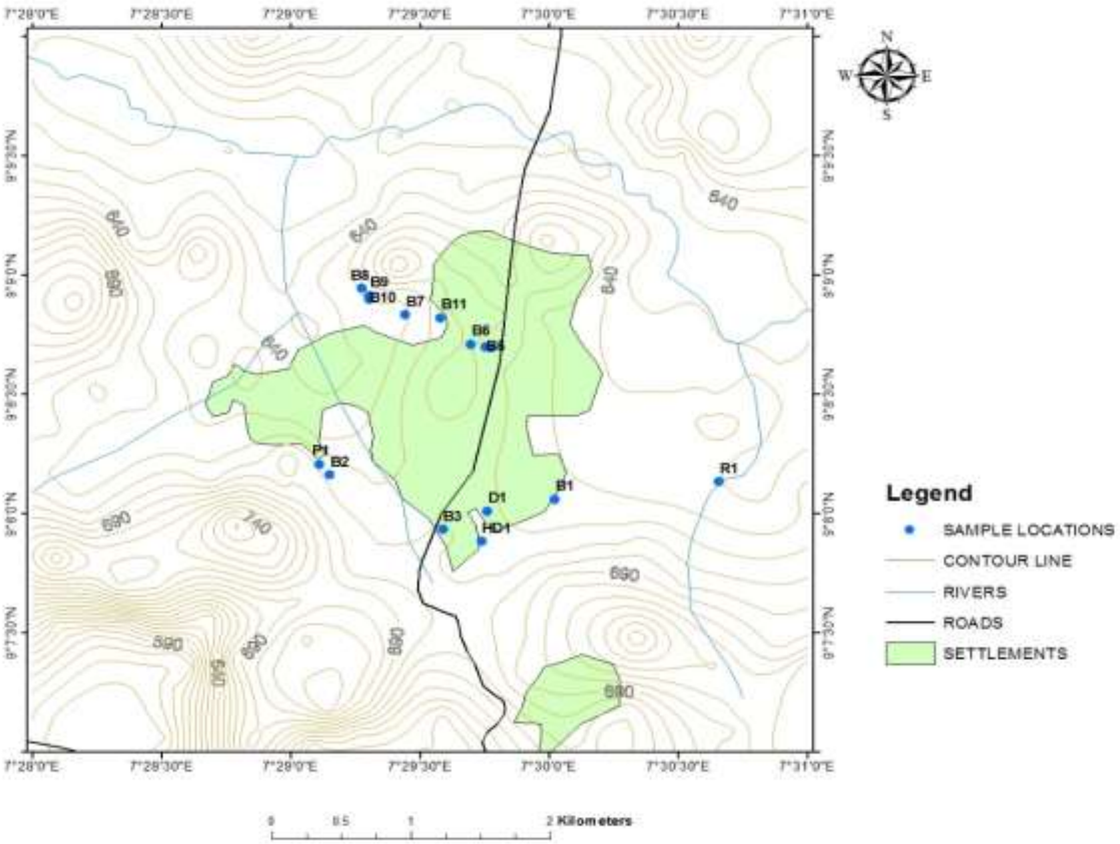

**Figure 4.2:** Water sampling points around Mpape Are

**Plate III:** Water sample collection from an abandoned quarry pit

**Plate IV:** Water sample collection from a river close to pedestrian bridge in Katampe I

**Plate V:** Water sample collection from a tap in Mashafa area of Mpape

**Plate VI:** Water sample collection from a hand-dug well in Eneje area of Mpape

## 4.2 Physico-Chemical Characterization

The location, elevation and coordinates of the study area are shown in Table 4.1 while the results of physico-chemical and bacteriological analysis of water samples is presented in (Tables 4.2). Statistical summary of the whole parameters is presented in (Table 4.3) and the result of the analysed parameters are compared with guidelines values of the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) and World Health Organisation (2017) to determine the suitability of groundwater within the study area.

**Table 4.1:** Location, depth of elevation and coordinates in the study area

| **Location** | **Elevation** | **Longitude** | **Latitude** | **Source** | **Type** |
|---|---|---|---|---|---|
| Eneje | 670.0 | 09°07'53.0" | 007°29'44.3" | Hand Dug Well | Groundwater |
| Crushed Rock Abandoned Quarry Site | 664.0 | 09°08'00.6" | 007°29'45.7" | Dam | Surface water |
| Eneje | 671.0 | 09°08'03.6" | 007°30'01.3" | Borehole | Groundwater |
| Katampe 1 | 639.0 | 09°08'08.0" | 007°30'39.5" | River | Surface water |
| Julius Berger Quarry Site | 664.5 | 09°08'12.4" | 007°29'06.6" | Pond | Surface water |
| Julius Berger Quarry Site Road | 672.5 | 09°08'09.7" | 007°29'09.1" | Borehole | Groundwater |
| Beside First Bank of Nig. Plc, Mpape | 676.7 | 09°07'56.1" | 007°29'35.3" | Borehole | Groundwater |
| Along Arab Contractors Quarry Site Road | 678.0 | 09°08'41.8" | 007°29'46.6" | Borehole | Groundwater |
| Along Arab Contractors Quarry Site Road | 679.3 | 09°08'42.0" | 007°29'45.3" | Borehole | Groundwater |
| Along Arab Contractors Quarry Site Road | 688.5 | 09°08'42.6" | 007°29'41.9" | Borehole | Groundwater |
| Along Mashafa Road, Mashafa | 648.6 | 09°08'50.0" | 007°29'26.7" | Borehole | Groundwater |
| Okada Junction, Mashafa | 656.6 | 09°08'56.6" | 007°29'16.6" | Borehole | Groundwater |
| Along Mashafa Road, Mashafa | 640.6 | 09°08'54.8" | 007°29'50.7" | Borehole | Groundwater |
| Opp. Mpape Hill, Mashafa | 650.5 | 09°08'54.0" | 007°29'18.3" | Borehole | Groundwater |
| Behind Setraco Quarry Site Fence, Mashafa | 659.7 | 09°08'49.3" | 007°29'34.7" | Borehole | Groundwater |

### 4.2.1 Physical Parameters of the Water Samples

The result of the physical parameters obtained from different sampling location is graphically presented in Figure 4.3. The findings of the results shows that the pH values ranged between 5.5 and 8.7 with an average value of 6.42 (Table 4.3 & Figure 4.3). The mean value of 6.42 of the pH falls below the acceptable range of 6.50-8.50 recommended by Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) (Table 4.3) and this indicates that the pH of the water samples in the area is slightly acidic. This can be attributed to the age long practice of mining operating activities in the area, resulting in acid-rain formation. The high level of rusting of roofing sheets in the area might have been caused by acid-rain. The acidic condition of the environment has enhanced the liberation and mobility of metals within the soil-water media. The upsurge in urbanization and industrialization in these areas further compound the quality attributes of the water system in the study area. Water temperature probe tests was taken at the same place each time and the water temperature varied from 20.80˚ C to 38.30˚ C with a mean value of 28˚ C.

