ASSESSMENT OF GROUND AND SURFACE WATER QUALITY IN SOME SUB-URBAN AREASOF OWERRI, IMO STATE

BY

KELECHUKWU JOY OKWUCHUKWU

(B. Tech., Environmental Technology)

20204255538

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,
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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc) DEGREE IN ENVIRONMENTAL MANAGEMENT

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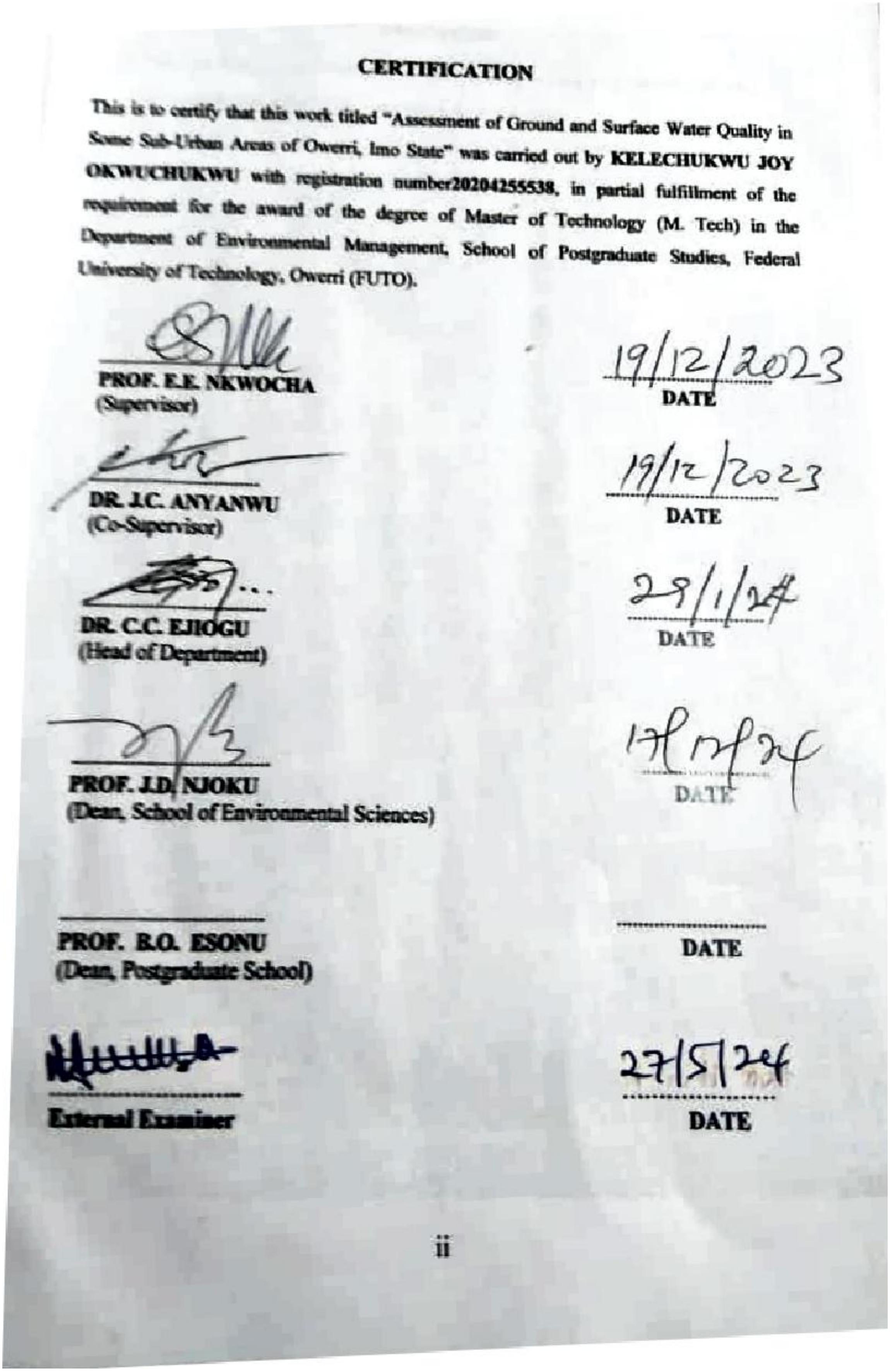

CERTIFICATION

This is to certify that this work titled "Assessment of Ground and Surface Water Quality in Some Sub-Urban Areas of Owerri, Imo State" was carried out by **KELECHUKWU JOY OKWUCHUKWU** with registration number**20204255538**, in partial fulfillment of the requirement for the award of the degree of Master of Technology (M. Tech) in the Department of Environmental Management, School of Postgraduate Studies, Federal University of Technology, Owerri (FUTO).

PROF. E.E. NKWOCHA
(Supervisor)

19/12/2023
DATE

DR. J.C. ANYANWU
(Co-Supervisor)

19/12/2023
DATE

DR. C.C. EJIOGU
(Head of Department)

29/1/24
DATE

PROF. J.D. NJOKU
(Dean, School of Environmental Sciences)

17/12/24
DATE

PROF. B.O. ESONU
(Dean, Postgraduate School)

DATE

External Examiner

27/5/24
DATE

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DEDICATION

I wish to dedicate this research work to God Almighty for his loving kindness, guidance, care and protection as he has been the reason for my survival.

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ABSTRACT

This study was carried out to evaluate the water quality of the two major sources of water, for drinking and domestic use, in Owerri-north; a suburban area of Owerri metropolis. The two main water sources, the boreholes and Uramiriukwariver representing ground and surface water respectively, were sampled in this study. The water samples from the river were collected from three spatial points, upstream, middle and downstream, while three boreholes, point 1, point 2 and point 3, were sampled, at different spatial points of approximately 14 km apart, while FUTO borehole served as the control point. The pollution levels of the water sources were determined using their physiochemical and biological parameter including, temperature, turbidity, electrical conductivity (EC), total dissolved solid (TDS), while the chemical parameters include pH, chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO), (HCO_3), total hardness (TH), Chloride (Cl), Nitrate (NO_3), Phosphate (POS_4), sulphate Acidity, Alkalinity, Total iron (Fe^{2+}), and biological parameters of *e. coli*, klebsiella, total coliform count and total bacterial count for which mean and standard mean error (SEM) were determined using the IBM SPSS software. The T-test was used to determine the difference in the physiochemical and biological properties of the Uramiriukwa river and the borehole water samples. Water quality index (WQI) of the Uramiriukwa river and borehole water samples were also determined using the weighted arithmetic method. Results from this study shows that the physical properties of the river were poor considering the high turbidity, TSS, TDS, colour, and turbid appearance, while the borehole was heavily polluted with coliforms, and bacteria, including *e.coli* and klebsiella. Spatial variations have no significant difference ($p>0.05$) for the river water samples at upstream, middle stream and downstream, while there was significant difference in the three borehole water samples used in this study. Also, there was significant difference ($p\leq0.05$) between the means physiochemical and biological parameters of the river and borehole water samples. Calculation for WQI showed that the borehole water was good for drinking, while the Uramiriukwa water samples were unfit for drinking with WQI score of 38.92 and 169.46 respectively. it was concluded that the river was polluted with solid and chemical wastes as a result of anthropogenic activities, including dredging, industrial activities, laundry, and indiscriminate municipal waste disposal, as observed during field study. The presence of high level of coliform in the borehole and river water samples is an indication of fecal contamination, which is an indication of possible health risk. Standard water treatment especially filtration and disinfection, are required for the surface and ground water in the study area, in order to improve their quality for drinking and domestic use. There is need to monitor and regulate human activities around the water sources, since they are major factor for the water qualities.

Keywords: Water quality, physiochemical parameters, biological parameter, Owerri-north, water quality index, borehole, Uramiriukwa river.

CHAPTER ONE

INTRODUCTION

1.1Background to the Study

Water is vital component in every living organism in the world, especially the human species, animals, plants and the ecosystems (Allaq. Mahid, Yahya et al, 2024).

There are three main sources of water: surface water (rivers, streams, lakes, ponds, etc), ground water (walls, springs etc) and rain water.

Contaminated water sources in urban and suburban areas are linked to transmission of diseases such as cholera, diarrheas (Geetha, Chellaswammy. Venkatachalam, 2024).

To achieve sustainable Development Goal target 6.1, water quality sources should be regularly monitored to ensure sustainability management practices and informed decision making (McDowel, Nobel, Kittridge et al, 2024).

In many developing nations of the world, including Nigeria, where it is primarily the responsibility of the government to provide drinking water for the populace, the provision of public water supply has reached an all-time low (Afolabi *et al*., 2012). The majority of the time, the government does not fully carry out its water provision responsibilities, prompting residents of urban and sub-urban cities to seek alternative sources of water supply. These alternatives include groundwater sources such as boreholes and wells, as well as surface water sources such as streams, lakes, and rivers.

Many of the urban and sub-urban villages in the Nigerian state of Imo do not have access to a public water supply, which poses issues for the provision of potable water. According to studies, private and public boreholes are the primary sources of residential water supply in the state's urban and rural populations (Mbuka-Nwosu *et al*., 2022).

However, even accessible drinking water would require a series of treatments before it could be safe or fit for drinking. The extent of treatment needed is therefore determined by the quality of the raw water source (Adejuwon and Mbuk, 2011). Therefore, water has to meet certain physical, chemical, and microbiological standards—that is, it must be free from disease-causing microorganisms and chemical substances—before it can be termed potable.

The World Health Organization (WHO, 2010) recommends that the minimum daily per capita water consumption to be 27 liters/person/day. However, many people manage with far less than 27 liters. This could be because approximately 70% of the renewable water resources are unavailable for human use or under developed or unevenly distributed (Minh, Pham&Rodgers, 2011).

Industrial and agricultural activities have contributed immensely in polluting several surface water and groundwater sources (Nikolaidis*et al.*, 2008). These chemicals and industrial effluents in water from industries include dissolved metals and their salts, acids, bases, organic and inorganic compounds, solvents, solutions etc (Sullivan*et al*., 2005). Within the variety of effluents from the industries are fluorine, wastewater, heavy metals, dyes and colorants, solvents etc. Agricultural activities such as deforestation, pastoral farming, ploughing and the use of fertilizers have contributed to the devaluation of drinking water quality in our environment (Spitsov*et al.*, 2020). The quality of water, whether used for drinking, domestic purposes, food production or recreational purposes has an important impact on health.

Contamination of water has increasingly become an issue of serious environmental concern after years of pollution (Akpoveta*et al.*, 2011). Natural water contains many dissolved substances: contaminants such as bacteria, viruses, heavy metals, nitrates and salt have polluted water supplies due to inadequate treatment and disposal of wastes from humans and livestock, industrial discharges and over use of limited water resources. Fresh water is a fundamental resource, integral to all environmental and societal processes. However, fresh water is only a small component of the total water resources. Most countries of the world now have water resources management policies aimed at achieving the goal six of the Sustainable Development Goals (SDG) for their economic and social development (Tsani,*et al.,* 2020). Achieving this objective requires that the needs and wants of the community for each water resource are defined and that these resources are protected from degradation (Di Baldassarre*et al.,* 2019). These community needs generally called the environmental values (or beneficial uses) of the water body, include water for drinking, and domestic use; the basis for which the wells were conceived and constructed. However, the environmental values for which a particular water source could serve depend on the environmental quality parameters of the water. Environmental quality parameters are the natural and man-made chemical, biological and microbiological characteristics of rivers, lakes and ground-waters, the ways they are measured and the ways that they change. The values or concentrations attributed to such parameters can be used to describe the pollution status of an environment, its biotic status or to predict the likelihood or otherwise of a particular organism being present. Monitoring of environmental quality parameters of a drinking water sources is a key activity in managing the environment (water body), restoring the environment if polluted and anticipating the effects of man-made changes on wells (Oluyemi, 2013).

1.2. Statement of the problem

Owerri is the capital of Imo State since 1976, with projected population of 532,781 in 2018 (projection based on 2012 estimates) and a growth rate of 3.6 per cent per annum. Owerri is expected to be one of the biggest towns in Nigeria by the year, 2030. This growth in population coupled with high price of land have compelled new immigrants into the town to relocate to the suburban areas such as Irete, Orji, Naze, Ulakwo, Egbu, and Agbala.

The increase in population in these areas has contributed to increase in waste generation which are indiscriminately dumped in open lands, near residential buildings, along major roads, and streets, where they accumulate over time, causing nuisance and health hazards to people and environment.

In the absence of a regular water supply systemin these areas, most residents either source their water supply from boreholes or nearby rivers such as Uramiriukwa and Otamiri. It is observed that lots of activities are carried out around these river banks: washing of clothes, fermentation of cassava, use of fertilizer by famers to improve soil quality and increase yields. The topographical nature of the area accelerates discharge of run-offs into these rivers. Also, regular sand mining along these rivers has increase their turbidity.

In the past few year’s residents of Agbala, and Ulakwo who depend on Uramiriukwa river and boreholes as their main source of water supply have recorded incidents of water-borne diseases such as typhoid, diarrhea, and dysentery especially among children and the aged. There is reported recrudesce of these diseases in these communities which has become a source of concern to local population and public health expert. It is not certain whether these diseases are caused by the consumption of water from boreholes or from Uramiriukwa river. These concerns create an urgent need for quality assessment of both Uramiriuka river and borehole water in the area for the protection of public health and their sustainable use.

1.3 Aim and Objectives

1.3.1 Aim of the Study

The aim is to assess the quality of ground and surface water in sub-urban areas of Owerri, Imo State.

1.3.2 Objectives of the Study

The specific objectives of the study are to:

i. determine the physiochemical characteristics of Uramiriukwa river and borehole water in the study area.
ii. determine the biological characteristics of Uramiriukwa river and borehole water in the study area?
iii. determine and compare the spatial variations of physiochemical and biological properties of Uramiriukwa river and borehole water in the study area.
iv. compare the water quality parameters of the two water sources in the study area.
v. determine the water quality indices of the two water sources in the study area.

1.4. Scope of the Study

This research focused only on the analysis of physiochemical and biological properties of surface and ground water which are the two main sources of water for drinking and domestic use in sub-urban areas of Owerri, Imo State. The suburbanareas sampled for this study is the Owerri-north Local Government Areas (LGA), The spatial variation of the sampled surface and ground water wascompared. The two water sourcessampled in this study are the boreholes from four different points, and theUramiriukwariver sampled from three different points, upstream, middle stream and downstream.The average parameters of the boreholes and Uramiriukwa river were compared with the drinking waterregulatory standards.

The physical parameters to be analyzed includes temperature, turbidity, electrical conductivity (EC), total dissolved solid (TDS), while the chemical parameters include pH, chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved oxygen (DO), (HCO_3), total hardness (TH), Chloride (Cl), Nitrate (NO_3), Phosphate (POS_4), sulphate Acidity, Alkalinity, Total iron (Fe^{2+}), and biological parameters of *e.coli*, klebsiella, total coliform count and total bacterial count.Level of contamination and pollution will be determined by comparing the result obtained from this study with the National Environmental Standards and Regulations Enforcement Agency (NESREA) permissible level, for safe potable water.