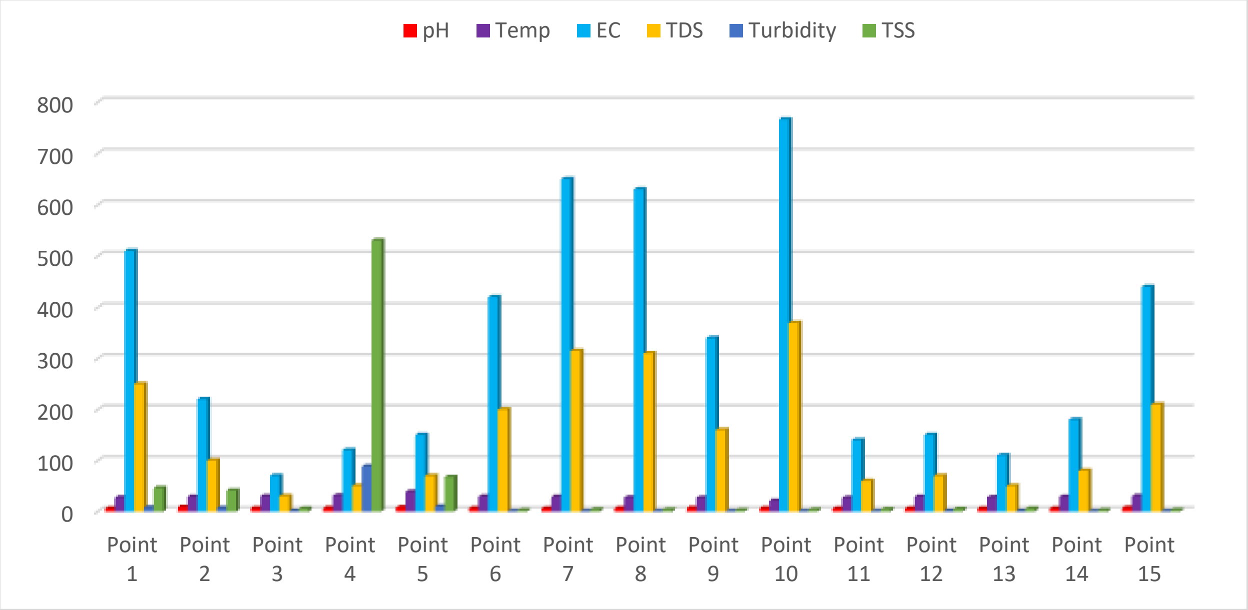

**Figure 4.3:** Result of the physical parameters obtained from different sampling points

Many biochemical processes in water are influenced by changes in pH and temperature. Chemical substances dissolve more readily in water under low pH and high temperature conditions (Amadi *et al*., 2013). Total dissolved solids (TDS) indicate the amount of substance dissolved in water. Its values ranged between 30.00 mg/l to 370.00 mg/l and a mean concentration of 155.00 mg/l which is within the permissible limit of 500.00 mg/l (WHO, 2017) (Figure 4.4). TDS mean value of 155.00 mg/l indicates moderate concentration of dissolved solid substances in the water samples while electrical conductivity that measures the amount of dissolved salts in water. Electrical conductivity depends on the dissolved ions in the water and their charge and movement. Because it is a good solvent, water dissolved mineral salts in the form of ions, which hold the electric current due to ionic conduction. When the EC of water is high, it shows that there is high concentration of ions in the water. The values of electrical conductivity (EC) obtained from the analysis varied from 70.00 µS/cm to 766.00 µS/cm with an average value of 326.40 µS/cm (Table 4.3) that is within limit of 1000.00 µS/cm (WHO, 2017) (Figure 4.4). These mean values show that both total dissolved solids and Electrical Conductivity are within the permissible limits of 500.00 mg/l and 1000.00 µS/cm (NSDWQ, 2015; WHO, 2017).

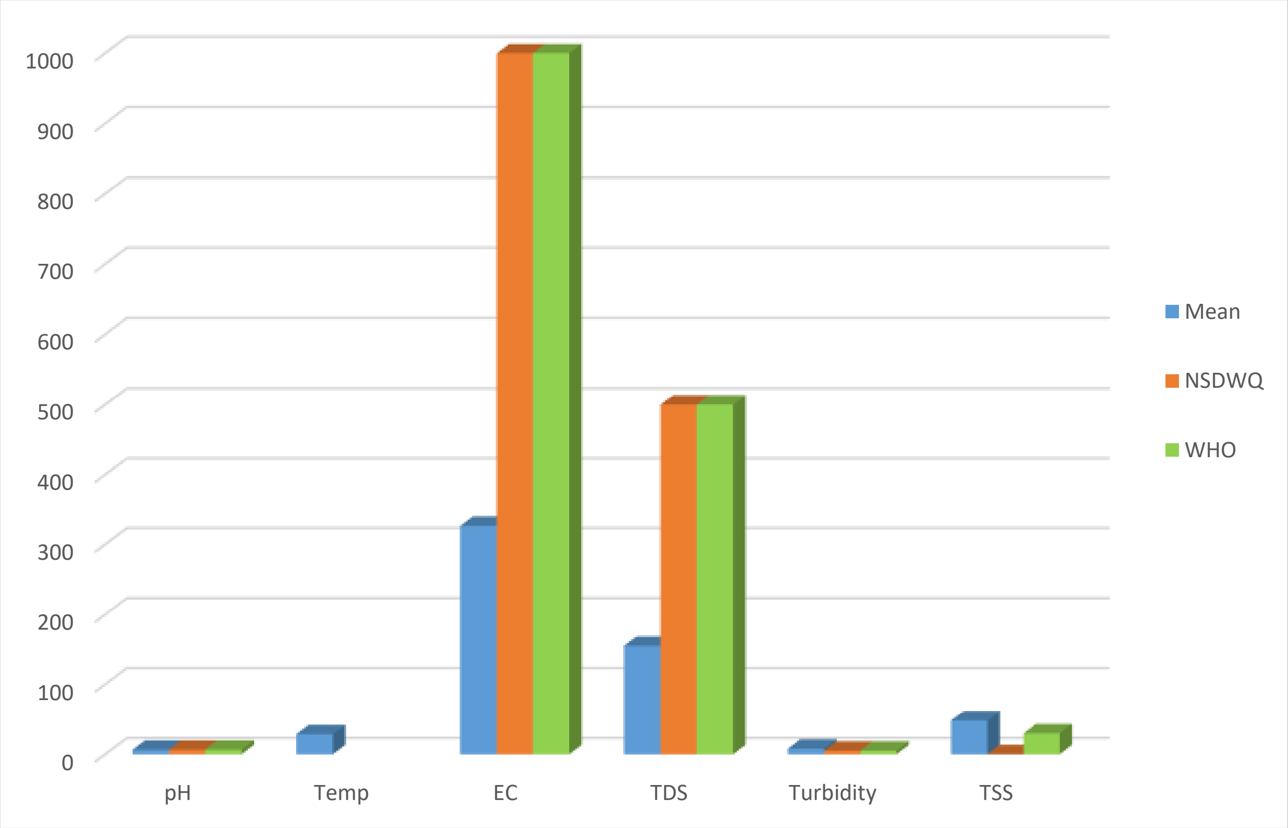

**Figure 4.4:** Comparison of mean result of the physical parameters analysed with Nigerian Standards for Drinking Water Quality (2015) and World Health Organization (2017)

The low values for EC obtained from most of the water samples infer that there is moderate concentration of dissolved salts and it implies that salinity of the water samples analysed is low. The turbidity value ranged from 0.20 NTU – 88.30 NTU with a mean value of 7.80 NTU which is above the allowable limit of 5.0 NTU (NSDWQ, 2015). Turbidity is the amount of cloudiness in the water caused by dissolved, total suspended solids or colloidal matter. It can be caused by silt, sand and mud; bacteria and germs; chemical precipitates. It is not associated specifically with faecal materials, but increase in turbidity are often accompanied with increase in pathogen numbers, including cysts or occysts. Turbidity values of 6.80 NTU, 88.30 NTU, 9.40 NTU and 7.60 NTU were recorded for sample codes SW 1B, SW 2B, SW 3B and HDW 1B (Table 4.2) and these water samples were collected from surface water and hand-dug well. The turbidity values ranged from 0.20 NTU to 88.30 NTU with a mean value of 7.80 NTU and they were found to be above the allowable limit of 5 NTU (WHO, 2017). Runoff from the nearly quarrying sites might have enhanced the turbidity of the uncovered surface water and be responsible for the high turbidity values reported in some of the water samples. The presence of suspended materials in water makes it turbid and this affects the colour and transparency of the water. The concentration of total suspended solids ranged from 2.20 mg/l to 530.50 mg/l with a mean value of 48.25 mg/l. The mean value is above the recommended limit of 30.00 mg/l (NSDWQ, 2015; WHO, 2017). High TSS decrease water's natural dissolved oxygen levels and block sunlight which may halt photosynthesis that could lead to stunted growth and eventual death of aquatic organisms. The result obtained for the physical parameters revealed that the mean values of pH, temperature, electrical conductivity and total dissolved solids were within the allowable limit while those of turbidity and total suspended solids were above the allowable limit (Figure 4.4).

### 4.2.2 Geochemical Parameters of the Water Samples

The concentrations of major cations in the water samples is presented in Figure 4.5. The concentration of sodium in the water samples ranged from 2.10 mg/l to 14.10 mg/l with an average value concentration of 5.08 mg/l (Table 4.3). This revealed that the water samples contain moderate concentration of sodium ion which is within the limit (Figure 4.6) when compared with the standard value of 200 mg/l by NSDWQ (2015). Sodium is primarily sourced from the weathering of the plagioclase feldspars of the igneous and metamorphic rocks. The concentration of potassium varied between 3.71 mg/l to 9.58 mg/l with an average value of 5.92 mg/l (Table 4.3). The mean concentration of potassium in the water samples is within the recommended limit of 12.00mg/l (WHO, 2017) (Figure 4.6). Potassium ions could have been derived from geogenic sources such as orthoclase, microcline and biotite or from rain water and leaching of fertilizers (anthropogenic sources). Calcium concentration varied from 2.02 mg/l to 18.68 mg/l with an average value of 12.57 mg/l which is within the permissible limit of 75.00 mg/l (WHO, 2017) (Figure 4.6). Calcium could have been derived from rain water or as leaches from fertilizers and it is identified as one of the most abundant substances in water. Magnesium concentration ranges from 2.00 mg/l to 7.20 mg/l with a mean value of 4.23 mg/l (Table 4.3). This mean value of magnesium concentration fall within permissible limit of 30.00 mg/l (Figure 4.6). Magnesium might have been sourced from the weathering of magnesium rich mineral like olivine contained in the rock type found in the study area.

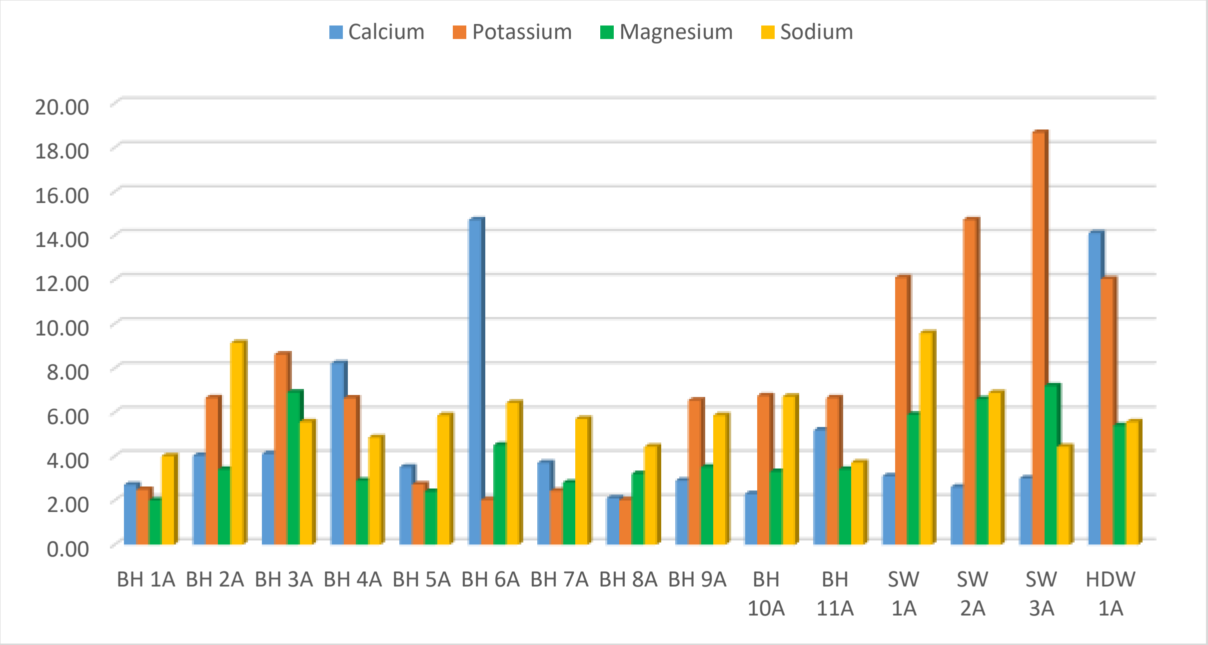

**Figure 4.5:** Concentration of major cations of the water samples in the study area

The low concentrations of calcium and magnesium imply that the water samples are soft water and would be suitable for domestic uses especially for cloth washing because little detergent would be required for washing. Water described as "hard" contains high level of dissolved minerals, specifically calcium and magnesium. Even though hard drinking water is not a health hazard, as it generally contributes to human dietary needs of Ca and Mg, high levels of these substances in water contribute to inefficient and expensive operation of water using appliances. All the water samples have concentrations of cations falling within the WHO acceptable limits. According to Buchanan, T. J. (1983), low mineralization indicates that the weathered zone has been highly leached of soluble minerals and/ or groundwater is likely derived from relatively recent recharge.

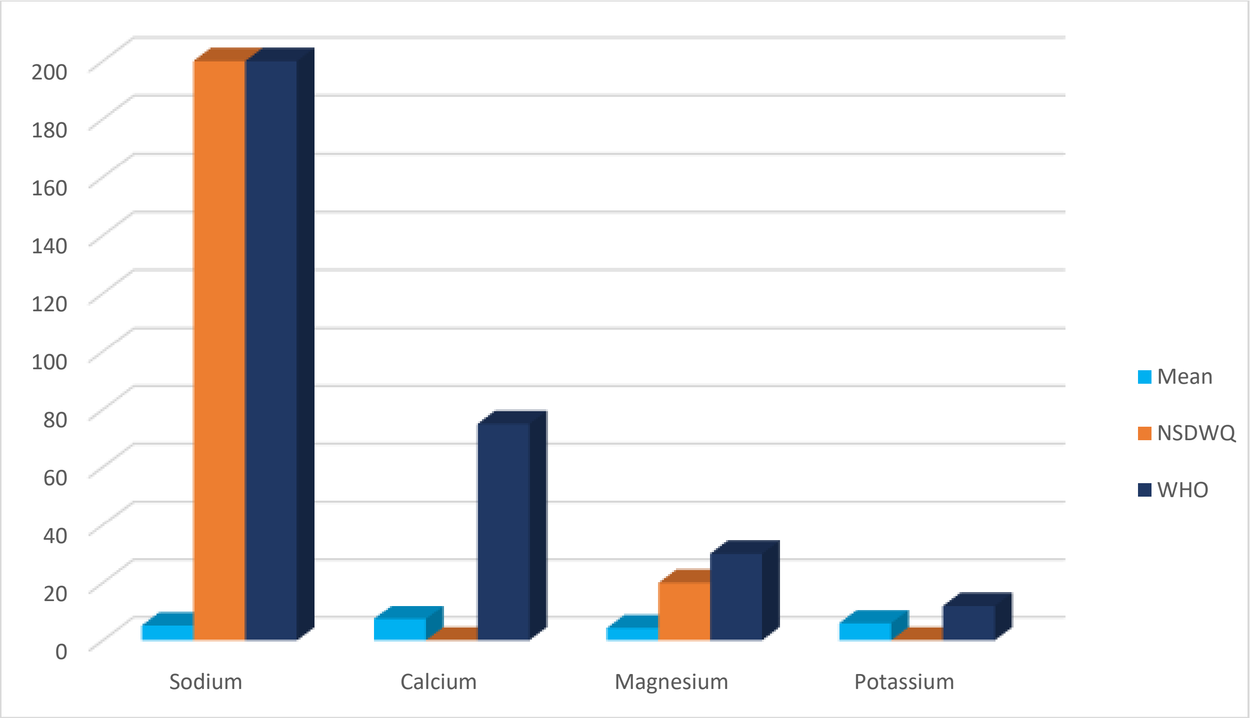

**Figure 4.6:** Comparison of mean concentration of cations of water samples with Nigerian Standard of Drinking Water Quality (2015) and World Health Organization (2017)

The average concentrations of the cations such as sodium 5.08 mg/l, potassium 5.92 mg/l, calcium 7.40 mg/l and magnesium 4.23 were within the acceptable limit of 200.00 mg/l, 12.00 mg/l, 75.00 mg/l, and 30.00 mg/l respectively (Figure 4.6).

The concentrations of major and minor anions in the water samples is presented in Figure 4.7. Chloride concentration ranged from 13.00 mg/l to 45.70 mg/l with an average value of 24.05 mg/l (Table 4.3). The chloride ions concentration is within the recommended limit of 200 mg/l by NSDWQ (2015) (Figure 4.8). Chloride can be enriched through liquid inclusions in rocks and minerals while the source in surface water is transported in the atmosphere and carried to the earth by rain. Sulphate concentration ranged from 11.60 mg/l to 19.00 mg/l with an average value of 13.11 mg/l which is within the allowable limit of 100 mg/l by NSDWQ (2015) (Figure 4.8). Sulphate is a by-product of the oxidation of sulphides from igneous rocks and volcanic source.

Biocarbonate ions occur in low concentration with values ranging from 3.00 mg/l to 14.50 mg/l with an average of 7.62 mg/l. Most of these bicarbonate ions could have been derived from the carbondioxide in the atmosphere and in the soil absorbed by water during percolation and its enrichment in the groundwater system is via geogenic processes. The concentration of carbonates ranged from 0.50 mg/l to 7.10 mg/l with an average concentration of 3.58 mg/l. Shallow water carbonates are primarily produced by the integration of the skeletons of benthic organisms, such as corals, echinoids, mollusks, foraminifera and coralline algae. In some environments, inorganic precipitates such as cements and ooids are also abundant.