1.5. Justification of the Study

This work presents an overview of the water quality and level of contamination of surface and ground water sources in Owerri sub-urban areas.Considering the level of human activities like indiscriminate direct disposal of municipal waste in the water bodies, buried waste,industrial waste disposal, agricultural activities, effluent disposal on water bodies, dredging, just to name a few. These activities call for concern of possible contamination, leachate, heavy metal contamination due to agricultural land run-off, rust from disposed metal, high counts of e. *coli*, coliform and bacteria due to sewage disposal etc.

This study will provide up-to-date information in the quality of the primary water sources in Owerri sub-urban areas. The result obtained from this study will help to enlighten residents, concerned stake holders, and ministries of the potential health risk and dangers of the water sources.The possible recommendation can serve as guidelines for formulation of necessary policy and measures needed to ensure safe and sustainable supply of quality water in the study area

CHAPTER TWO

LITERATURE REVIEW

2.1 Chemistry of Water

Water, is a naturally occurring inorganic substance, composed of the chemical elementshydrogen and oxygen with the chemical formula H_2O, which means that every molecule of water is made of two atoms of hydrogen and one atom of oxygen. Water exists in gaseous, liquid, and solid states and is one of the most plentiful and essential of compounds on earth (Zumdahl&DeCoste, 2011).

Water is transparent, tasteless, odorless, and nearly colorlesschemical substance. It exists in gaseous, liquid, and solid states and is the main constituent of Earth's hydrosphere and the fluids of all known living organisms (in which it acts as a solvent). It is vital for all known forms of life, despite providing neither food, energy, nor organic micronutrients (USA Department of Interior, 2015).

Water freezes at 0^oC and boils at 100oC under standard atmospheric pressure of 760 mmHg. Water can dissolve many substances, easily giving it different tastes and odours. In fact, all substances dissolve in water and hence it is referred as universal solvent (Aliyu, 2016).

2.2. Ground water

Groundwater is the water found beneath earth’s surface, in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers(Famiglietti, 2014) found within 100 meters below the surface of the Earth (see fig 2.1) (SGS, 2012).

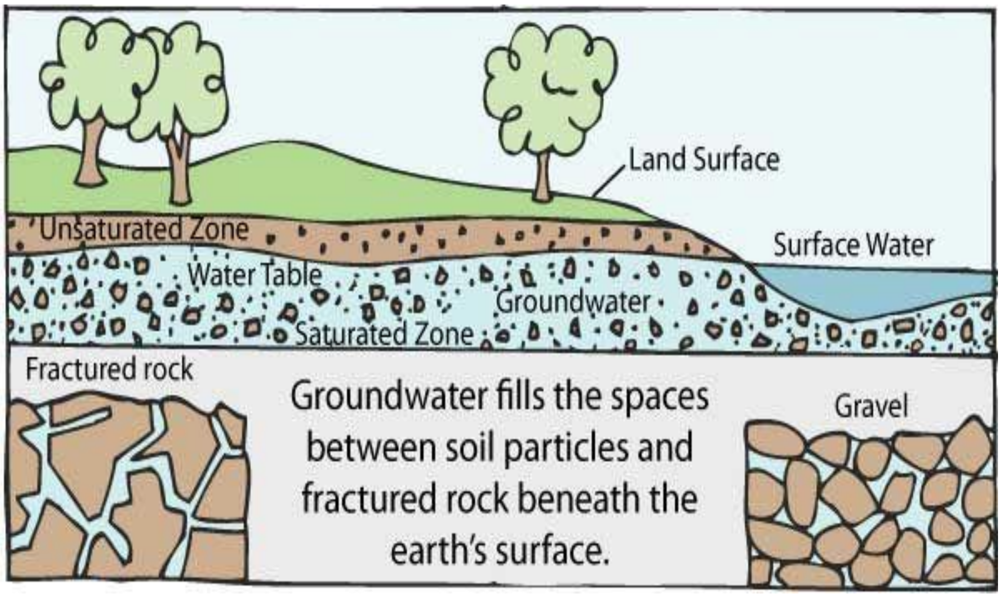

Figure 2.1: An illustration showing groundwater in aquifers

Source: Wikipediae

About 30 percent of all readily available freshwater in the world is groundwater. Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies. For example, groundwater provides the largest source of usable water storage in the United States, and California annually withdraws the largest amount of groundwater of all the states (Lall *et al.* 2020).

The natural chemistry of ground water varies depending on the nature of the sub-soils and rocks that it passes through. For instance, in Ireland, lime stone and bedrock dominated sub-soils are common and consequently groundwater is often hard, containing high concentrations of calcium, magnesium and bicarbonate. However, in areas where volcanic rocks or sandstones are present, softer water is normal in in considering the impact of human activities, it is necessary to first take the natural (or baseline) water quality into account. Ground water is usually considered to be pure and safe to drink as it undergoes a filtering and cleaning process through a subsoil cover and rock medium that surface water does have. However, this does not guarantee purity of ground water as mismanagement and indiscriminate dumping of waste on soil can lead to significant contamination of ground water.

According to PradhanandPirasteh(2011), groundwater plays an important role in both private and public water supplies all over the world. It occurs in many geological formations. Nearly all rocks in the upper part of the earth's crust possess voids or pores filled with water or air; this is the vadoze/unsaturated zone. At greater depths, all empty voids are filled with water, this is the saturated zone, and hence groundwater refers only to the saturated zone below the water table. In consolidated rocks the only voids may be the fractures or fissures. Occurrence of groundwater varies with the geology of the area. In the Basement Complex terrain, groundwater occurs in the weathered regolith and in fractures in the fresh crystalline rocks. Where thick weathered zones or fractures in fresh rocks occur, wells and boreholes tap the groundwater for water supply. The use of surface geophysical techniques coupled with down the-hole-hammer has revolutionized groundwater development in the Basement Complex areas. The volume of water that will drain under gravity from initially saturated rock mass to the total volume of that rock is called the specific yield of that material. Low land area aquifers are large but water security is compromised by limited and poor-quality surface water, restricted access to the aquifer via borehole and greater demand (Calow, Roger, Alan, Nicol & Nick, 2011). Groundwater with low values of NO_3^-, Cl^- has zones characterized by confined aquifer conditions, while zones with higher DO, NO_3^- and seasonally variable Cl^- are characterized by unconfined aquifer conditions.

2.3. Borehole water

Water boreholes are deep, narrow wells that tap into naturally occurring underground water. To use this water, a high efficiency pump is installed to extract the water from the permeable rock below. As the water passes through the ground, it flows through layers of rock and chalk which act as natural filters. Studies shows that borehole water produces a private water supply that is often purer than that provided from water treatment companies (Hobson, 2004).

Although engineers and environmental consultants use the term *borehole* to collectively describe all of the various types of holes drilled as part of a geotechnical investigation or environmental site assessment (a so-called Phase II ESA). This includes holes advanced to collect soil samples, water samples or rock cores, to advance *in situ* sampling equipment, or to install monitoring wells or piezometers (Hellström, 2008). A typical borehole used as a water well is completed by installing a vertical pipe (casing) and well screen to keep the borehole from caving. This also helps prevent surface contaminants from entering the borehole and protects any installed pump from drawing in sand and sediment (Lynn & Nasr-El-Din, 1998).

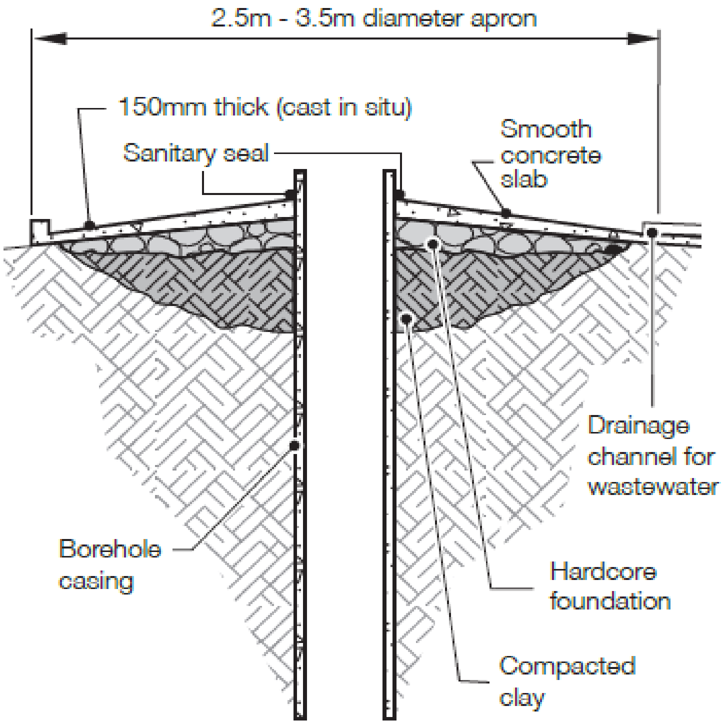

Figure 2.2.: A sanitary seal and well apron

Source: WHO, (2013)

In general, groundwater contains no or low levels of harmful pathogensbut it can be polluted with naturally occurring chemicals (WHO, 2013). In fact, boreholes are generally consisted safe for drinking, however, needs to be cleaned every four years (Hasen, 2020). Furthermore,the quality of water drawn from handpumps fitted to boreholes isvariable. Contamination can be caused by poor sanitary protection at thetop of the borehole. The installation of a sanitary seal and a well aproncan dramatically reduce contamination from the ground surface (see Figure2.2) (WHO, 2013).

2.4. Surface Water Resources

Surface water is any body of water found on the Earth’s surface, including both the saltwater in the ocean and the freshwater in rivers, streams, and lakes. A body of surface water can persist all year long or for only part of the year.

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. Precipitation and water runoff feed bodies of surface water. Evaporation and seepage of water into the ground, on the other hand, cause water bodies to lose water. Water that seeps deep into the ground is called groundwater (National Geographic, 2022).

Surface water and groundwater are reservoirs that can feed into each other. While surface water can seep underground to become groundwater, groundwater can resurface on land to replenish surface water. Springs are formed in these locations.

There are three types of surface water, which includes:

i. Perennial
ii. Ephemeral
iii. 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. Man-made surface water is found in artificial structures, such as dams and constructed wetlands (National Geographic, 2022).

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 percent of all water used in the United States came from surface water. Wetlands with surface water are also important habitats for aquatic plants and wildlife (National Geographic, 2022).

River waters are composed of surface runoff and ground water that flow into streams.The constituents in streams include those contributed in precipitation plus materials added by land erosion and solution of chemicals during travel over and through the soil minus removal of chemicals by plants or reactions with soil constituents.These may originate from point source discharges of waste water or increased contributions from non-point source discharges because of changes in land use patterns(Garfield,1991).

Surface water could be regarded as including all inland waters permanently or intermittently occurring on the earth surface in either liquid (river, temporary streams, lakes, reservoirs, bogs) or solid (glaciers, snow cover) condition.

Surface water plays a very important role in economics and the functioning of ecosystem. Lakes can be subdivided in three different ways, according to their topographic and morphological, percolation and hydrological regime, which are as follows:

i) Into lowland, foothill and mountain rivers depending on relief.

ii) Into large, medium and small, depending on river sizes

iii) Into snow fed, glacier fed and groundwater fed, depending on sources of supply.

Natural water flow moving under the force of gravity along their channels and fed by surface and underground runoff are called rivers. Rivers can be divided into mountain, which have slower flows and wider, often terraced valleys. The rivers of polar region and high mountain areas can be mainly supplied by glacier melting.

A network of tributaries usually supplies the main river, which can flow into the ocean, an interior (partially enclosed) sea, an endorheic (drain-less) lake or it can appear into an arid desert. A main (trunk) river and all its tributaries constitute a river system. A lake may be present within a main (or tributaries) river.

Rivers are classified according to their topographic/morphological features and their hydrological regime. These in turn influenced by climate, soils, reliefs and vegetation.

Topographic/morphological types of rivers include:

i. Mountain Rivers with large channels gradients and rapid flow.
ii. Rivers of glaciated areas, the channels of which have been considerably transformed by glaciers at least in former times.
iii. Lowland rivers with small slopes and slow flow in meandering channels.

The hydrological types of rivers are fairly diverse. The main criterion for their evaluation is the dependence of runoff variation on seasonal variation in rainfall and air temperature. River types are determined according to various criteria such as river size, flow conditions, sources of feeding, water regime, degree of channel stability, ice regime e.t.c. (Ayenimo, Adeeyinwo,and Amoo2005).

2.5. Sources of water

Water is a factor of production in virtually all enterprises and industry, and its importance in disease control has long been recognized and most water related diseases occur in large numbers i.e. epidemic proportion: a classic example is the Broad Street cholera epidemic in London (Opera, 2015).

A number of natural states of water exist. It forms precipitation in the form of rain and aerosols in the form of fog. Clouds consist of suspended droplets of water and ice, its solid state. When finely divided, crystalline ice may precipitate in the form of snow. The gaseous state of water is steam or water vapor (Baroni *et al*. 2007*)*.

Water covers about 71% of the Earth's surface, mostly in seas and oceans (about 96.5%).Small portions of water occur as groundwater (1.7%), in the glaciers and the ice caps of Antarctica and Greenland (1.7%), and in the air as vapor, clouds (consisting of ice and liquid water suspended in air), and precipitation (0.001%). Water moves continually through the water cycle of evaporation, transpiration (evapotranspiration), condensation, precipitation, and runoff, usually reaching the sea (Ball, 2008*)*.

Water resources are natural resources of water that are potentially useful for humans, for example as a source of drinking water supply or irrigation water. Water occurs as both "stocks" and "flows". Water resources can be stored as lakes, water vapor, groundwater, rivers, stream, spring, aquifers, ice and snow. Of the total volume of global freshwater, an estimated 69 percent is stored in glaciers and permanent snow cover; 30 percent is in groundwater; and the remaining 1 percent in lakes, rivers, the atmosphere, and biota (Gleick, 1993*)*. The length of time water remains in storage is highly variable: some aquifers consist of water stored over thousands of years but lake volumes may fluctuate on a seasonal basis, decreasing during dry periods and increasing during wet ones. A substantial fraction of the water supply for some regions consists of water extracted from water stored in stocks, and when withdrawals exceed recharge, stocks decrease. By some estimates, as much as 30 percent of total water used for irrigation comes from unsustainable withdrawals of groundwater, causing groundwater depletion (Wada *et al*. 2012*)*.

Though it is enshrined as human rights, the provision of adequate potable water remains a problem in most developing countries which have huge debt burden and low governmental commitment (Fawell, 2015). Globally, 1.1 billion of the world's population has no access to safe drinking water and 80% of that population live in Sub-Saharan Africa, Eastern Asia and Southern Asia. Eighty-four percent of these people are the rural dwellers.

Most urban communities in developing countries depend on municipal treatment plants as their secured source for pipe borne potable water. Often, these treatment facilities fail to deliver or/and fail to meet the water requirement of the communities due to mismanagement, corruption or increase in population. The scarcity of pipe borne safe water has made communities to find alternative sources of drinking water (Adekunle*et al*., 2019). These include rain water which is the purest natural water, surface waters e.g. rivers, streams, ponds, dams and lakes and underground water such as wells, borehole and springs. These alternatives are the only sources of drinking water available to most rural communities. One of the short falls of these traditional supplies of water apart from being unsafe is that they are season dependent i.e. the sources fill up in raining seasons and dry up in dry seasons (Adekunle*et al*., 2019).