The concentration of nitrate varied from 2.50 mg/l to 24.40 mg/l with an average value of 13.59 mg/l. This is observed to be within the limit of 50 mg/l WHO (2017) (Figure 4.8). Nitrate in water samples could result from agricultural activities (including excess application of inorganic fertilizers and manures), wastewater disposal and oxidation of nitrogenous waste products in human and animal excreta. Some water sources may also have nitrate contamination as a consequence of leaching from natural vegetation. High nitrate content in water causes cyanosis and asphysia (blue-baby sydrome), a disease in infants below three (3) months (Amadi *et al*., 2016).

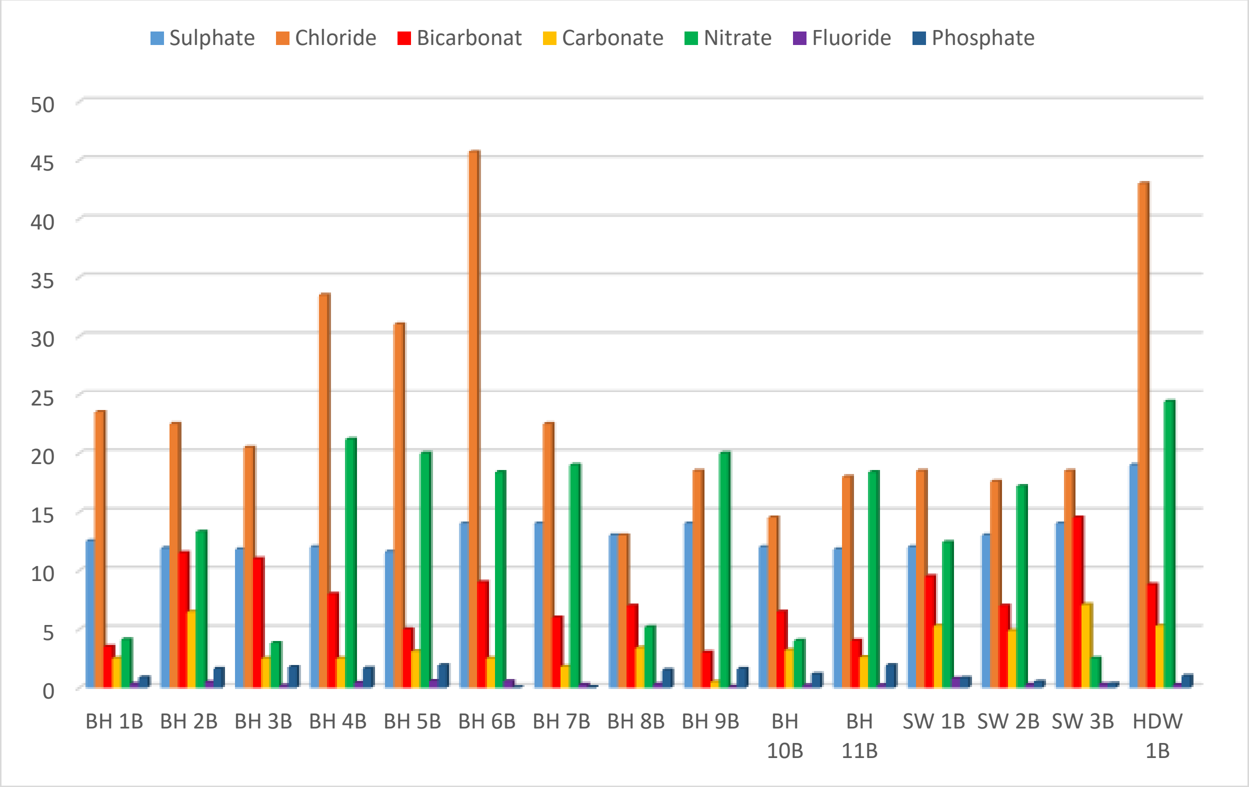

**Figure 4.7:** Concentration of major and minor anions of the water samples

The concentration of fluoride ranged from 0.08 mg/l to 0.78 mg/l with an average value of 0.34 mg/l. The average fluoride ions value of 0.34 mg/l is within the allowable limit of 1.5 mg/l (NSDWQ, 2015) (Figure 4.8). It has been reported that high fluoride content in water has the potential to cause dental and skeletal fluorosis in animals (Aminu *et al*., 2014; Maspalma *et al*., 2016; Okunlola *et al*., 2016). The concentration of phosphate ranged from 0.04 mg/l to 1.90 mg/l with an average value of 1.113 mg/l. The average concentration of phosphate ions of 1.113 mg/l is within the acceptable limit of 5.00 mg/l (NSDWQ, 2015) (Figure 4.8). This can be inferred that the concentrations of phosphate found in trace amount are not toxic to man and animals. However, high concentration of phosphate in water may cause taste and odour problems.

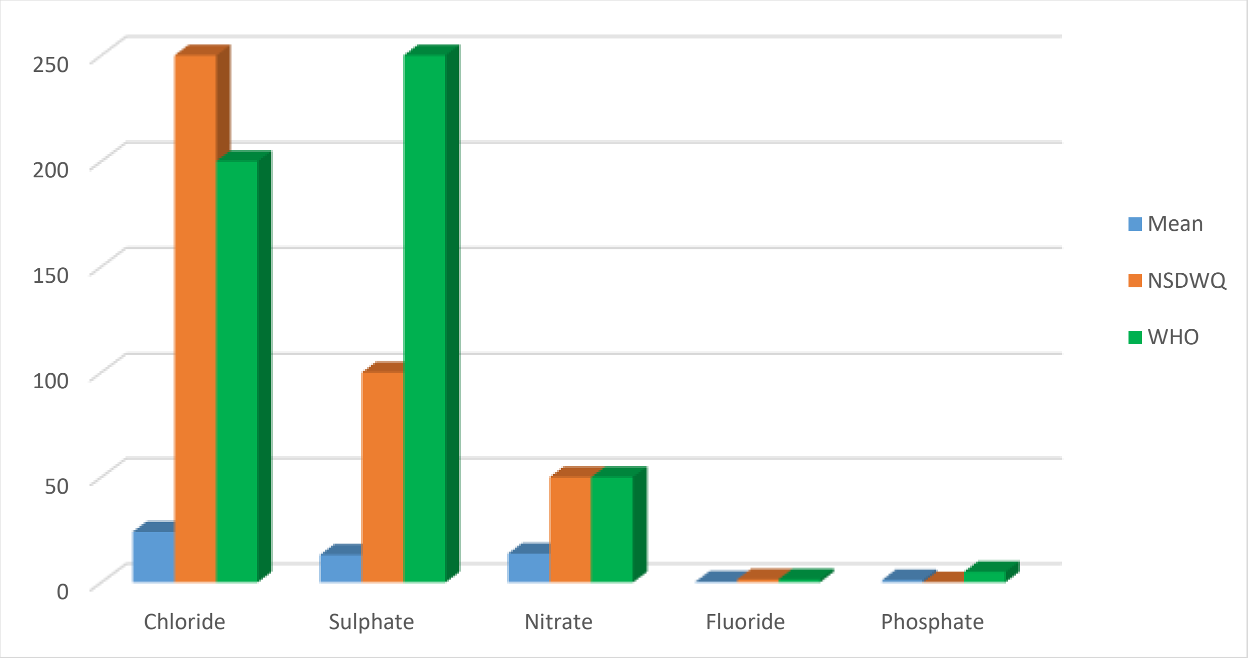

**Figure 4.8:** Comparison of mean concentration of anions of water samples with Nigerian Standard for Drinking Water Quality (2015) and World Health Organization (2017)

The average concentrations of the anions such as chloride 24.05 mg/l, sulphate 13.12 mg/l, nitrate 13.59 mg/l, fluoride 0.34 mg/l and phosphate 1.113 mg/l were observed to be within acceptable limit of 200.00 mg/l, 250.00 mg/l, 50.00 mg/l, 1.50 mg/l and 5.00 mg/l respectively (NSDWQ, 2015) (Figure 4.8), thereby indicate no serious pollution. Though their presence may be as result of poor sanitation, leachate from dumpsite, industrial effluent and fertilizer application or geogenically induced via chemical weathering and bedrock dissolution.

### 4.2.3 Trace Elements Parameters of the Water Samples

The term trace element refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Some of the trace elements analysed in this present study included iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), nitrate (Ni), chromium (Cr) and cobalt (Co) (Table 4.2). Heavy metals can enter a water supply by industrial and consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater.

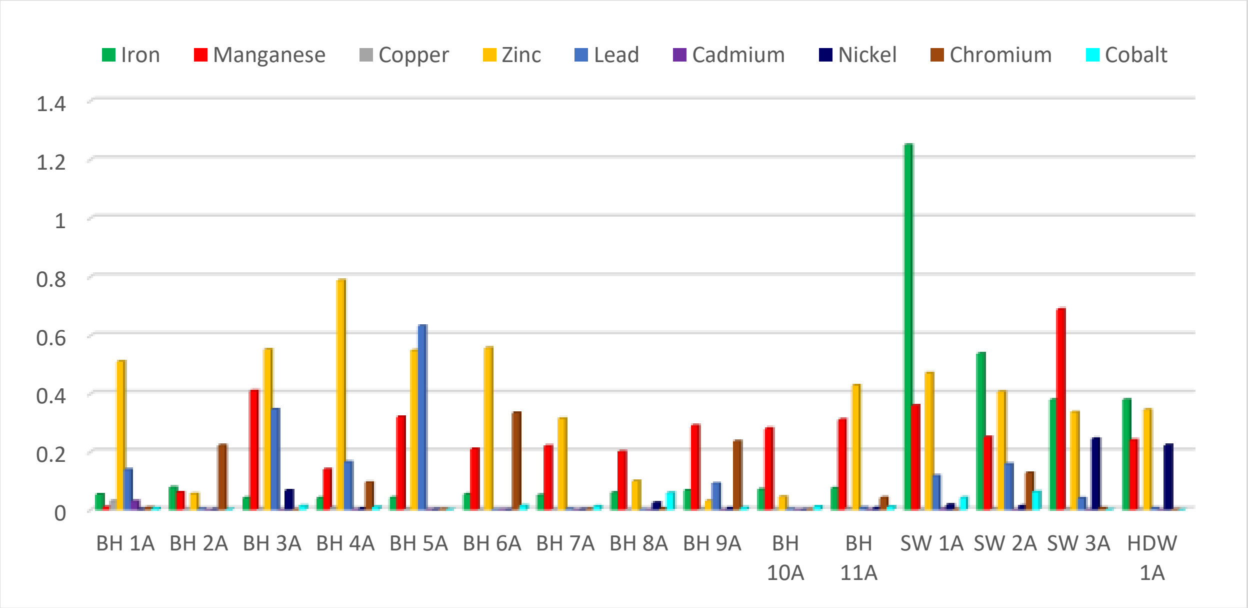

**Figure 4.9:** Concentration of trace metals of water samples in Mpape

The result of the concentration of trace metals in the water samples analysed is presented in Figure 4.9. The concentration of iron in the water samples ranged from 0.04 mg/l to 2.53 mg/l with a mean value of 0.36 mg/l (Table 4.3). The water samples obtained from surface water sources (rivers and dams) labelled SW 1A, SW 2A, SW 3A and the one obtained from hand dug well labelled HDW 1A have iron concentration of 1.25 mg/l, 0.54 mg/l, 2.53mg/l and 0.38 mg/l (Table 4.2) are found to be higher that the recommended limit of 0.3 mg/l (WHO, 2017) (Figure 4.9) while those water samples obtained from the groundwater sources (mainly boreholes) labelled BH 1A to BH 11A (Table 4.2) are found to be within the acceptable limit (WHO, 2017) (Figure 4.9) but the average concentration of iron of 0.36 mg/l shows that it is slightly above the permissible limit of 0.30 (NSDWQ, 2015) (Figure 4.10). Iron is an essential nutrient that is vital to the processes by which organisms cells generate energy. High iron content in water does not actually constitute any health problem; rather it affects the colour, taste and odour of the water. The high iron content in the water samples obtained from the surface sources may be attributed to the decomposing of the abandoned metallic objects from the nearby dumpsite, or derived from dissolution of ferromagnesian minerals in rocks by chemical weathering of rock and run-off. The concentration of manganese ranges from 0.01 mg/l to 0.69 mg/l with an average value of 0.27 mg/l. Out of all the samples analysed to determine manganese concentration, only four samples BH 1A, BH 2A, BH 4A and BH 8A are found to be within the acceptable limit of 0.2 mg/l (WHO, 2017) (Figure 4.9) while the remaining samples have concentrations above the limit for safe drinking water (Figure 4.9). The mean value of manganese which is 0.27 mg/l is found to be higher than the permissible limit of 0.2 mg/l by WHO (2017). The possible source of manganese in groundwater might be from rain water and leaches of rock weathering. At a concentration levels higher than 0.2 mg/l, manganese causes a bitter taste to water, stains cloths and metal parts and precipitate in foods when used for cooking and it also promotes the growth of algae in reservoir (Todd, 1980).

The concentration of copper ranged from 0.001 mg/l to 0.003 mg/l with a mean of value of 0.0048 mg/l. The mean concentration value of copper in the water samples is within the acceptable limit of 1.0 mg/l (NSDWQ, 2015) (Figure 4.10). Drinking of water containing copper in excess of the permissible limit with short term exposure can cause gastrointestinal distress while the long-term exposure may cause liver or kidney damage. Copper is an essential substance to human life, but in high doses it can cause anemia, liver and kidney damage, and stomach and intestinal irritation. Copper normally occurs in drinking water from copper pipes, as well as from additives designed to control algal growth.

The concentration of zinc in the analysed water samples ranged from 0.031 mg/l to 0.788 mg/l with a mean value of 0.366 mg/l. The mean value of 0.366 mg/l is within the permissible limit of 1.0 mg/l (WHO, 2017) (Figure 4.10). About three-quarters of the total zinc supply is used in metal form. Zinc is sourced from leakages from zinc pipes, car tires containing zinc and motor oil from zinc tanks release zinc compounds on roads. Zinc compounds are present in fungicides and insecticides, and consequently end up in water. When inadequate safety measures are taken, zinc may be emitted from chemical waste dumps and landfills, or from dredge mortar. Children's immune systems and enzyme systems may be affected when there is zinc deficiency in their body while the symptoms of taking zinc above the permissible limit include tastelessness, loss of appetite, nausea, vomiting, dizziness, fevers and diarrhea.

The concentration of lead varied between 0.001 mg/l to 0.6333 mg/l with an average value of 0.114 mg/l (Table 4.3). Majority of the samples analyzed show traces of lead that exceeded the recommended limit of 0.01 mg/l (NSDWQ, 2015) (Figure 4.9). The average concentration of lead in the analysed water samples is 0.114 mg/l and this is higher than the allowable limit of 0.05 mg/l by WHO (2017) (Figure 4.10). The possible sources of lead in the water samples can be natural and anthropogenic. Natural sources may be due to mobilization from soil, vegetation, alluvium, harmattan dust while the anthropogenic sources may be linked to discharge from mining operation and waste incineration.

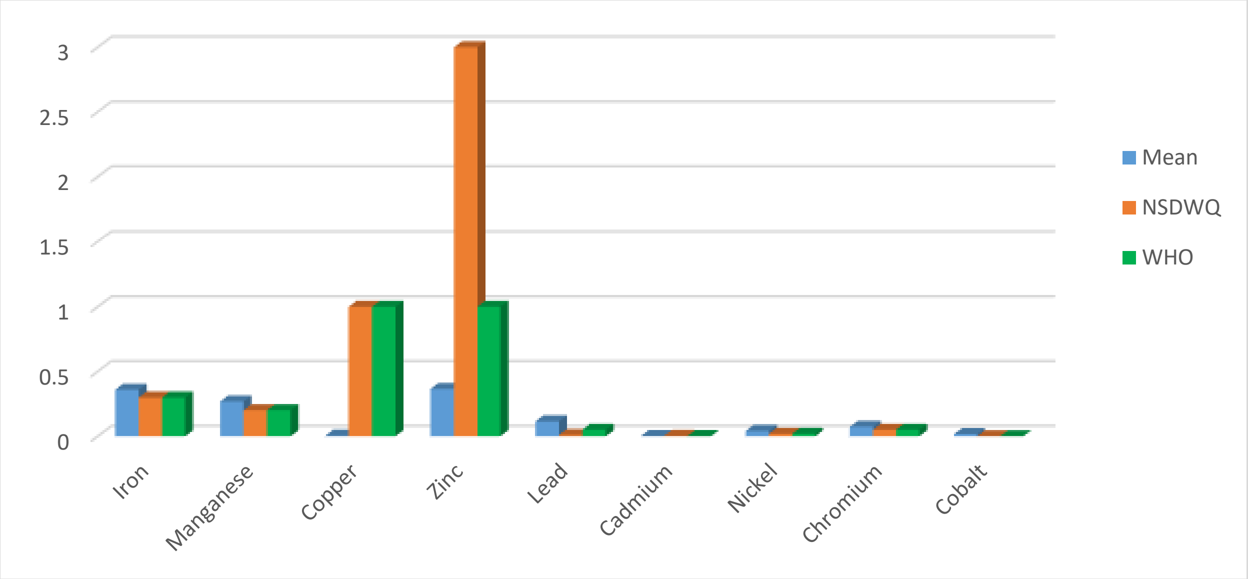

**Figure 4.10:** Comparison of mean concentration of trace elements of water samples with Nigerian Standard for Drinking Water Quality (2015) and World Health Organisation (2017)

In humans, exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Various effects occur over a broad range of doses, with the developing foetus and infant being more sensitive than the adult. High levels of exposure may result in toxic biochemical effects in humans which in turn cause problems in the synthesis of haemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system.