2.6. Domestic Water Use

Domestic water use includes indoor and outdoor uses at residences, and includes uses such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, watering lawns and gardens, and maintaining pools. Domestic water use includes potable and non-potable water provided to households by a public water supplier (domestic deliveries) and self-supplied water use. Self-supplied domestic water use is typically withdrawn from a private source, such as a well, or captured as rainwater in a cistern (Dieter *et al*. 2015)**.**

2.6.1. Main Sources of Domestic Water

The major sources of drinking water include: Streams, Lakes, Rivers, Ponds, Rainwater and Underground water (spring, wells, and boreholes). Underground water is safer and purer for domestic use than surface water because the ground itself serves as an effective filter medium (Willey, Sherwood, &Woolver, 2018). Water from deep wells and deep springs usually dissolves a lot of salts and other minerals which is a major problem with underground water and so the water becomes salty, sometime too salty or "hard" for any use unless the salts are removed which is expensive (Chesebrough*et al*., 2019).

In the Third World, the development of water is mostly government-driven. Failure to develop efficient water supply systems in these countries is a product of the interplay of several factors. Among them, securing finances to build, maintain and expand the systems is perhaps the most important. The availability of finance especially for day-to-day operations and maintenance is significant in view of the low level of public finances for urban development, including water supply (Jones 1995; Urban Age, 1993).

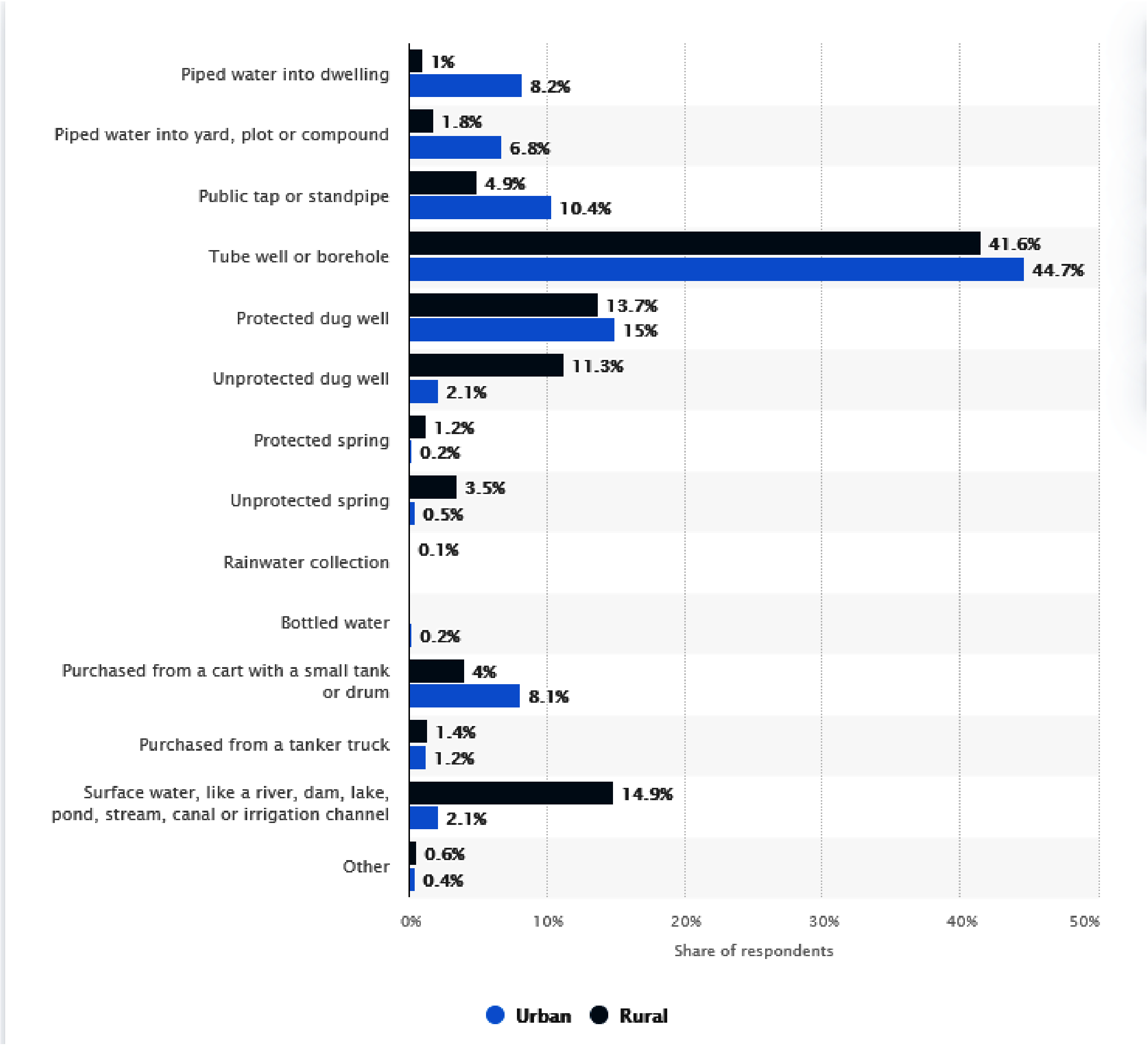

Figure: 2.3.: Graph showing sources of domestic water use in Nigeria, in 2020.

Source: Sasu (2022).

Water supply in Nigeria most vividly reflects this situation. Irrespective of the fact that several public waters work exist and have been in operation for several years in Nigeria, hardly any is performing efficiently. Most urban areas presently lack effective public water systems that could ensure regular supplies to the population. The output from these systems meets only a small percentage of the water need in the cities (Ayoade, 1981; Sik Lee and Anas, 1992). In addition, extensive areas in many cities do not have any network connections. Also, lack of proper water-works management, lack of appropriate technology and ineffective commercial operations were identified as problems militating against portable water supply and studies shows that the major sources of domestic water in Nigeria are alternative water supply, including wells, and boreholes, which are mainly found in cities, provided by individuals for private use or commercial purpose, others includes, streams/rivers/springs, tanker-drawn water and rainwater which are water sources in the rural areas as shown in Figure 2.3(Ayoade, 1981; Olajuyigbe&Fasakin, 2010).

2.6.2. Source of Domestic water in Imo State

Communities of Imo State, of Nigeria are not exempted in this development challenge, and according to studies, boreholes water source from ground water is the major sources of domestic water supply in urban and rural communities of in Imo State.According toMbuka-Nwosu*et al.* (2022), a large proportion of households (99.89% in the dry season and 99.56% in the wet season) in rural communities of Imo State use borehole water for their daily domestic use. The same study shows that proportion of ownership of these boreholes varies across communities, ranging from 25% in to 64%. Thus, a larger proportion (58.11%) of these rural residents depend on public free borehole water or buy water from available commercial borehole sources.

The study of Mbuka-Nwosu*et al.* (2022) also showed that in Aboh Mbaise LGA in Owerri Senatorial Zone, the streams tend to be distant from human settlements and undermines access and use of this water source. Despite the variation in utilising the different sources of rural water supply, again borehole water the principal source of water supply in these communities.

Iwuala*et al.* (2020) who showed that borehole water is the major source (65.4%) of potable water supply for urban residents of Imo State and less than half (33%) of these residents own a private borehole water source while others depend on commercial borehole. This is also supported by Onyenechere and Osuji (2012) which showed that a larger proportion of residents in Owerri city rely on borehole water, especially from commercial borehole owners.

2.7. Potable Water

Potable water is free of pathogens and toxic chemicals. Purification can be done by coagulation, which is by adding alum, Nitrogen aluminates or Ferric chloride to the water. Using the sand bed method, filtration can be carried out or repair sand bed filters can also be used. For the correction of pH of potable water, limestone is added. Potable water is often treated by chlorination. This makes the water free from any coliform organism no matter how polluted the original water may have been (WHO, 2018). Water treatment involves the conversion of water taken from the natural sources, the “raw water” into that suitable for domestic use. Ground water and surface water usually require more critical treatment than rain water. Harvested water also requires some form of treatment. Most important is the removal of pathogenic organisms and toxic substances such as heavy metals that can cause health problems (Jan and Robert, 2017). Storage of water may be regarded as a form of treatment. *Schistosoma mansoni cercariae* are normally unable to survive 48 hours of storage.

Also, the number of faecal*Escherichia coli* will be considerably reduced when the raw water is subjected to storage (Willey, Moelling& Broecker, 2018). The Nigeria based National Agency for Food and Drug Administration Control NAFDAC in association with the World Health Organization (WHO), recommended that potable water for consumption should not contain any microorganism that is known to be pathogenic and the coliform number per 100ml of water must be zero (WHO, 2018).

2.7.1. Availability and Sources of water in Nigeria

According to Oja (2022), Nigeria has 215 cubic kilometres of available surface water per year and also plenty stored in the ground. About 70% of Nigeria's population have access to basic water supply but little access to clean drinking water.In the rural areas of Nigeria, about 39% of households lack access to at least basic water supply with an average Nigerian using only 9 litres per day compared to national acceptable minimum standards of 12 to 16 litres (Oja, 2022).

Some of the most common sources of drinking water in Nigeria includes tube wells/boreholes, and dug wells, while pipe-borne water accounts for only 9.5% of domestic water supply to households; a significant drop from 61.6% between 1995 and 2022 (Oja, 2022).

Borehole accounts for 21.5% of tap water supply to households in Nigeria. About 86% of Nigerian households declared not to treat water before drinking, and 77.3% of Nigerians' household drinking water is contaminated by disease causing bacteria especially *e.coli*(Oja, 2022).

Nigeria has the 3rd largest market share for water filtration products within Sub-Saharan Africa, corresponding to 15% of the total (with South Africa coming in first at 43% and Ethiopia second at 18%), with the top 5 bottled water brands in Nigeria being Eva Water (by Coca Cola) Nestle Pure Life, Aquafina (from PepsiCo), Cascade, Redeemed Water and Bigi Table Water, with numerous sachet drinking water packaging companies all approved and regulated by the National Food and Drug Administration and Control (NAFDAC) (Oja, 2022). However, studies shows that about 30% of these commercial bottled water and Sachet Drinking Water contains disease causing bacteria, while over 58% of Commercial Sachet

Drinking Water are unfit to drink because they do not meet the recommended W.H.O standard (Maduka *et al.* 2014; Balogun *et al.* 2014;Angnunavuri*et al*., 2022).

Studies have also shown that unsafe water sources are the cause of 7.34% of deaths in Nigeria, with the most common waterborne diseases in Nigeria include cholera, typhoid, hepatitis and dracunculiasis. About 29% (26.5 million) of Nigerian children do not have enough water to meet their daily needs and 73% of diarrhea and enteric disease cases in Nigeria are connected to low access to safe and clean water, sanitation and hygiene (WASH). These diseases tend to disproportionally affect the poor and disadvantaged, especially children. The poor access to improved water and sanitation in Nigeria is still the major contributor to high mortality rates among children less than 5 years old (Oja, 2022).

2.8. Non-Potable Water

Non-potable water is one contaminated with domestic and industrial wastes. There are so many characteristics that make water not potable such as taste, smell, pH, colour/turbidity and mineral salts (WHO, 2015).

2.9. Water Quality

The importance of high-quality water cannot be over-emphasized as it sustains human life and maintains health. Most waters, before they reach the consumer, have been exposed to greater or lesser amount of contamination, but in many cases, they have also undergone a more or less complete purification by natural agencies (Ebiringer and Wilson, 2016).

Clean drinking water is an essential need of mankind. For drinking water purpose, water must be free from pathogenic organisms and hazardous chemicals. Quality of water is an important factor in development and use of surface and groundwater resources. Two major sources of water whose quality are assessed by chemists are the surface (streams, rivers, ponds, lakes) and ground waters (wells, boreholes). The reason is that surface waters are prone to contamination because it was reported that surface waters are generally poor in quality. Groundwater on the other hand is more reliable for domestic and agricultural irrigation needs (Okeola, Kolawole, and Ameen 2010). The quantity and quality of water have been causes for concern since ancient times. For example, the Egyptians built staggered dams along the Nile River to ensure a reliable water supply, and they even understood the potential for waterborne disease transmission, as evidenced by their use of filtering processes (Dorevitch, Panthi, Huang, Li, Michalek, Pratap, Wroblewski, Liu, Scheff, and Li, 2011). Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrological and human factors may cause periodic changes in groundwater quality. Its chemistry in turn, depends on a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water and inputs from sources other than water interaction. Such factors and their interactions result in a complex groundwater quality. Domestic and industrial discharges into groundwater and surface water bodies vary in nature, quality and quantity, thus contributing significantly to chemical, biological and physical pollution of these water bodies. Most of these pollutants enter the streams and rivers and are transported downstream passing through regional and international water bodies carrying with them wastes whose quality and quantity are yet to be determined (Akakuru, Maduka, and Akakuru, 2013).

The chemical constituents of groundwater are known to cause some health risks, so supply cannot be said to be safe if specific information on water quality which is needed for sustainable resource development and management is lacking. Therefore, water supply and water disposal should be optimized to maintain water standards for drinking, domestic and other purposes. This is the reason why water quality has been the subject of many recent studies (Magesh and Chandrasekar, 2013; Singh, Shashtri, Mukherjee, Kunari, Avatar, Singh, and Singh2011), mainly because of the increasing challenges of water scarcity and poor water distribution. Many countries are beginning to experience difficulties with water supply because of increased demand for water by agriculture and industry, coupled with poor management or a lack of management of water resources (Pfister, Bayner, Kochler, and Hellweg, 2011). Moreover, the pollution from industrial activities, urban areas and non-point sources, such as agriculture and cattle farms has promoted deterioration in water quality farms (UNEP, 2008).

2.9.1. Quality Water Guidelines

Water quality refers to suitability of water for a certain purpose. Hence quality of drinking is the suitability of water for drinking and domestic uses including personal hygiene. A good quality (safe) drinking water is that which is aesthetically acceptable and does not contain pathogenic agents and dangerous chemical substances.

The consequences of contaminated water are so all pervasive that they defy effort to draw up global balance sheet. The cost of dirty water includes not only loss of lives but also loss of socioeconomic momentum. For instance, World Bank estimated that Peru loss due to reduction in agricultural exports and tourism was about $1000 million (US dollars) in the first 10 weeks after cholera outbreak in January, 1991. Due to the importance of water for sustenance of life and livelihood, WHO in 1983-84 published the first guideline for drinking water quality and subsequent editions, were published in order to update previous publications. It is a UN document for member States to either adopt or adapt in their own countries based on their local situations. WHO guideline defined safe (quality) drinking as water that "does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages" (WHO, 2016).

The Federal Ministry of Environment is a ministry of the Federal Government of Nigeria created in 1999 with a mandate to address environmental issues and to ensure the effective coordination of all environmental matters in the country.As part of her visions and missions, the ministry sets out to ensure the control of environmental issues and the protection and conservation of natural resources. It also formulates policies and supervises activities for curbing desertification and deforestation;the management of flood, erosion and pollution, as well as climate change and clean energy (Opeyemi, 2021).

The ministry, through the National Environmental Standards and Regulations Enforcement Agency (NESREA) is responsible for Ecosystem Conservation, Pollution Control, Environmental Education, Sustainable Waste Management, with a specific function of carrying out effective environmental compliance monitoring and enforcement programmes to ensure the sustainable use of Nigeria’s natural resources, and to protect citizens’ wellbeing and control air, land and water pollution. Therefore, the ministry responsible for drinking water standards in Nigeria (Opeyemi, 2021).