The concentration of cadmium varied between 0.0001 mg/l to 0.0300 mg/l with a mean value of 0.0025 mg/l. Most of the water samples have cadmium values within the acceptable limit of 0.001 mg/l (WHO, 2017) except water samples BH 1A and SW 1A (Table 4.2) (Figure 4.9) with the values of 0.003 mg/l and 0.0026 mg/l respectively which are found to be above the permissible limit of 0.001 mg/l (WHO, 2017). Cadmium derives its toxicological properties from its chemical similarity to zinc an essential micronutrient for plants, animals and humans. Cadmium is biopersistent and, once absorbed by an organism, remains resident for many years (over decades for humans) although it is eventually excreted. In humans, long-term exposure is associated with renal dysfunction. High exposure can lead to obstructive lung disease and has been linked to lung cancer, although data concerning the latter are difficult to interpret due to compounding factors. Cadmium may also produce bone defects (osteomalacia, osteoporosis) in humans and animals.

The concentration of nickel ranged from 0.001 mg/l to 0.245 mg/l with an average value of 0.041 mg/l (Table 4.3). The mean value was observed to be above the limit of 0.02 mg/l (WHO, 2017). Small amounts of Nickel (Ni) are needed by the human body to produce red blood cells, however, in excessive amounts, can become mildly toxic. Short-term overexposure to nickel is not known to cause any health problems, but long-term exposure can cause decreased body weight, heart and liver damage, and skin irritation. Concentration of nitrates ranged from 2.50 mg/l to 24.40 mg/l with an average mean of 13.59 mg/l. The mean value obtained for nitrate is found to be within permissible limit of 50.0 mg/l (NSDWQ, 2015) (Figure 4.10).

Chromium concentrations varied from 0.001 mg/l to 0.333 mg/l with a mean value of 0.073 mg/l (Table 4.3) which is found to be above the permissible limit of 0.05 (NSDWQ, 2015). The presence of chromium in the water samples could have resulted from the leaching of metal alloys and pigments for paints, cement, paper, rubber, and other materials. The average concentration of chromium was found to be above the permissible limit of 0.05 mg/l (WHO, 2017). Low-level exposure to chromium can irritate the skin and cause ulceration while long-term exposure can cause kidney and liver damage, and damage too circulatory and nerve tissue. It often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of chromium.

The values for cobalt concentration ranged from 0.0005 mg/l to 0.0620 mg/l with a mean value of 0.0171 mg/l (Table 4.3). Cobalt is a naturally-occurring element that has properties similar to those of iron and nickel. The presence of cobalt in the water samples might be from both natural sources and human activities. It occurs naturally in soil, rock, air, water, plants and animals. It may enter air and water, and settle on land from windblown dust, volcanic eruptions, and forest fires and may additionally get into surface water from runoff and leaching when rain water washes through soil and rock containing cobalt. Cobalt is essential element, required for good health in animals and humans, and therefore, it is important that foodstuffs contain adequate quantity of cobalt. The average concentration of most trace elements analysed such as iron 0.36 mg/l; manganese 0.27 mg/l, lead 0.114 mg/l, cadmium 0.001 mg/l, nickel 0.041mg/l and chromium 0.073 were found to be above the permissible limit of 0.3 mg/l, 0.2 mg/l, 0.05 mg/l, 0.001 mg/l, 0.02 mg/l and 0.05 mg/l but the average concentration of copper 0.0048 mg/l and zinc 0.366 mg/l were found to be within the permissible limit of 1.00 mg/l and 3.0 mg/l (NSDWQ, 2015; WHO, 2017) (Figure 4.10) respectively.

### 4.2.4 Metal Pollution Index

Pollution is the introduction of contaminants into the natural environment that causes adverse change on the recipient. It is created mostly by human actions, but can also be natural in some cases. A groundwater pollutant is any substance that, when it reaches an aquifer, makes the water unclean and unsuitable for drinking purposes. Sometimes the substance is a manufactured chemical or microbial contamination. Groundwater contamination can also occur from naturally occurring mineral and metallic deposits in rock and soil which host the groundwater or in the course of its movement. Metal pollution index (MPI) is a method of rating that shows the composite influence of individual parameters on the overall quality of water (Amadi, 2011; Amadi *et al*., 2012b). The rating has values starting from zero to five or above (Table 4.4), reflecting the relative importance individual quality parameter and divided by the recommended standard (Si).

The higher the concentration of a metal compared to its maximum allowable concentration, the worse the quality of the water.

PI = Ci/Si

Where:

PI: pollution index

Ci: mean concentration

Si: Nigerian Standard for Drinking Water Quality (NSDWQ, 2015).

**Table 4.4:** Water Quality Classification based on Pollution Index (Amadi, *et al*., 2012)

| Class | Pollution Index (PI) | Status |
|---|---|---|
| Class 1 | PI <1 | No pollution |
| Class 2 | PI: 1-2 | Slightly polluted |
| Class 3 | PI: 2-3 | Moderately Polluted |
| Class 4 | PI: 3-5 | Strongly Polluted |
| Class 5 | PI: >5 | Seriously Polluted |

The metal pollution index (MPI) of all the water samples was calculated and presented in Table 4.5 using the above formula. It can also combine physico-chemical and microbial index which makes it possible to compare the water quality of various water bodies. Water quality and its suitability for drinking purpose can be examined by determining its quality index.

The result obtained from the metal pollution index analysis based on the water quality classification presented in Table 4.5 revealed that there is low concentration of copper, zinc and cobalt in the water samples analysed which invariably do not cause pollution while there is moderate pollution caused by the presence of lead, cadmium and nickel because they have moderate concentration in the water samples but the presence of the elements such as iron, manganese and chromium have slightly polluted the water and this correspond to the finding from the physico-chemical analysis previously discussed which showed that these elements have concentration slightly higher than the recommended limit by (NSDWQ, 2015).

**Table 4.5:** Calculated Metal Pollution Index for the water samples in Mpape

| Parameters (mg/L) | Ci | MACi | MPI Value | Rating |
|---|---|---|---|---|
| Fe | 0.36 | 0.3 | 1.2 | Slightly polluted |
| Mn | 0.27 | 0.2 | 1.35 | Slightly polluted |
| Cu | 0.0048 | 1.0 | 0.0048 | No pollution |
| Zn | 0.366 | 3.0 | 0.122 | No pollution |
| Pb | 0.114 | 0.05 | 2.28 | Moderately polluted |
| Cd | 0.0025 | 0.001 | 2.5 | Moderately polluted |
| Ni | 0.0414 | 0.02 | 2.07 | Moderately polluted |
| Cr | 0.0725 | 0.05 | 1.45 | Slightly polluted |
| Co | 0.0171 | - | 0.0171 | No pollution |

**MPI Value = $C_i$/MAC**

### 4.2.5 Bacteriological Parameters of the Water Samples

All water samples analysed have high *E.coli* and *total bacteria* count except two samples. These two samples are sample code BH 8C with the *E.coli* value of 0.0 cfu/100ml and *total coliform* of 9.0 cfu/100 ml and BH 10C of 0.0 cfu/100 ml and 6.0 cfu/100 ml respectively (Figure 4.11). The concentration of *E.coli* in sample BH 4C and the *total coliform* in sample code SW 2C, SW 3C and HDW 1 were too numerous to count (Table 4.2). During rainfalls, *E.coli* from human and animal wastes (Figures 4.13 and 4.14) especially via open defecation are transported into the surface water sources or infiltrated into the groundwater aquifers and contaminated the water sources.