Assessing quality of drinking water is a rigorous task which entails assessing the physical, chemical and bacteriological parameters of water. There are myriad of chemical / radioactive substances, bacteriological agents and physical properties of water that need to be considered in order to determine its quality (safety) for drinking. However, the greatest risk to human health especially in developing countries is from faecal contamination of water sources (WHO, 2016). For that reason, bacteriological analysis is the most important analysis and *e.coli* count is the most appropriate indicator of faecal pollution in assessing quality of drinking water.

Table 2.1: WHO and NESREA guideline for physiochemical properties of water

Parameters	**WHO**	**NESREA**
pH	6.5-8.5	6.5-8.5
Odour	unobjectionable	unobjectionable
Appearance	Clear	clear
Colour	15	15
EC(μs/cm)	1000	1000
TDS(mg/l)	500-1000	500
Temperature (ºC)	AMBIENT	30.00
Alkalinity (mg/L)	150	150
DO (mg/l)	6.5-8.0	<7.50
BOD	15	15
COD	10	40
Total Acidity	NS	NS
Sulphate (mg/l)	250	400
Nitrate (mg/l)	50	50
Phosphate(mg/l)	0.05	5
Turbidity (NTU)	5	10
Iron (mg/l)	<0.1	1.00
Lead (mg/l)	0.01	0.01
Total Hardness (mg/l)	150	150
Total Chloride (mg/l)Cl-	250	400
TSS (mg/l)	20.0	10.0
Total Coliform Count (cfu/100ml)	10	0.10
e.coli(cfu/100ml)	0	0
Klebsiella(cfu/100ml)	0	0

Water Quality Index

A Water Quality Index (WQI) offers a way to evaluate water quality from multiple parameters and simplify their interpretation (Lumb*et al*., 2011). WQI is created in order to compare water quality at different locations and over time (Espejo *et al*., 2012). The first attempt to develop a WQI was in Germany in 1948, when researchers found a correlation between pollution levels and certain communities of organisms (fish, benthic organisms and plants). Later, the German researcher Horton developed Horton’s Index in 1965. Lumb *et al*., (2011) argued that WQI was used in a program to reduce pollution and to inform the population. He also stated the importance and widely uses of the WQI which was developed by the National Sanitation Foundation of the United States (NSF) in 1970, based on that determined the nine most important parameters driving overall water quality. Therefore, the WQI are not recent, and have been widely used in various parts of the world to assess water quality. At the present time, new indices have been developed and implemented in a range of countries and by using different parameters (Rubio-Arias *et al.*, 2013).

The water quality ratings assigned to water quality index values are given in Table 2.2 below;

Table 2.2: Water quality index and water quality status

Water Quality Index (WQI)	**Water quality status**
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
Above 100	Unfit for drinking

Source: Chatterji and Razuiddin, (2002).

2.10. Water Treatment

Treated water is defined as drinking water that has undergone various standard processing steps including one or a combination of the following physical and chemical treatment: Filtration, ozonation, distillation (Percival *et al.*, 2016) and other more rigorous disinfection techniques aimed at inactivating pathogens and producing a highly safe product (Edberg, 2015).

2.10.1. Treatment Method

The treatment of drinking water is required due to the existence of undesirable physical, chemical and microbiological traits or constituents which are harmful to public health (Percival *et al.*, 2016; Edberg, 2015). Technically, when none of these factors occur, there should be no need to apply any treatment. Nonetheless, not all areas in the world are naturally provided with good quality water sources.

Also, the growing demand for drinking water consequent to the growing human population is putting enormous pressure on providing good quality water sources with the reported increasing use of water sources of dubious bacteriological quality (Sakai *et al.* 2016). Maintaining safety and quality is especially difficult in highly urbanized and Industrial areas where contamination from industries and domestic wastes are prevalent and water safety management plans are lacking. One of the major microbiological contaminants are the pathogenic bacteria such as pathogenic strains of E. *coli, Campylobacter, Salmonella* and *Shigella*; Parasites like *Cryptosporidiumparvum* and *Guardia lamblia* and pathogenic viruses (Gibot-Leclerc *et al.,* 2021). The most powerful disinfection treatment for water includes Filtration, distillation, Ozonation, chlorination and UV radiation.

i. Filtration

Filtration is one of the most commonly used microbiological treatment method for drinking water. It plays an important role in the natural treatment of groundwater as it percolates through the soil. It is also a major part of most water treatment. Since surface water is subject to run-off and does not undergo natural filtration, it must be filtered to remove particles and impurities.

ii. Distillation

Distillation is a process that relies on evaporation to purify water. Contaminated water is heated to form steam. Inorganic compounds and large non-volatile organic molecules do not evaporate with the water and are left behind. The steam then cools and condenses to form purified water (Edberg, 2015).

iii. Ozonation

Ozonation is a chemical water treatment technique based on the infusion of ozone into water. Ozone is a gas composed of three oxygen atoms (O_3), which is one of the most powerful oxidants. Ozone is usually effective against bacteria and viruses but not much on parasites for instance *Cryptosporidium parvum* cysts.

iv. Chlorination

Water chlorination is the process of adding chlorine or chlorine compounds such as sodium hypochlorite to water. This method is used to kill bacteria, viruses and other microbes in water. In particular, chlorination is used to prevent the spread of waterborne diseases such as cholera, dysentery, and typhoid (Dege, 2011).

2.11 Physicochemical and Biological parameters

Assessment of water quality can be defined as the analysis of physical, chemical and biological characteristics of water. The physicochemical parameters are temperature, pH, electrical conductivity, total hardness, magnesium, total chloride, nitrate, sulphate, total dissolved solid, total iron, phosphate, alkalinity, acidity, dissolved oxygen, total solids.

i. **pH**: The pH can be viewed as an abbreviation for power of hydrogen or more completely, power of the concentration of hydrogen ion. Acid rain contains dissolved Carbon dioxide (CO_2), Nitrogen dioxide (NO_2) or Sulphur dioxide (SO_2) often yields an elevated Hydrogen ion (H+) ion concentration and Carbonic acid (HCO) and may cause serious threat to groundwater pH (Chris, 2012). The pH of rainwater is about 5.7 (Goel, 2009). Increase in acidity is also attributed to the oxidation of reduced Sulphur compounds in the soils of the areas. The pH affects the solubility and toxicity of metals by influencing chemical kinetics of important constituents. Other acids such as HNO_3 and HNO_2 are formed as a consequence of the decomposition of organic matter and sulphuric acid is produced when minerals such as pyrite (FeS_2) breakdown. High pH levels make water to become less corrosive as most natural water is alkaline in nature due to presence of bicarbonates and carbonates formed due to dissolution of atmospheric Carbon dioxide. pH can be drastically changed due to prevailing biochemical activities undergoing in water. Photosynthetic activity increases the pH due to consumption of free CO_2 and dissociation of bicarbonates into carbonates. The carbonate is much stronger alkaline than the bicarbonates (Goel, 2009). The pH scale commonly ranges from 0 to 14 as value range of pH from 7 to 14 is alkaline, 0 to 7 is acidic while 7 is neutral. Mainly drinking water pH lies from 4.4 to 8.5. Akakuru*et al*, 2013 investigated some boreholes in Owerri and found out that majority of the samples are odorless and that pH values range from 6.2–10.7. According to the author drinking water with an elevated pH (above 11) can cause skin, eye and mucous membrane irritation. pH values below 4 can have corrosive effects. Okeke and Adinna,(2013) also reported that Uramiriukwa River had a pH range of 6.3-6.5 within the rainy and dry season period compared to other rivers in Nigeria like River Asa 6.8-6.9 and River Kaduna 6.4-7.2. He argued that the low pH in Uramiriukwa River could be as a result of predominant soil type in the river or due to the buildup of organic matter.

ii. **Alkalinity**: Alkalinity is a water characteristic that shows the capacity of water to neutralize acids by accepting Hydrogen ions (H^+) and preventing sudden changes in the acidity levels of water.Alkalinity is due to the presence of these forms of the Carbonate anions (HCO_3^-), (CO_3^{2-}) and (OH^-) that act as buffer system (Chris, 2012). Borates, phosphates, silicates and other bases also contribute to alkalinity if present in groundwater. Alkalinity is an important property when determining the suitability of water for other uses such as irrigation, or mixing with pesticides and when treating contaminated water. Limestone bedrock and thick deposits of glacial till are good sources of carbonate buffering. (Muthukumaravel*et al*, 2010). Inorganic ligands (anions) form complexes with metals (cations), this removes free divalent toxic metal ions such as Cd^{2+}, Cu^{2+}, Pb^{2+}, Zn^{2+} or methyl-metal complexes. Metal complexes are not biologically available and hence not toxic. Alkalinity is measured in $CaCO_3$ mg/L. According to Fakoyode (2005), pH that is near to neutral (pH 7) is indicative of unpolluted water. Carbon dioxide (CO_2) readily dissolves in water as illustrated in equation 1. The dissolved CO_2 (aq) reacts with water molecules to form Carbonic acid (H_2CO_3) as shown by equation 2 and Carbonic acid is very unstable and quickly dissociates into H^+ and a Bicarbonate ion (HCO_3^-) as demonstrated in equation 3. At pH 6.3, the amount of CO_2 dissolved in water equals the amount of bicarbonate ion (HCO_3). Dissolved carbon dioxide is dominant when pH is <6.3.

At higher pH, basic water, HCO_3^- dissociates to yield H+ and aCarbonate ion (CO_3^{2-}) asper equation 4.

$CO_{2\,(g)} \leftrightarrow CO_2\,(aq)$……………………………….(1)

$CO_2\,(aq) + H_2O\,(l) \leftrightarrow H_2CO_3\,(aq)$……………………(2)

$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$ (pH 6.3) ………………………(3)

$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$ (pH 10.3) ……………………….(4)

At pH 10.3, the bicarbonate ion concentration equals the carbonate ion concentration. CO_3^{2-} is dominant at pH >10.3 and HCO_3^- dominates between pH 6.3 and 10.3. The pH of most natural water falls in the range of 6 to 9 because of the bicarbonate buffering (Chris, 2012).

iii. **Electrical Conductivity:** Goel, (2009) proposed a factor of 0.65 that can be employed to convert the conductivity values in μmho/cm at 25°C into dissolve solids. The electrical conductivity is the capacity of waters to conduct current, and is caused by the presence of salts, acids and bases, called electrolytes, capable of producing cation and anions. As the conductivity is directly related to the presence of dissolve salts, its magnitude can give the fair idea of the level of dissolved solids. Okeke *et al*(2013) analyzed that dry season increases the Electrical Conductivity of rivers due to low precipitation, high atmospheric temperature and evaporation while Akakuru*et al*(2015) reported Conductivity values of groundwater ranging from 0.03ųs/cm - 0.44 ųs/cm, with an average of 0.0235 ųs/cm in Owerri.

iv. **Temperature**: Water temperature exerts a major influence on its chemical and biological properties, and determines the growth and activities of living organism organisms, can influence water quantity measurements, and governs the kinds of organisms that live in water bodies. Temperature governs the kinds of organisms that can live in rivers and lakes. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are none.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature. Water, particularly groundwater, with higher temperatures can dissolve more minerals from the surrounding rock and will therefore have a higher electrical conductivity(USGS, 2018)**.**

v. **Odour:**Odour itself does not have any deleterious health effects on humans, as water can picks up taste and odor from chemicals, even those in the air, that dissolve in it easily because it is the "universal solvent." However, water that has been contaminated by sewage, wastewater, volatile organic compounds, or bacteria should not be ingested. Odour is therefore an important indicator of water quality that should be closely monitored (Jones, 2020).

vi. **Turbidity:**it is the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid include clay, silt, very tiny inorganic and organic matter, algae, dissolved colored organic compounds, and plankton and other microscopic organisms (USGS, 2018).

vii. **Dissolved Oxygen (DO):** DO is one of the most important parameters. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. (Premlata, 2009). In the progress of summer, dissolved oxygen decreased due to increase in temperature and also due to increased microbial activity (Moss*et al*., 1996, Morrissette&Mavinic 1978, Sangu 1987, Kataria*et al*.,2010). The high DO in summer is due to increase in temperature and duration of bright sunlight has influence on the % of soluble gases (O^2 & CO^2). During summer the long days and intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO_2 and giving off oxygen. This possibly accounts for the greater qualities of O_2 recorded during summer (Krishnamurthy*et al*., 1997). DO in sample is measured by titrimetric measurementusing Winkler’s method after 5 days incubation at 293 K. The difference in initial and final DO give the amount of oxygen consumed by the bacteria during this period. This procedure needs special BOD bottles which seal the inside environment from atmospheric oxygen.

viii. **Biological oxygen demand (BOD):** BOD is a measure of organic material contamination in water, specified in mg/L. BOD is the amount of dissolved oxygen required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials (e.g., iron, sulfites). Typically, the test for BOD is conducted over a five-day period (Sitaram, 2022).

ix. **Chemically oxygen demand (COD):** COD is another measure of organic material contamination in water specified in mg/L. COD is the amount of dissolved oxygen required to cause chemical oxidation of the organic material in water. Both BOD and COD are key indicators of the environmental health of a surface water supply. They are commonly used in waste water treatment but rarely in general water treatment (Sitaram, 2022).

x. **Total acidity:** Acidity is a measure of the capacity of water to neutralise bases. Acidity is the sum of all titrable acid present in the water sample. Strong mineral acids, weak acids such as carbonic acid, acetic acid present in the water sample contributes to acidity of the water. Usually dissolved carbon dioxide (CO2) is the major acidic component present in the unpolluted surface waters (Saxena, 2016). In addition to harming your body, acidic water can corrode pipes. Due to its high acidity, water with a low pH can start to dissolve metal pipes over time, causing leaks and further increasing the presence of heavy metals in drinking supply. This is concerning, as exposure to heavy metals can be dangerous, potentially leading to heavy metal poisoning and toxicity (Anyanwu *et al.*, 2018).

xi. **Total Dissolved Solid**: Total Dissolved Solid is a function of temperature and pH. At higher temperatures and lower pH groundwater dissolves more minerals. Total

Dissolved Solids (TDS), is defined as the concentration of all dissolved minerals in the water. Natural waters contain a variety of both ionic and uncharged species in various amounts and proportions that constitute the Total Dissolved Solids (Agbaire and Oyibo, 2009). Poor chemical quality of water is a health risk in the long term for consumers. Urban waste waters are often high in nutrients concentrations (macronutrients Na, Ca, P, K, Mg and micronutrients Fe, Zn, Cu,) and other chemicals which can stress the bacterial populations, in rainy seasons they are washed to the groundwater by infiltration. The chemical composition of groundwater may be altered by the precipitation of ions from solution to form insoluble compounds. TDS in groundwater is due to enhancements of weathering of minerals from acids produced as byproducts of the degradation process. Sources of ion TDS include hard water ions (Ca^{2+}, Mg^{2+}, HCO_3^- and CO_3^{2-}), fertilizer in agricultural runoff (NH^{4+}, NO_3^-, PO_4^{3-}, and SO_4^{2-}), urban runoff/salinity from tidal mixing, minerals or irrigation water and acidic rainfall (H^+, NO_3^-, SO_3^{2-} and SO_4^{2-}).