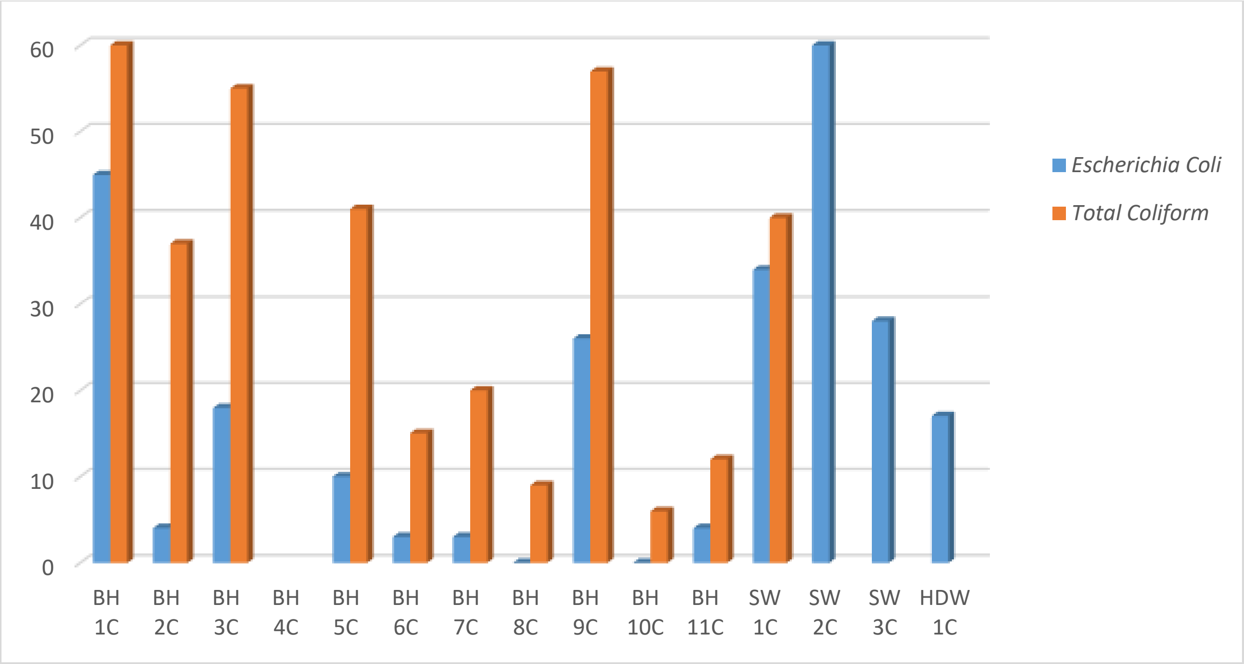

**Figure 4.11:** Concentration of *E.coli* and *Total Coliform* in the water samples

The concentration of *Escherichia coliform* (*E.coli*) ranged between 0.0 cfu/100 ml - 60.00 cfu/100 ml with an average value of 16.80 cfu/100 ml while that of *total coliform* (TC) ranged from 6.0 cfu/100 ml to 60 cfu/100 ml with a mean value of 23.47 cfu/100 ml (Table 4.3). The mean results of 0.0 cfu/100 ml and 10.0 cfu/100 ml obtained for both *E.coli* and *total coliform* are above the maximum permissible limit of NSDWQ (2015) and WHO (2017).

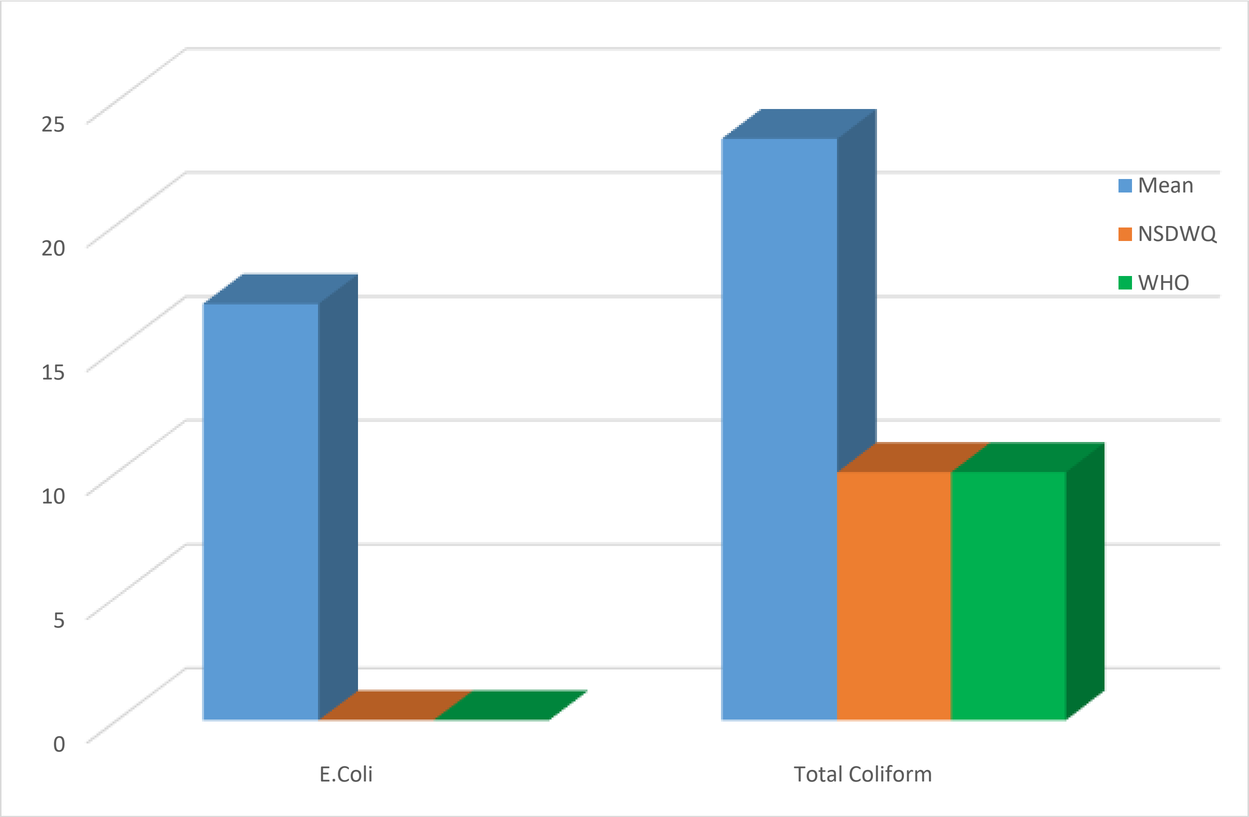

**Figure 4.12:** Comparison of mean concentration of *E.coli* and *Total Coliform* with Nigerian Standard of Drinking Water Quality (2015) and World Health Organization (2017)

The bacteriological quality of most water resources within the study area was very poor mainly due to surficial contamination that may possibly arise from two main sources which are by the widespread and indiscriminate defaecation by animals including humans and cows (Plate VII and VIII) that freely roam the study area and possibly due to poor refuse disposal methods as most biological wastes including adult and baby diapers were dumped in the open waste dumps. The result of bacteriological analysis confirms the chemical signature suggesting the presence of pollutants in the water samples studied.

**Plate VII:** Open defecation along the water drainage by a man in Mpape

The practice of open grazing (Plate VIII) and defecation along stream channels as currently practiced in the area reveals poor sanitation in the area and this practice favours bacteria contamination of water (Plate VII). Furthermore, siting of shallow hand-dug wells near sewage track, unlined pit-latrine and soakaway exposes the shallow groundwater system in the area to faecal contamination and this explains the prevalence of waterborne diseases such as cholera, typhoid and diarrhea among children in the area. The upsurge in the population of Mpape due to low tenement rate, availability of menial jobs and proximity to the centre of Federal Capital Territory has exerted pressure on the shallow groundwater system and the associated impact on the water quality can not be completely ignored.

**Plate VIII:** Drinking of contaminated surface water (pond) in Mpape by cows

Bacteriologically, the water is poor due to the confirmed presence of *E.coli* and *total coliform*, an indication of faecal contamination. Due to the poor bacteriological quality of most of the surface water samples which were used for domestic purposes including drinking, several water borne diseases like typhoid, diarrhea and cholera could occur in some parts of the study area. Drinking water contaminated with *E.coli* and *total coliform* are known to cause urinary tract infections, bacteraemia, meningitis, diarrhea, acute renal failure and haemolytic anaemia.

### 4.3 Water Quality Analysis

Water quality classification based on WQI value is shown in Table 4.6 while the result of computed WQI values for the water samples is presented in Table 4.7 below.