xii. **Total suspended solids:** Total suspended solids are the dry-weight of suspended particles, that are not dissolved, in a sample of water and can be trapped in a filter. It stands for total suspended solids, and refers to waterborne particles that exceed 2 microns in size. The residue retained on the filter is dried in an oven at 103–105°C until the weight of the filter no longer changes (Campbell*et al.*, 2021).Total suspended solids (TSS) values are often related to the turbidity (cloudiness) of water. If TSS is high and the water is murky then light from the sun will not travel well through the water, making it difficult for plants and algae to grow.

xiii. **Total Iron**: Iron is not toxic, but imparts objectionable taste to water and may leave brown stains on porcelain and in clothing. Objectionable taste is due to reduced form (Fe^{2+} and HS), on exposure to air, water becomes reddish brown due to Ferric Hydroxide and prolonged consumption of such water may lead to liver disease (Ranjana, 2010). Largest contributors of iron in groundwater are minerals contained within the underlying bedrock, soil and sand, the most common is Ferrous Iron, limestone, shale and coal which often contain the Iron rich mineral Pyrite, acidic rain also releases Iron into groundwater as it increases with depth (Lenntech, 2009). An aquifer in which groundwater is in a mildly oxidized state and a near neutral pH, the most likely Iron is Fe^{3+} and is tied up in solid phases. At a given temperature changing from their oxidized form / giving up of electrons (Fe^{3+} and SO_2^-) to the reduced (accepting electrons) form requires a decrease in redox potential (dissolved oxygen) or a decrease in pH. Nitrate to Nitrogen gas, Fe^{3+} (insoluble) to Fe^{2+} (soluble), Sulphate to Hydrogen Sulphide and at very low redox potential, Methane formation occurs. Reduction/treatment of iron can be achieved by using a water softener, Potassium Permanganate or green sand filters and aeration (addition of oxygen to water) all aid in precipitation of iron. Salts may be concentrated in the groundwater as result of evaporation and transpiration. This depends on vegetative cover, warmth, soil type, and climate.

xiv. **Total Chloride**: Akakuru*et al*(2015), provided insight on some groundwater results in Owerri as Chloride concentration ranges from 0.04mg/l – 5.2 mg/l. All type of natural and raw water contains chlorides. It comes from activities carried out in agricultural area, industrial activities and from chloride stones. Its concentration is high because of human activities. In small amount they are not significant. In large concentrations they present problem. Usually chloride concentration is low (Muthukumaravel*et al*., 2010).

XV. **Total Hardness:** Hard water is water that has high mineral content. Hard water is formed when water percolates through deposits of limestone, chalk or gypsum, which are largely made up of calcium and magnesium carbonates, bicarbonates and sulfates. Hard drinking water may have moderate health benefits (WHO, 2021).

With hard water, soap solutions form a white precipitate (soap scum) instead of producing lather, because the 2+ ions destroy the surfactant properties of the soap by forming a solid precipitate (the soap scum). A major component of such scum is calcium stearate, which arises from sodium stearate, the main component of soap:

$$2C_{17}H_{35}COO^{-}\ (aq) + Ca^{2+}\ (aq) \rightarrow (C_{17}H_{35}COO)_2Ca\ (s)$$

Hardness can thus be defined as the soap-consuming capacity of a water sample, or the capacity of precipitation of soap as a characteristic property of water that prevents the lathering of soap. Synthetic detergents do not form such scums. Apart from interference with action of soap and detergent, hard water can result in deposits of calcium carbonate, calcium sulphate and magnesium hydroxide ($Mg(OH)_2$) inside pipes and boilers, causing lower water flows and making for less efficient heating.

The World Health Organization says that "there does not appear to be any convincing evidence that water hardness causes adverse health effects in humans" (WHO, 2021). In fact, the United States National Research Council has found that hard water actually serves as a dietary supplement for calcium and magnesium (WHO, 2021). However, some studies have shown a weak inverse relationship between water hardness and cardiovascular disease in men, up to a level of 170 mg calcium carbonate per litre of water. The World Health Organization has reviewed the evidence and concluded the data was inadequate to allow for a recommendation for a level of hardness (WHO, 2021).

xvi. **Nitrate**: Most natural water is deficient in nitrate having a concentration usually below 5 mg/L, but certain polluted surface water and ground water may have substantially higher quantities. According to Akakuru*et al*(2015), the chloride, sulphate and nitrate concentration levels in groundwater in Owerri study area fell below the WHO (2006) recommended highest permissible limit for drinking water, thus indicating good quality. As seen sulphate and nitrate values range between 1.0 mg/l – 4.2 mg/l, and 0.01 mg/l – 4.06 mg/l, respectively. Generally, nitrate content shows very low values, with undetectable values in some samples.

The nitrate has gained major significance because of its implication in infant methaemoglobinaemia, a disease characterized by bluish coloration of skin. In these diseases, the normal haemoglobin is converted into met haemoglobin due to formation of ferric ions in the harem, and loses its capacity to carry oxygen (Goel, 2009). Nitrate contamination of groundwater results from leaching of fertilizer, septic tank leachate, unsewered sanitation, pit latrines, animal waste or human waste mineralization of decomposing or oxidation of decaying matter by soil micro-organisms (Suthra*et al.*, 2009). Unutilized urea leached to groundwater for microorganisms to degrade is also another source of groundwater nitrate (Singh,Khurana, Manish, Tadav& Yadav, 2012). Nitrate can readily be transported beneath the soil zone because it is relatively soluble and not prone to ion exchange (Suthra*et al.*, 2009). Nitrate can be endogenously reduced to nitrite, which can then undergo nitrosation reaction in the stomach with amines to form a variety of N-nitroso compounds (NOC). These compounds are carcinogens, thereby causing health hazards like impairing the ability of the blood to carry oxygen (Blue-baby syndrome or infantile methemoglobinemia), gastrointestinal cancer, Alzheimer disease, vascular dementia, adsorptive secretive functional disorders of the intestinal mucosa, multiple sclerosis, NonHodgkin's lymphoma and hypertrophy of thyroid (Suthra, 2009). In Aarlborg, Denmark, water had a relatively high nitrate content of about 30mg/l and there was a slightly greater frequency of stomach cancer (Singh *et al.,* 2012). Nitrate contamination can be treated by technologies such as ion exchange; denitrification and reverse osmosis or anaerobic reduction in the subsurface which can limit Nitrate contamination of groundwater (Singh *et al.,* 2012).

xvii. **Sulphate:**Sulfate is a chemical commonly found in air, soil and water. Since it is soluble (easily dissolved) in water, sulfate is found at high concentrations in many aquifers and in surface water.Sulfate has laxative effects and may imparts an unpleasant taste to water on levels above 250 mg/L. High sulfate levels may also corrode plumbing, particularly copper and lead piping. In areas with high sulfate levels, plumbing materials more resistant to corrosion, such as plastic pipe, are commonly used. It is measured by nephelometric method in which the concentration of turbidity is measured against the known concentration of synthetically prepared sulphate solution. Barium chloride is used for producing turbidity due to barium sulphate and a mixture of organic substance (Glycerol or Gum acetia) and sodium chloride is used to prevent the settling of turbidity (MPCA, 2009).

xviii. **Chloride**: It is measured by titrating a known volume of sample with standardized silver nitrate solution using potassium chromate solution in water or eosin/fluorescein solution in alcohol as indicator. The latter indicator is an adsorption indicator while the former makes a red colored compound with silver as soon as the chlorides are precipitated from solution(Patil*et al*., 2012).

xix. **Phosphate:** These are also measured spectroscopically. Yellow colour is developed from the action of phosphates on molybdate ion under strong acidic conditions. The intensity of colour is directly proportional to the concentration of phosphate in the sample. Phosphate complexes are reduced by weak reducing agents such as ascorbic acid or tartaric acid (potassium antimonyltartarate) Most of the physico- chemical parameters are determined by standard methods prescribed by ASTM (2003) and APHA (1985), Trivedy and Goal (1986).

xx. **Total coliform:** thisinclude bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste. It is the total coliform group is a large collection of different kinds of bacteria. All coliform bacteria are not pathogenic or disease-causing, but they are associated with other disease-causing organisms. The drinking water standard for total coliform bacteria is <1 or zero colony-forming-units per 100 ml of water sample. This means it should be absent in potable water (WSDH, 2021).

xxi. **Total Bacteria count:**

The total bacteria count is one of the key indicators in the field of hygiene management. It indicates how many microorganisms are present in a sample. Total bacterial count (TBC) is the count of the number of bacterial colony-forming units present in a sample. The aerobic plate count (APC) established by the Association of Official Analytical Chemists (AOAC) is used to determine TBC in a sample (Maturin & Peeler, 2001).

xxii. **Total *E. coli:*** thisis a sub-group of the fecal coliform group. Most *E. coli* bacteria are harmless and are found in great quantities in the intestines of people and warm-blooded animals. Some strains, however, can cause illness. The presence of *E. coli* in a drinking water sample almost always indicates recent fecal contamination, meaning there is a greater risk that pathogens are present (WSDH, 2021).

2.12. Water pollution

According to Gharibi, Sowlat, Mahvi, Mahmoudzadeh, Arabalibeik, Keshavarz, Karimzadeh &Hassani, *(*2012) the rate of increase in urban, agricultural, and industrial activities has raised scientists' concerns aboutenvironmental issues and in particular about water pollution.

The introduction of pollutants into the natural water body usually occurs directly through point sources (septic tanks, disposal sites, etc.,) near the ground water. Although most groundwater is of high quality, at some locations, it is becoming increasingly difficult to maintain the purity of groundwater. Migration of dangerous contaminants and agrochemicals through the vadoze zone is a possible pollution pathway for vulnerable drinking water resources (Andricevic, Srzic&Gotovae, 2011).

Water percolating through soils picks up naturally occurring minerals, salts and organic compounds. As the water migrates downwards the concentration of dissolved minerals and salts typically increase, a process known as mineralization. In some cases, the percolating water accumulates mineral concentrations high enough that the groundwater no longer can be used as a water supply or even for irrigation without treatment. Some of the more common natural contaminants include hydrogen sulphide, which often originates as a result

of decomposition of organic materials, radon, a radioactive gas formed from the natural decay of uranium found in many rocks. Many surface water reservoirs used as drinking supplies are fenced to keep people from contaminating the water. Signs warn, for example, that the reservoir is a municipal drinking water supply and that no human access is permitted. Unfortunately, groundwater reservoirs typically are not protected this effectively. Often land is zoned and developed or farmed without considering the underlying groundwater aquifers and the necessity of protecting the aquifer's recharge areas. Even aquifers that serve as municipal water supplies for thousands of people often are left mostly or entirely vulnerable.

2.12.1.Sources of groundwater pollution

According to Akhionbare (2015)**,** filtration through the soil over long distances usually removes virtually all suspended matter, including turbidity and bacteria. Also emphasizing, on the other hand, the slow movement increases opportunities for contacting and dissolving chemicals present in the soils and biological or physicochemical reactions may either reduce or increase the concentrations of various constituents.

2.12.1.1. Saltwater intrusion

One of the major sources of pollution of groundwater is saltwater intrusions. Others include seepages from underground storage tanks, oil wells, septic tanks, landfills and agricultural leaching (Adewuyi, Anyakora&Ukpo2010). In most coastal areas, the groundwater flow gradient pushes fresh water toward the ocean. Thus, water typically exits on land (and enters seawater) at subsea outcrops of the aquifer. If the original groundwater gradient changes for example as a result of pumping, then seawater can intrude into the coastal aquifer. Extensive pumping of groundwater can create local trough in the groundwater table (for unconfined aquifer) or the potentiometric surface (confined aquifer). These troughs can cause saline water in adjacent bedrock or salt rich clay to migrate into the aquifer. If heavy pumping of groundwater occurs in coastal aquifers lateral influx of saline water from bedrock or clays can occur at the same time as seawater. Intrusion of sea water into groundwater is particularly prevalent in areas where the coastal shelf is narrow or where submarine canyons breach the shelf. Intrusion of sea water into groundwater can make an aquifer too salty for drinking. It can also make the aquifers water too saline to be used for irrigation. Usually, the contaminated parts of an aquifer can be reclaimed by stopping the intrusion and then promoting natural flushing of the groundwater by fresh sources of water.

2.12.1.2. Underground storage tanks.

Many underground storage tanks are associated with gas stations. Most of the extensive groundwater contamination that have occurred over the years have come from these tanks and from other subsurface impoundment used by industry and the government. Solvent leakage from underground storage tank used by the computer industry in Silicon Valley near San Jose, United States resulted in the largest concentration of federal groundwater clean-up sites (superfund sites) in the country as reported by Winter, Harvey, Frankie and Alley, (2013). Also in 2015, the USEPA reported that approximately 566,000 underground storage tanks nationwide store petroleum or hazardous substances in which over the last few years, the percent of confirmed releases pending cleanup completion has declined from 18.8 percent in 2010 to 13.6 percent at end of fiscal year 2015. Looking back several more years, the percent of confirmed releases pending cleanup completion was 26.4 percent in 2005.

2.12.1.3 Mine Drainage.

The construction and by products of mining operations can pose serious threats to groundwater. Subsurface excavation and drilling at mines often results in disrupted groundwater flow. Furthermore, the rocks that were exposed during the mining operations on the walls of the pit are exposed to attack by water containing dissolved oxygen. If the rocks in contact with such water contain pyrite or metal sulfides an acidic effluent would be produced (Dlamini, Fadiran& Thwala, 2013). Mining wastes are broadly defined as solid, semi-solid or liquid waste materials from the extraction and processing of ores and minerals. These wastes include soil, waste rock and overburden as well as tailings, slag and other processed materials. Inactive and abandoned mines are also sources of contamination.

2.12.1.4 Contamination caused by well.

Improperly built wells can result in contaminated groundwater by establishing a pathway or a conduit for pollutants entering a well from surface drainage or by allowing communication between aquifers of varying quality. Unused wells sometimes are simply abandoned or truncated just below the ground surface and ploughed over, or otherwise destroyed properly. Such wells can contaminate groundwater in several ways. Another type of well that often causes groundwater contamination is the dry well; a cased or uncased hole in the ground that does not penetrate the groundwater table. Such wells sometimes are used to dispose of a variety of potential contaminants, including household and septic wastes, rinsate from commercial and industrial operations, waste oil, solvents and storm water runoff. Nola, Noah, Ewoti,Nougang,Krier,Chihib,Hornez &Njiné(2011)

emphasized that lack of sanitary facilities and availability of pit latrines, discharge of waste water without prior treatment, indiscriminate dumping of waste contribute to borehole water contamination where people still practice open defecation.

2.12.1.5Land use

Many groundwater contaminants cause harm only after relatively long exposure (chronic toxicity). This is not so, for nitrate (NO_3). Consuming water containing high concentrations of nitrate can have almost immediate effects on a person (acute toxicity). According to Taiwo, (2010) nitrate in water used for drinking is detrimental to infant health and can lead to methemoglobinemia or blue baby syndrome. Nitrates mostly often enter the groundwater from fertilizers, manure, septic systems, or nitrate laden wastewater percolating downward from holding ponds. Nitrate is very soluble in water and not readily absorbed by soil, so it is typically very mobile in the subsurface environment. When transported by water into a geologic medium that lacks oxygen in certain types of soil, nitrate is subject to denitrification whereby some of it can be converted into gas and released to the atmosphere. However, denitrification is not enough to solve the problem of high nitrates. The increased use of chemical fertilisers as well as an increase in the production of animals and animal wastes has resulted in greater quantities of nitrates leaching into and degrading groundwater.

2.12.1.6 Urbanization

African cities have a long history of water supply from surface and groundwater sources. However, due to deteriorating quality and quantity of surface water through increased urbanization and industrialization and high cost of developing new dams, urban groundwater is viewed as a better option (Ocheri, Odoma& Umar, 2014). This advantage notwithstanding, urbanization has important overall implications for freshwater use and waste management and specifically for the development, protection and management of sub-surface water in an urban environment. In a comprehensive study of groundwater quality of the southeastern parts of Lagos from 1999-2001 on the impact of urbanization, Ocheri*et al*(2014) found that of the water samples analyzed, concentrations of sulphate, nitrate and chloride at objectionable proportion were noted in all the wells. Nitrate particularly was noted to be very high and is linked with anthropogenic activities. Groundwater in Lagos is particularly vulnerable to contamination due to shallow depth and the unconsolidated permeable sand and gravel aquifer. In a similar study, Eni, Obiefuna&Ekwok, *(*2011) assessed the impact of urbanization on the sub-surface water of Calabar town noted water to be acidic, nitrate and faecal coliform to have very high concentration in the wells. Results of multiple regression show faecal coliform, pH, and chlorine have positive relationship with urbanization. High faecal coliform is often associated with the sanitary condition of the environment of the wells. Amadi, Ameh &Olasehinde(2010) examined the effect of urbanization on groundwater quality of Makurdi metropolis. Results of analyses show water samples collected within the vicinity of dumpsite have low pH, higher concentration of iron, manganese, calcium, total dissolved solids and total coliform when compared to those far away from the dumpsite suggesting leachate influence. Presence of coliform is traced to sanitary condition of the well. In a related study, Tse and Adamu (2012) in the chemical and bacteriological analyses of hand dug wells in Makurdi town noted water to be slightly acidic, moderately hard and had low total dissolved solids. Heavy metal such as iron, zinc, copper, lead and cadmium occurred in traces, while high concentration of coliform is noted in all the wells.

2.12.1.7. Landfill, Dumpsite and Abattoir Wastes

Proper management and protection of urban groundwater quality has been a major problem in Nigerian cities. Waste dumpsites are not properly designed nor constructed as landfill sites. Consequently, wastes dumped at dumpsites over the years are expected to have bio-degenerated and generate leachates which could become point source of pollution into soil and groundwater (Ocheri*et al*, 2014). The rate and characteristics of leachate production depends on a number of factors such as solid waste composition, particle size, degree of compaction, hydrology of the sites, age of the landfill, mixture and temperature of the condition and availability of oxygen (Ocheri*et al.*, 2014). Ikem *et al*(2002) evaluated groundwater quality characteristics near two waste sites in Ibadan and Lagos found the concentrations of nitrate, ammonia, chemical Oxygen Demand, aluminum, cadmium, chromium, iron, lead, nickel and total coliform to exceed WHO prescribed limit for drinking water. The elevated concentration of these elements in groundwater is traced to leachates from the dumpsites. Longe and Enekwechi (2007) investigated potential impact and influence of local hydrogeology on natural attenuation of leachate at municipal landfill and groundwater of Lagos City and noted elevated nitrate, chloride, sulphate in groundwater and heavy metal. Chromium and calcium were also detected at measurable level in groundwater down the gradient of the landfill location without any particular attenuation pattern of the well-studied. As recorded in Ocheri*et al*(2014) the impact of leachate from dumpsites on groundwater quality in Isolo, Ojota and FESTAC areas of

Lagos Metropolis were assessed and elevated concentrations of iron, magnesium, nitrate, phosphate, sulphate and coliform were found above the prescribed limit for drinking water. They noted the concentrations of these elements were higher in water samples collected close to dumpsite than those far away thus suggesting the influence of leachate generated from dumpsites. Also, in Ilupeju and Agbara industrial area, effluents discharged were noted to pollute the groundwater sources of the area. High concentrations of elements above WHO allowable limit in drinking water were observed in cadmium, antimony, barium, tellurium, tungsten, copper, lead and nickel linked to industrial effluent. In Ibadan, hydrogeological investigation of waste dumps noted the concentration levels of electrical conductivity, total dissolved solids, sodium, potassium, magnesium, nitrate and chloride

were higher in water samples collected near the dumpsite than those far away. This is traced to leachate from dumpsite. Bayode *et al*(2012) assessed the impact of some waste dumpsite on the groundwater quality in some parts of Akure metropolis and of the parameters analyzed, pH, electrical conductivity, total dissolved solids, calcium, and nitrate concentrated exceeded WHO prescribed limit for drinking water. This especially true of water samples collected within the vicinity of the dumpsite implying leachates may have contributed to the concentration level. Ocheri (2014) also recorded pollution of groundwater from dumpsites in the basement complex of Southwestern Nigeria and found concentration levels of physico-chemical and bacteriological loading higher in wells close to dumpsite than those far away. Further Studies carried out in Ibadan and Minna metropolis confirmed the pollution of hand dug wells from abattoir wastes. This is evident in high faecal coliform and nitrate concentrations in the wells located close to abattoir. In a related study, Ahmed (2003) investigated the effect of sanitation on groundwater in Kaduna, noted high peak values of sanitation pollution indicators such as coliform and nitrate. Hand dug wells located close to pit latrine and soak away have higher concentration of these pollution bacteria.

2.12.1.8. Seasonal Effect

Season is believed to influence the concentration level of the physicochemical and bacteriological loading in water sources. Agbaire and Oyibo (2009) investigated seasonal variability of physico-chemical elements in boreholes in Abraka town. The result show total dissolved solids were lower in the dry season. Ocheri*et al*(2010) assessed seasonal variation in nitrate level in Makurdi metropolis and found 80% of the wells had nitrate concentrations above the WHO allowable limit for drinking water for wet season. Other parameters whose concentrations were higher in the wet season are pH, turbidity, electrical conductivity, chloride, iron, calcium, chromium, biochemical oxygen demand and faecal coliform bacteria. Nwafor, Okoye &Akinbile(2013) analyzed the seasonal influence on the physico-chemical concentrations in hand dug wells in Akure town, of the parameters studied, pH, total dissolved solids, total alkalinity, potassium, iron, sulphate have higher concentrations in the wet season. Whereas, temperature, turbidity, total hardness, chloride, magnesium, electrical conductivity, sodium, nitrate have higher concentrations in the dry season. Seasonal variation also changes the aesthetic quality of the water and brings discomfort amongst consumers. Seasonal variations in water quality arise due to variations in ecological activity, precipitation and geology of the area. When boreholes penetrate fractured material in an area of thin overburden, they respond quickly to percolated water from the rain. The ecosystem, characteristics of the surrounding area, residence time and geological characteristics affect the physico-chemical and micro-biological seasonal variations of groundwater parameters (Singh *et al.*, 2012).

2.13. Sources of surface water pollution

Studies carried out in most cities in Nigeria had shown that industrial effluent is one of the main sources of surface water pollution in Nigeria (Ekiye and Zejiao, 2010).

Industrial effluents when discharged directly into the rivers without prior treatment have capacity of increasing water quality parameters. The resultant effects of this will be on the receiving streams and rivers. The impacts could include water quality impairment, reduction in fish abundance and effect on water-usage for recreation, industrial and domestic purposes. High phosphate concentrations in these effluents could result into nutrient enrichment of the receiving water bodies thereby leading to ecological disaster. Khan, Hussain,Hussain, Jamila, Ahmed, Riaz, Zain & Saboor,(2012), also included improper disposal of solid waste, sewage water, and too much use of fertilizers as other main reasons of water contamination.

2.13.1. Municipal and agricultural wastes

According to Taiwo,Adeogun, Olatunde &Adegbite, (2011) waste management is a major problem in most developing nations of the world including Nigeria. Indiscriminate disposal of municipal wastes remains a major threat to surface water pollution in Nigeria. In most cases, sewage and waste water from homes are routed into the rivers and streams. He also observed high water quality parameters of a stream in Abeokuta due to direct discharge of poultry wastes into the stream. The use of pesticides and fertilizer for bumper food production is a well-known policy of several Governments all over the world. However, agriculture remains the major source of nitrate and phosphate pollution of surface water. It has also been observed that pathogenic contamination of Nigeria's rivers comes from aquaculture practices involving fertilization of ponds with cow and poultry manures; and direct dumping of faecal matters into the rivers (Obasohan,Chijioke, Igwegbe, Ibearugbulem, & Abubakar 2010).

2.13.2 Sediment pollution

Sediment acts as a sink for pollutants. There is a direct link between surface water and sediment contamination. Accumulated heavy metals or organic pollutants in sediment could be released back into the water with deleterious effects on human health. In a study on the Lagos Lagoon carried out by Adeboyejo,Clarke,&Olarinmoye(2011), the levels of Organochlorine Pesticides (OCP) in sediment were investigated from

three stations along the Lagoon. The concentration in sediment (μg kg^{-1}) ranged from (Non-Detectable) ND to 2.96,0 to 1.83, 0.62 to 43.54, ND to 15.6, ND to 32.13, ND to 7.15, ND to 1.3 and 0 to 2.42 for aldrin, dieldrin, chlordane, endrin, endosulfan, heptachlor, HCD and HCH, respectively. The findings showed that these chemicals tend to bind with river's sediment particles with resultant effects on water pollution.

2.13.3Urban run-off

Urbanization in most Nigerian cities has resulted in the concentration of large population in some areas living under poor sanitation conditions. Urban storm water runoff contains a variety of contaminants including household pesticides, animal wastes, heavy metals and volatile organic compounds. The runoff contains these contaminants and can be discharged to streams or surface impoundments from which they can get into groundwater.

During rainfall, some of these wastes are washed into the poor drainage systems and subsequently, into nearby rivers (Taiwo *et al*., 2011). Lack of town planning principles and strategies in Nigeria's cities and towns had aggravated the risks of urban run-off with resultant effect on surface water. The poorly managed drainage system in the country had caused the surface water impairment due to erosions during rainfall. Rainfall runoff carries all sorts of pollutants from houses, industries, farmland and dumping sites.

Research has shown that some of the water quality parameters of both ground and surface water often rise up during rainfall with high values of turbidity, solids and anionic species often been recorded (Taiwo, 2010; Taiwo *et al*., 2011).

Agricultural run-off of pesticides, plant and animals' wastes is also a major contributing source of organic pollution to water bodies in Nigeria. High TSS found in rivers in Nigeria has tendency of reducing the light penetration into the river leading to a reduced photosynthesis with consequent effects on both phytoplankton and zooplankton populations of the aquatic environment. A study by Osibanjo*et al*., (2011) reported high TSS values in Rivers Ona and Alaro in Ibadan. Clogging of TSS on fish gills could also result into stress, reduced growth, suppressed-immune system leading to increased susceptibility to disease and osmotic dysfunction and death. In surface water, TSS could cause drift in invertebrate population whereas Edet and Worden (2009) assessed the seasonal and tidal effects on the physical parameters of river and groundwater in Calabar, Nigeria. The researchers reported a significant seasonal effect on temperature and DO in the river water. They also observed that a significant tidal influence existed on DO in both river-and groundwater. Comparison between groundwater and river water showed statistically significant difference in EC, TDS, DO, Na, Cl^- and NO_3^-. The significant differences in EC, TDS, Na and Cl^- were attributed to tidal flushing; while NO_3^- was as a result of anthropogenic pollution. The study concluded that tidal flushing, anthropogenic effects and oxygen supply during recharge contribute to the shaping of water chemistry in the area. High Pb concentration in some surface water samples have been attributed to the use of leaded petrol in vehicles. Taiwo, (2010) found elevated values of lead at a sampling site of Alakata stream in Abeokuta. High lead level in surface water may also be due to vehicular deposition. Dry deposition of particulate lead on water bodies is capable of increasing Pb level of surface water. Lead is a potential killer especially in children. In some villages in Gummi and Bukkuyum Local Government area of Zamfara state, more than 400 deaths were reported due to lead poisoning (Galadima, Garba, Leke. Almustapha&Adam, 2011). Heavy metals are potential threats to the environment and ecosystem due to their persistence and bio-accumulation in food chain. The presence of oil and grease on the surface of water bodies in Nigeria is a sign of pollution which may have serious effect onthe aquatic ecosystem of the nation. Oil and grease are toxic to aquatic organisms in general and also capable of reducing dissolved oxygen. The activity of oil exploitation and refininghas reduced the water quality of Nigeria’s river in the Niger Delta region. Besides the oil region of Niger Delta, which is synonymous with oil spill pollution, elevated levels of oil and grease have been reported by Osibanjo*et al.* (2011) at the downstream of Rivers Ona and Alaro in Ibadan, Southwestern Nigeria. The authors attributed these to urban run-off from auto repair workshop and petroleum depot.

2.13.4 Effluent discharge and oil spill

According to Ekiye and Zejiao, (2010), its study carried out in most cities in Nigeria showed that industrial effluent is one of the main sources of surface water pollution in Nigeria. Industrial effluents when discharged directly into the rivers without prior treatment have capacity of increasing water quality parameters. Less than 10% of industries in Nigeria treat their effluents before being discharged into the rivers. This has led to high load of inorganic metals such as Pb, Cr and Fe in most of water bodies (Wakawa, Uzairu, Kagbu&Balarabe,2008). The resultant effects of this will be on the receiving streams and rivers. The impacts could include water quality impairment, reduction in fish abundance and effect on water-usage for recreation, industrial and domestic purposes. High phosphate concentrations in these effluents could result into nutrient enrichment of the receiving water bodies thereby leading to ecological disaster. Metal pollution of Warri River by industrial discharges has been reported by

Ayenimo*et al*., (2005). The river was monitored for heavy metals such as Fe, Cu, Ba, Pb, Cd, Cr, Ni and Co. Results showed elevated values of these metals at sampling point located near an industry. Correlation analysis of the metals also suggested common source. Other water quality parameters showed elevated values indicating pollution by the nearby industry.

The activities of the oil industries in the Niger-Delta region of Nigeria have impacted negatively on the surface water quality around the area. This has led to water scarcity, disruption of socio-economic activities and poor aesthetic quality of most of the water bodies polluted by the oil spills (Taiwo,Olujimi, Bamgbose& Arowolo, 2012). Most of the rivers around the Niger-Delta region of the country could not be abstracted for treatment for drinking purpose because of pollution by crude oil. The impact of oil activities in these areas had done much havoc to the environment of this region most especially on the water resources.

2.14.Overview of Water Policy Reform in Nigeria

The World Bank has been providing assistance to Nigeria in the water supply sector since 1979 while the responsibility for water resources development in Nigeria are vested on government agencies including the Federal Ministry of Water Resources, State Water Agencies and nongovernmental or donor agencies such as Non-Governmental Organization (NGO), Water AID, European Union (EU), World Bank and UNICEF etc.; (Adah and Abok, 2013). The first generation of assistance was directed at investments and strengthening institutions at the state level, especially since urban water supply is constitutionally a responsibility under Nigeria’s constitution.