**Table 4.6:** Water quality classification based on WQI value

| WQI Value | Water Quality |
|---|---|
| <50 | Excellent |
| 50-100 | Good water |
| 100-200 | Poor water |
| 200-300 | Very poor water |
| >300 | Unsuitable for drinking |

**Table 4.7:** Result of computed WQ1 values for the water samples in the area

| **Parameters (mg/L)** | **C** | **S** | **$q_i$** | **$w_i$** | **$q_iw_i$** |
|---|---|---|---|---|---|
| pH | 6.42 | 6.5-8.5 | 85.60 | 0.133 | 11.385 |
| Temp ($^0$C) | 28.65 | Ambient | - | - | - |
| EC (µs/CM) | 326.4 | 1000.0 | 32.64 | 0.001 | 0.033 |
| TDS | 155 | 500.0 | 31.00 | 0.002 | 0.062 |
| Turbidity (NTU) | 7.80 | 5.0 | 156.00 | 0.200 | 31.200 |
| TSS | 48.25 | 30.0 | 160.08 | 0.033 | 5.280 |
| Na | 5.08 | 200.0 | 2.54 | 0.005 | 0.013 |
| Ca | 7.40 | 75.0 | 9.87 | 0.013 | 0.128 |
| Mg | 4.23 | 30.0 | 14.10 | 0.033 | 0.465 |
| K | 5.92 | 12.0 | 49.33 | 0.083 | 4.094 |
| Fe | 0.36 | 0.3 | 120.00 | 3.333 | 399.960 |
| Mn | 0.27 | 0.2 | 135.00 | 5.000 | 675.000 |
| Cu | 0.0048 | 1.0 | 0.48 | 0.010 | 0.005 |
| Zn | 0.366 | 1.0 | 36.60 | 0.010 | 0.366 |
| Pb | 0.114 | 0.05 | 228.00 | 20.00 | 4560.000 |
| Cd | 0.0025 | 0.001 | 250.00 | 1000.00 | 250000.000 |
| Ni | 0.0414 | 0.02 | 207.00 | 50.00 | 10350.000 |
| Cr | 0.0725 | 0.05 | 145.00 | 20.00 | 2900.000 |
| Co | 0.0171 | - | - | - | - |
| $SO_4^{2-}$ | 13.107 | 250.0 | 5.24 | 0.004 | 1310.000 |
| $Cl^-$ | 24.053 | 200.0 | 12.03 | 0.005 | 2406.000 |
| $HCO_3^-$ | 7.62 | - | - | - | - |
| $CO_3^{2-}$ | 3.58 | - | - | - | - |
| $NO_3^-$ | 13.593 | 50.0 | 27.19 | 0.020 | 0.544 |
| $F^-$ | 0.339 | 1.5 | 22.60 | 0.667 | 15.074 |
| $PO_4^{3-}$ | 1.113 | 5.0 | 22.26 | 0.050 | 1.113 |
| E.Coli (cfu/100ml) | 16.80 | 0.0 | 1680.00 | 0.000 | 0.000 |
| Total Coliform (cfu/100ml) | 23.47 | 10.0 | 234.70 | 0.100 | 23.470 |

The computed WQI values is presented in Table 4.7 while the overall water quality index (WQI) was calculated by applying the formular (Amadi, 2014).

$$\text{Overall WQI} = \frac{\sum qiwi}{\sum wi} = \frac{272694.192}{1099.702} = 247.97$$

The computed overall WQI was 247.97 belonging to the very poor water category (Table 4.6). The high value of WQI obtained may be as a result of high concentration of some analysed parameters such as turbidity, total suspended solids, lead, cadmium, nickel, chromium including high counts of *E.coli* and *total coliform bacteria* in the water samples. In natural waters, metal can occur in dissolved and particulate forms. Dissolved metals may form dissolve organic and inorganic complexes depending on the physicochemical properties of the water. The build-up of metals in sediment has significant environmental implication for local communities, as well as for river-water quality. The river in the study area can be said to be under increasing pressure from industrial activities such as rock blasting, block moulding, mechanic workshop and car wash. Indiscriminate discharge of wastes from home, agricultural wastes and sewage pipes into the river also increase the pollution load of the water system on a daily basis, however, affecting the water and sediment quality, which poses potential threat not only to aquatic organisms but also to the economy and human well-being.

Wastes that could be bio-degradable and non-biodegradable are found in the area (Plate IX**)**. The biodegradable wastes are those domestic wastes which include food remains, garden and paper which can be decomposed by microbes, while the non-biodegradable wastes are wastes that cannot easily decompose and are non combustible in nature. These include metals, glass, ceramics, stones and nails among others There are various methods of waste management but the commonest one in this area is open dumping method. It involves dumping of the waste in a designated spot which is uncovered. Open dumps are unsanitary, unsightly and generally smelly, with foul odour as they attract rats, insects, flies, snakes.

**Plate IX:** Indiscriminate disposal of wastes in Mpape

The accelerated pace of industrial development coupled with uncontrolled growth of the population in the study area has resulted in the increasing production of solid/liquid wastes. The waste materials generated from the mining and domestic garbage are usually disposed indiscriminately and this has been found to have negative effects on water resources (Plate IX). Surface water is more prone to pollution while groundwater pollution happens mostly due to percolation of pluvial water and the infiltration of contaminants through the soil. The contaminant fluid emanated from the decomposition of organic matter is rich in dissolved minerals, containing substantial amount of polluting substances. When the contaminant liquid (leachate) diffuses into the groundwater table, it affects the potability of water sources, putting the local community into serious health risk.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

In this study, the water quality status of surface water and groundwater sources from the Mpape region of the Federal Capital Territory of north-central Nigeria was investigated using physicochemical and bacteriological indicators. The results obtained for the observed physical parameters were within recommended limits (NSDWQ, 2015; WHO, 2017) except turbidity and total suspended solids. The results of laboratory analysis of water samples showed that the average concentrations of several physicochemical parameters such as sodium, calcium, magnesium, potassium, sulfate, chloride, nitrate, fluoride and phosphate are shown to be within the recommended limit (NSDWQ, 2015; WHO, 2017). However, mean concentrations of lead, cadmium, nickel, and chromium were found to exceed their respective allowable limits, while mean concentration values of iron and manganese were slightly above the recommended limit. The significant presence of these parameters can be attributed to rock-water interactions leading to rock dissolution, chemical weathering, and dilution effects of leachate from nearby landfill sites. Analysis of the metal contamination index based on the water quality classifications revealed that the analysed water samples had low concentrations of copper, zinc, and cobalt, which were always non-polluting while lead, cadmium, and nickel are present in moderate concentrations in water samples, but the presence of elements such as iron, manganese, and chromium readily contaminate water and these findings correspond to the results of the physico-chemical analysis where concentrations of these elements were shown to be slightly higher than the recommended limits (NSDWQ, 2015).

Bacteriological results were poor due to the significant presence of *E. coli* and *total coliforms* in water samples obtained from groundwater, whereas those obtained from surface water were bacteriologically very poor, The levels of these bacteria were high and too numerous to count. Evaluation based on the Water Quality Index (WQI) showed that more than 85% of the samples were contaminated with *E. coli* and *total coliform* due to human contamination in most of the water samples analysed.

## 5.2 Recommendations

Physico-chemical and bacteriological properties of the water sources in the study area were assessed and due to the high counts of the *E.coli* and *total coliform* discovered in almost all the water samples, adequate regular water quality monitoring is recommended in combination with community-led interventions focused on public health, hygiene education, better strategies to protect water sources, and treatment of water sources. It is recommended to grout the base and properly cover the local hand-dug wells to prevent material from entering the wells. Also, due to the poor bacteriological conditions of the water source, boiling of water before drinking is advocated as most bacteria cannot withstand high temperature while the trace amounts of toxic metals can be reduced from entering waterways by planting riparian margins and maintaining and incorporating vegetated swales and constructed wetlands and distillation, ion exchange, reverse osmosis, and activated carbon filtration can also be employed to remove them. Finally, people need to be made aware of the importance of personal hygiene and good sanitation to prevent the widespread or outbreak of water borne diseases in the area.

## 5.3 Contribution to Knowledge

The practice of open defecation along stream channels as currently practiced in the study area reveals poor sanitation in the area and this practice favours bacteria contamination of water. Furthermore, siting of shallow hand-dug wells near sewage track, unlined pit-latrine and soakaway exposes the shallow groundwater system in the area to faecal contamination and this explains the prevalence of waterborne diseases such as cholera, typhoid and diarrhea among children in the area.

The bacteriological quality of most water resources within the study area was very poor mainly due to surficial contamination that may possibly arise from two main sources which are by the widespread and indiscriminate defaecation by animals including humans and cows that freely roam the study area and due to poor refuse disposal methods as most biological wastes including adult and baby diapers were dumped in the open waste dumps. The result of bacteriological analysis confirms the chemical signature suggesting the presence of pollutants in the surface water and ground water in the study area.

has contributed to the knowledge in such a way that people are now made to be aware through the findings of this research that intakes of contaminated water caused by the pollutants of physical and bacteriological substances coupled with high concentration of heavy metals such as lead, zinc, chromium, cobalt are dangerous to health. Hence, there is need for them to be sensitized on the importance of personal hygiene and good sanitation to prevent the occurrence or spread of water borne diseases that can lead to sickness and increase in mortality rate especially among the children with low immunity in the study area.