Adah and Abok, (2013) pointed out that the States that benefited from the World Bank Water projects are Kaduna in (1979), Anambra (1980), and Bornu (1985) and Lagos (1989). The second generation of assistance was in the form of a loan of US$256 million for the National Water Rehabilitation Project (1991-2001) , which targeted the entire country. Concurrently also, the World Bank supported the First Multi-State Water Supply Project (1992-2000) with a loan of US$101 million, which was targeted at Kaduna and Katsina States. The third generation of assistance (2000-2004) was the provision of US$5 Million under the Small Towns Water and Sanitation Pilot Project aimed at satisfying the needs of 16 towns.

2.14.1 National Water Supply and Sanitation Policy of 2000 (NWSSP)

This policy spelt out the Institutional Framework for Water Supply andDevelopment thus;

i. The Federal Ministry of Water Resources:

Charged with the responsibilities of policy advice and formulation, data collection, monitoring and co-ordination of water resources development (of which water supply is a component) at the National level.

ii. **The River Basin Development Authorities (RBDAs)**

This came into existence following the promulgation of Decree 25 of 1976. The current law on RBDAs is the RBDA Act; cap 396 Laws of the Federation of Nigeria, 1990. The authorities are charged with the development, operation and management of reservoirs for the supply of bulk water for water supply amongst other uses in their areas of jurisdiction.

iii. **The National Water Resources Institute:**

Responsible for manpower training, research, development and studies under the National Water Supply Training Network in the water supply sector.

iv. **The State Water Agencies:**

These agencies are responsible mainly for urban, semi-urban and rural water supplies. In some States separate agencies exist for rural water supplies and urban and semi-urban water supplies.

v. **The Local Government Authorities:**

These are responsible for the provision of potable water to rural communities.

2.14.2 The National Water Policy (NWP) Document of 2004

Water abstraction for public water supply is guided by the National Water Policy. In order to meet Nigeria's water supply demand, the following policy objectives had been drawn and the guiding principles for implementation. The formulation of the water resources policy was guided by; The Millennium Development Goals (MDGs), NEPAD Objectives and the resolutions of various conferences, conventions and meetings based on the international trends and agreements in water Policy. The International trends and agreements in water policy highlighted the fact that water management and development should be conducted on a participatory basis with decision making occurring at the lowest appropriate level.

2.15. Water provision in Owerri Suburban

Currently water provision in Owerri is poor. It was observed that though majority of the residences are connected to the public water supply in the area, water flow is extremely irregular and people are also forced to resort to alternative sources which is in agreement with Banerjee *et al*(2008), who found that piped water reaches most urban Africans more than other forms of supply but not as large a share as it had in the early 1990s. The National Water Supply and Sanitation Policy (NWSSP) document of FMWR (2000), and the National Water Policy document of FRN (2004), recognized and gave Imo State Water Cooperation and other sister agencies mandate and responsibilities for the establishment, operation, quality control and maintenance of urban and semi-urban water supply systems. It empowered them to encourage private ownership of water supply and sanitation facilities and to license and monitor private water supply and quality of water supply to the public. The entire decrees and edict in the legal framework and the mandate provided by the water policy documents are tools of empowerment, dominance and control of water supply and sanitation provision in the city. Those are pointers to the fact that the state government through its agency, the state water corporation, despite its peculiar constraints, is in control. Its scale of provision both in terms of quantity and quality cannot be equaled by any other category of water and sanitation service provider in Owerri.

Imo State Water Corporation (ISWC) has the advantage of possessing reticulation and distribution network as well as treatment plant which other providers do not have and it does not depend on groundwater. The ISWC also has state government presence. However, the political will to ensure efficiency and maximum output in the running of its day-to-day activities or to provide water adequately in the city is lacking. Strategies for boosting its services are lacking and that is why till date ISWC has not been able to provide water meters to consumers in line with the NWSSP document' recommendation.

It has not succeeded in funding its activities sufficiently from monies realized from charges nor has it sourced for external loans to overhaul its system.

Currently, the ISWC’s control of Owerri urban and suburban water and sanitation service provision is not in doubt, but its short-comings which undermine its powers have to be highlighted. From field observation, it was discovered that ISWC does not collaborate with North L G A in water and sanitation services provision. It is due to ISWC’s non-provision of technical assistance to the water supply unit that resulted in engagement of engineering construction firms for construction of its facilities. ISWC does not have a popularly acceptable regulatory framework and does not monitor other providers nor does it provide them licenses with which to operate. ISWC ought to regulate the activities of other providers and ensure that the quality of water provided is high and their charges will not exclude the poor from being served. Since the National Water Policy (NWP) mandates State Water Agencies (SWA) to encourage private ownership of water supply and sanitation facilities, regulating them is imperative. ISWC has not yet adopted the National Water Policy of 2004, nor has it adopted the policy to suit local needs and peculiarities as it is expected. Though the edict establishing ISWC stipulated that it performs certain specific functions, for some reasons the act has not been effectively enforced.

The failure of ISWC to deliver services to Owerri suburban dwellers puts groundwater in jeopardy and endangers groundwater sustainability in the long run. The other alternative sources all abstract groundwater except where rain water is harvested. On the average 10 boreholes (estimated number) exist in every ward in Owerri suburban. Groundwater is also a preferred source because it is a common property resource. The onus lies on ISWC to fore warn the public of over dependence on groundwater, especially of the longtermimplications. It has been known to deplete and degrade groundwater and affect continuous aquifer systems in communities where water is used for both domestic and agricultural purposes (Hadipuro and Indriyanti, 2009). Burke and Moench (2000) are of the view that legislation and regulation would help nip this likely problem in the bud. During the oil boom days of the 1970s and early 1980s, the country invested heavily in water resources development.

Table 2.3: Water consumer units served by ISWC in Owerri in 2008

Category	**Number of units**
Residential homes	33,111
Hotels	113
Hospitals/clinics	78
Banks	21
Car-wash enterprises	138
Block industries	137
Fuel stations	36
Hair dressing salons	13
Institutions	401

Source: Imo State Water Corporation (2011)

One distinctive feature of ISWC water service is its low tariff, which is lower in comparison with water bought from commercial boreholes or bottled water. The tariff charged is based on flat rate, according to the category of the buildings or tenements. The lowest tariff is N300 (about US $0.83) a month for a room connected to the network. For a rooming apartment with water system facilities, it is N550 per month; for a three-bedroom flat it is N1500. Previously as at 2008, it was N50 per room and N350 for a flat of three bedrooms, showing an astronomic increase in tariffs.

Table 2.4: Tariffs for water provided by ISWC in 2010

Category	**Monthly Tariff**	
	N	**US$**

Five (5) Room Boys Quarters	1500	4.17
One (1) Room	300	0.83
Rooming Apartment (water system facilities)	550	1.53
One (1) Bedroom Flat	650	1.81
One (1) Bedroom Flat with Boys Quarters	900	2.50
Two (2) Bedroom Flat	1200	3.33
Three (3) Bedroom Flat	1500	4.17
Four (4) Bedroom Flat	2500	6.94
Four (4) Bedroom with Boys quarters	3000	8.33
Single Bungalow with One to Four Rooms	3500	9.72
Single Bungalow with Above Four Rooms	4000	11.11

Source: Imo State Water Corporation (2011).

Note: US $ stands for United States of America's dollar; Exchange Rate: N360.00 to US $ 1

2.16. Water quality challenges and its environmental impact

The challenges in suburban water management are ample and are threatening the sustainability of the suburban water system as a significant fraction of the urban population has no access to proper (good) water supply.

Gold face and Irokalibe (2008) observed that water management cannot be done with poor data management. In the past ten years, no single pan Nigerian hydrological yearbook has been published. Without water assessment there cannot be decision support system (DSS) models necessary for understanding the impact of abstraction and groundwater aquifers. There is currently no effective water resources data management system for the nation. Therefore, Nigeria does not only need to set up nationwide networks for these data collection but also an institute to use the data and make models.

The inability of stakeholders in water management to comply with the existing policies on water management and development constitute a great challenge in the system hence retards its efficiency. The poor state of power supply from the Power Holding Company of Nigeria, Plc. (PHCN), limited distribution system that was put at 40%, ageing plants, vehicles, machineries and limited-service coverage due to limited reticulation pose a serious problem to many water supply projects in the Country.

Fragmented sectorial practices according to Goldface and Irokalibe (2008) have also led to disjointed development and have critically led to a situation where there is presently nothing in place to significantly ensure the quality of water. There are no clear responsibilities, no mandated water quality standards, no effective water monitoring, no enforcement, no sanctions for polluters, and no remediation.

Climate change and water scarcity go hand-in-hand to cause some of the biggest contemporary challenges to human race. These issues have a reciprocal relationship, identified by the Intergovernmental Panel on Climate Change (IPCC), in which, "water management policies and measures can have an influence on greenhouse gas (GHG) emissions" (Adah and Abak 2013). As renewable energy options are pursued, the water consumption of these mitigation tactics must be considered in producing alternatives ranging from bio-energy crops to hydropower and solar power plants.Producing potable water for the public involves finance in the purchase of materials/equipment and paying of bills-(chemicals, power, maintenance and overhead costs). In this case there is a scenario of high production and maintenance cost.

The situation where projects are not adequately monitored by coordinating agencies is detrimental to economic progress and against social benefits for the government to carry out such projects. Huge capital investment without corresponding financial discipline and accountability for performance, along with political interference in decisions about allocations and pricing are reflected in the inefficient operations, inadequate maintenance, financial losses and unreliable service delivery as witnessed. The sustainability of a project is tied to continuous maintenance which involves continuous flow of funds. Cost recovery measures are not adequately put in place in our water management approach because water supply has always been considered as a social good. There is no appropriate metering system, and where they do exist utility officer do not make use of them for proper pricing system.

The accelerating growth in suburban population could see a supply-demand gap in water resources. Currently, due to urbanization process large number of people don't have access to clean water on the global scale, (NAS, 2009). This is a great challenge to the water management sector of the economy. More strategic and proactive approach need to be adopted to handle this situation.

2.17Water-borne diseases

Impact of water borne diseases on children is greater than the combined impact of HIV/AIDS, tuberculosis and malaria (WGAASD, 2010). Lack of safe drinking water especially in the suburb has resulted in an increased demand for sachet water.

According to Zeenat, Hartha, Viola & Vipra, (2009), due to this increased demand several companies engaged in the manufacture is increasing with the attendant increase in the profits while Udoh (2012) estimated the Nigerian sachet water sales at NGN 7 billion (USD 44.5million) daily. The sachet water quality literature is generally littered with poor study designs and tiny sample sizes, and a recent review according to Stoler, Weeks & Fink,(2012b) reveals occasional bacteriological quality concerns. Sachet water is usually consumed without further processing especially during the dry and hot seasons in Nigeria. However, there are possibilities that large numbers of potential pathogens and opportunistic bacteria would be ingested which will pose serious health concerns to people, particularly those with weakened immune system (Zeenat *et al*., 2009) whereas the quality of water is of vital concern for mankind since it is directly linked with human welfare. According to Ranjana (2010), the quality of public health depends to a greater extent the quality of groundwater.

At least 30,000 people per day die in the third world because they have inadequate water and sanitation facilities (UN, 2010). The control of water pollution in developing countries is a necessity. Nigerian children of age less than 5 years make up 17% of the total annual deaths of 1.8 million being recorded globally due to poor sanitation (Water Initiative, 2010). Research has also shown high prevalence of waterborne diseases such as cholera, diarrhoea, dysentery, hepatitis, polio, typhoid etc. among Nigerians (Afolabi, Ogbuneke, Ogunkunle, &Bamiro,2012). Many health challenges such as mortality, morbidity and poverty have been reported in the literature as consequences of lack of safe drinking water supplies as well as poor sanitary condition (Nwankwoala, 2015). In addition, unsafe drinking water was said to have contributed to numerous health problems in developing countries including the one billion or more death incidents of diarrhea that occur annually (Mark, Pximing& Sarah, 2002). Considering the issues of safe drinking water in the developing and underdeveloped nation, transmission of waterborne diseases is still a matter of major concern, despite worldwide efforts and modern technology being utilized for the production of safe drinking water (WHO, 2010).

Despite the inevitable need of water for human life, its supply is grossly inadequate in many developing countries of the world. The situation is more worrisome in Nigeria especially in the rural areas. For instance, recent reports by the World Health Organization (WHO, 2010) placed Nigeria at third position globally on the list of countries with inadequate water supply and sanitation coverage. The report further adjudged Nigeria as one of the countries that are “off-track’’ in meeting the water and sanitation targets of the

Millennium Development Goals (MDGs) by 2015, due to lack of coordination, abandonment and poor funding of various water projects. In 2009, Nigeria was ranked 130 out of 147 countries on the world Water Poverty Index (WPI) (FRN, 2009). Inability to supply water through pipe borne system makes it difficult to cover many homes in both urban and rural areas of Nigeria.

Consequently, many households have resorted to self-help to salvage the situation by constructing shallow wells, but the wells can hardly ensure adequate water supply in terms of quantity and quality. This is because shallow wells do not provide all-year round water supply and the water quality is inadequate. As a result, governments at all levels have adopted the construction of boreholes as an alternative to pipe-borne water supply and as a quick solution to the perennial water supply problem, especially in the rural areas. Therefore, many boreholes have been sunk in most semi-urban and rural areas of the country to supply water with different types of pumps fitted; some manual and some motorized. This, of course, is a common scene in Akoko Area of Ondo State where at least 75 % of the about 40 towns and villages are rural and are not connected to public pipe-borne water supply. However, it has been observed that many boreholes sunk by the successive governments are either not properly done or well-maintained to last long in the rural areas. Oloruntade, Konyeha& Alao, (2014) therefore reported that the extent to which the boreholes construction has effectively served as an alternative to pipe borne water supply is not known. Thus, contamination of drinking water from any source is of primary concern due to the danger and risk of water diseases. TheWorld Health Organization (WHO) reported that 40% of deaths in developing nations occur due to infections from water related diseases and an estimated 500 million cases of diarrhoea, occurs every year in children below 5 years in parts of Asia, Africa and Latin America (WHO 2006; 2010).

Furthermore, declining water quality has become a global issue of concern as human population grow, industrial and agricultural activities expand and climate change threatens to cause major alterations to the hydrological cycle. Water quality issues are complex and diverse and are deserving urgent global attention and action (UN – Water 2011).

Public drinking water systems associated with water borne disease outbreak (WBDO) are identified as either community or non-community based on definitions of the Safe Drinking Water Act. A community water system serves year-round residents (an average of 25 or more persons or 15 or more service connections). Non-community systems can serve transients or non-transients. A non-transient system regularly serves at least 25 of the same persons at least six months of the year (e.g. schools, hospitals, or factories that have their own water supply). Transient systems serve persons at campgrounds, motels, gas stations, or other businesses that have their own water supply. WBDOs that occur in individual water systems (e.g., private wells) are also reported.

For an event to be defined as a WBDO, two or more persons must have experienced a similar illness. This criterion is waived for single cases of laboratory-confirmed Primary Amebic Meningoencephalitis (PAM) and for single cases of chemical poisoning if water quality data indicate contamination by the chemical. Waterborne pathogens of concern in our environment have multiple transmission routes, including person-to-person contact and ingestion of contaminated food. Thus, epidemiologic evidence must implicate water as the probable source of the illness (Craun, Gunther, Rebecca, & Michael, 2006).

2.18 Assessment of water Quality

The maintenance and assessment of water quality are important procedures in modern society. Earliest and simplest methods were purely subjective- does the water look clean, smell right, e.t.c? such assessment of water quality sufficient for some consumer process but for most the fact that water is such solvent and can contain all kinds of dissolved substances led to requirements for more precise assessment methods. These have been met through hydrochemical analytical techniques. Each chemical parameter has an associated standard and water is chemically tested as routine measure to ensure it fulfils the quality standards for the various consumer processes. However, there are thousands of chemical pollutants but only a small number can be analysed in any one sample. Scientists have also found that biological surveillance of aquatic systems can prove valuable in assessing water quality and detecting pollution. Aquatic organisms show a lasting response to the intermittent pollution episodes which may be missed by routine chemical monitoring which only samples a relatively tiny volume of water at a particular point in time (Kiely,1998). Aquatic organisms also provide an assessment of the average water quality that has pertained over a period of time. Organisms can also accumulate and magnify low levels of chemicals which may be below the detection point of analytical chemical methods but which can analysed from biological tissues.

Biological methods also provide information on the impact of pollutants on the ecology of the system, which chemical methods, by themselves, cannot do. However, most biological techniques have the disadvantage of not being able to give an accurate measure of the exact quality of pollutants and concentration of chemicals and they may not pick up slight changes in water quality that do not impact significantly on the ecological system but which nevertheless may be of importance to some consumer processes. Thus, modern approaches to the description of water quality utilize three approaches:

- Quantitative measurements, such as of physicochemical parameters in water, in sediments or in biological tissues.
- Biochemical\Biological tests (including BOD estimation, toxicity testing e.t.c)
- Semi-quantitative and qualitative descriptors involving biological indicators and species inventories (Chapman, 2021).

The actual process of water quality assessment is an evaluation of the physicochemical and biological nature of the water in relation to its natural quality,human effect and intended uses,' i.e. basically to verify whether the observed water quantity is suitable for its intended use(Chapman, 2021). It includes the use of monitoring.Monitoring involves the collection of information at set localities and at regular intervals to:

- Obtain information concerning substances entering the environment, the quantities, sources and distribution.
- Evaluate the effects of these within the environment.
- Provide a basis for detecting trends in concentrations and effect and to establish cause and effect relationships (e.g. acidification and eutrophications).
- Examine how far inputs, concentrations and trends can be modified, by what and at what cost (Chapman, 2021; Mason*et al.*,1991).

The water quality assessment processes have the same philosophies in marine and fresh water systems, although much more has been published concerning fresh water largely because of the greater importance to human societies (Chapman, 2021) on behalf of UNESCO and WHO, presents a comprehensive outline of the design of water quality assessment procedures and protocols and the selection of water quality variables for rivers lakes and ground waters.

2.19. Strategies to combat water quality problems

There are four fundamental strategies to combat water quality problems that can form the basis of policy solution for improving water quality (WHO, 2010).

Pollution prevention strategies focus on the reduction or elimination of waste at the source. Prevention is widely regarded as the cheapest, easiest and most effective way to protect water quality. In industry, solution includes reformulating products so that they produce less pollution and require fewer resources (including water) during their manufacture. In agriculture, reducing the use of toxic materials for pest control, nutrient application and overall water usages through precision farming can reduce pollution (Obilonu*et al.*, 2013). In human settlement, the most obvious solutions include increasing improved sanitation coverage, consideration of settlement design (such a type of materials used for construction), the location of storm water, as well as reducing waste water production (UNEP 2009).

The purpose of water treatment is to correct deficiencies in quality as described by Akhionbare (2015). The ultimate goal is to make the water safe for human consumption and to provide a finished product that is attractive and pleasing to the consumer. The author also reiterated the degree of both surface and groundwater treatment. The surface water treatment starts with the protection from storm runoff while the treatment process includes clarification, pH adjustment and disinfection. The process for groundwater as described by the author includes pH adjustment and disinfection. Coagulation a process of clarification involves the addition of alum (aluminum sulphate) with reacts with the alkalinity in the water to form a gelatinous precipitate that is effective in promoting coagulation of small suspended particles into larger ones that separate more rapidly in the settling basin.

The next process is the pH correction and hardness. The natural groundwater from springs and wells usually has low pH values and is hence aggressive due to the pressure of dissolved CO_2. This is usually the first step in groundwater treatment. For the surface water, due to the alum reaction with alkalinity, the water may be rendered acidic in nature creating a necessity for lime addition which is a medium for pH adjustment.

Disinfection is the next process which involves the killing of germs and bacteria. This is generally seen in our homes when water is boiled at certain degrees for different purposes. For larger purposes the use of chlorine (calcium hypochlorite) with a brand name OLIN BLUE DRUM-High Test Hypochlorite (HTH) is used. Chlorine does not increase the acidity level of the water because of the presence of OCl^- which kills the microorganisms.

$$Cl_2 + H_2O \rightarrow H^+Cl + HOCl$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

Other compounds with disinfecting ability include ozone and Ultraviolet light. Several studies have also shown that proportions of antibiotic resistant bacteria in waters may increase when exposed to low doses of Ultraviolet light or chlorine as described by Jing-Jing Huang *et al.*, 2013. Tetracycline resistance *e.coli* did not show any tolerance to UV lights but had a potential higher tolerance level to chlorination.The use of ozone is because of its very wide spectrum disinfecting ability and it is very unstable and also a powerful oxidizing agent which is toxic to organisms living in water.

Waste water is usually disposed of into water bodies ideally following treatment to render it environmentally safe. However, it can safely be used sometimes even untreated in circumstances where impacts on human health and environment are well understood and all possible action is taken to eliminate risks (FAO 2010). If well regulated, safe use of waste water for example, in agriculture, can reduce the pressure exerted by human activities on existing fresh water resources and augment water supply in water scarce and semi - arid zones and in rapidly growing periurban setting (Obilonu*et al*., 2013).

Furthermore, waste water can be a source of nutrients and when properly managed is potentially valuable for certain agricultural uses, reducing the need for expensive chemical fertilizer (Obilonu*et al*., 2013). Additionally, agriculture may act as a form of biological treatment, moving nutrients from water that otherwise may pollute water courses. In periurban and rural areas, treated human waste water can be a viable source of water for reuse, after applying ecological sanitation. It involves the separation of urine and faecal matter.

Sterile urine may be applied directly to plants while fecal matter is composted until it is safe for land application. This approach has been implemented in several countries and regions including China, India, Burkina Faso, Kenya, Niger, Sweden, and parts of Eastern

Europe (UNEP 2009). By recycling water and using dry pre-stored human wastes, jobs are created for local populations as well as market opportunities for provision of indigenous fertilizers and soil conditioners for agriculture. Some industries, such as food and processing industry utilized large volumes of water, and often also discharge considerable quantities of waste water. Such waste water can be reuse in other applications that do not require high quality, or apply appropriate technologies to process waste water for producers requiring water of high quality. Examples can be derived from Namibia and Singapore, where fresh water resources for both industrial and human consumption are supplemented with treated waste water (UN – Water, 2011).

Healthy ecosystem provides water quality benefits in the form of water purification, often at far lower cost than subsequent engineering efforts to clean contaminated water (Obilonu*et al*, 2013). When water systems, including watersheds, are adversely impacted by water quality, strategies to remediate pollution and restore systematic health and function are important (UNEP 2009) Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Society for Ecological Restoration International, 2004). Strategies for fresh water restoration can be straight forward as removing up stream dams and restoration of rivers and wet lands. One of the well – established approaches that can be used to deal with pollution from both point and non – point sources is ecohydrology (Obilonu*et al*, 2013). An eco-hydrological approach is based on the understanding of the inter relationships between the ecological processes and the water cycles in a given catchment and supports the role of ecosystem processes in water quality improvement. Eco-hydrology can address water related threats such as reducing flood risk by creating wet lands that prevent pollutants from entering water ways. Examples of eco-hydrology approaches can be found worldwide including Iraq, Japan, and Poland (UNEP, 2009).

In summary, water plays an important role in the life of human and its environment. The need for potable water cannot be over emphasized due to related diseases associated with contaminated and polluted water. Therefore, the action by the government and individuals to provide quality water is highly recommended.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

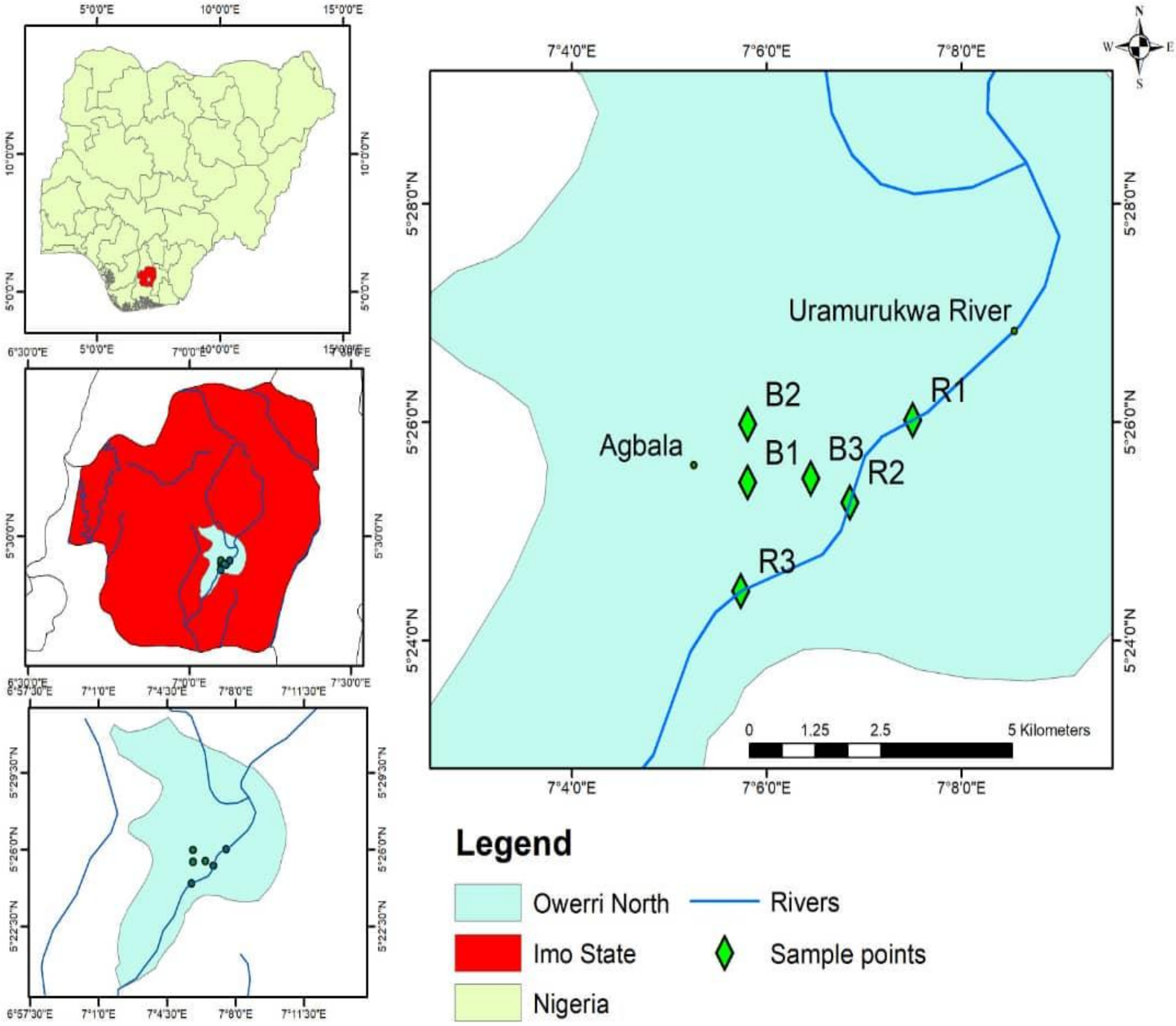

Figure 3.1. Map showing the Study Area and the Sampling points

Source: Author's Mapping

3.1.1 Location

The study areasare parts of the Owerri suburban,in theOwerri North Local Government Area of Imo State, Nigeria, that lies between 5.4567° N, 7.1144° E.Its headquarters are in the town of Orie Uratta.It has an area of 198 square km, with a population of 175,395 (NPC, 2006).It encircles Owerri Municipal like a peninsula. Six major roads that leads out of the municipal cuts across Owerri North Communities.In North, Orlu road leads to Amakaohia andAkwakuma communities.In the East,Okigwe road leads to Orji Community.In the West,MCC road off Wetheral to ObibiUratta and Ihitaoha communities. In the south,Mbaise road leads to Egbu and Emekuku Communities, while Aba Road leads to Naze,Agbala and UlakwoCommunities.

3.1.2 Climatic conditions of the study areas

The climatic conditions of Owerri-north is characterized by a tropical climate, and has significant rainfall most months, with a short dry season. According to the Köppen-Geiger classification, the prevailing climate in this region is categorized as Am. The average annual temperature is 25.9 °C | 78.6 °F. Precipitation here is about 2412 mm | 95.0 inch per year, and the aeras are located in the northern hemisphere. Summer begins in September and ends at the end of June. The months of summer are: June, July, August, September. The best time to travel is January, February, March, April, May, November, December.

The least amount of rainfall occurs in January. The average in this month is 30 mm | 1.2 inch. In September, the precipitation reaches its peak, with an average of 321 mm | 12.6 inch.

The temperatures are highest on average in February, at around 28.0 °C | 82.3 °F. At 24.2 °C | 75.6 °F on average, July is the coldest month of the year.The variation in the precipitationbetween the driest and wettest months is 291 mm | 11 inch. The variation in annual temperature is around 3.7 °C | 6.7 °F. The month of highest relative humidity is October (89.33 %). The month with the lowest relative humidity is January (60.34 %). The month which sees the most rainfall is October (6.27 days). The driest month of the year is January (28.07 days) (Climatedata, 2022).

3.1.3. Vegetation and soil type of the study area

The area lies in the rain forest belt of Nigeria of about 120km north of the Atlantic coast. Rainforest is characterized by growth of tall trees. However, interference by man in form of cultivation burning and felling of trees contributed to the disappearance of features of tropical rain forest. Natural vegetation in the region has long been disturbed and almost eliminated by human interference. The present regions vegetation cover in some areas largely reflects the pattern of agricultural cultivation; even in some area the vegetation is dense. Due to great demand of land in the area coupled with other human activities especially over grazing, the rain forest has been replaced by some economic crops such as oil palm forest. The soil of the area is loamy with scattered pebbles. Thick vegetative covers have prevented soil erosion. However, erosion is acute where forest clearing and over cropping have opened up the soil to erosion elements (Onunkwo, 2015).

3.1.4. Population and Economics Activities

The study area was formerly a predominantly agricultural area, but now it is a predominantly commercial and administrative area since after the creation of Imo state on February 3rd 1976. Economics activities include booming hotel services, commercial nerve center with booming activities of retail trade in its functional markets (Eke Ukwu Owerri, New Market,Relief Market,Nkwoukwu Market,Cluster Market,Alaba Market,Orie ObibiMarket and light industries (bakeries, block industries e.t.c.). Owerri has an airport located at 14miles southeast of the city, called the Sam Mbakwe Airport which provides service to Abuja, Lagos, Port Harcourt and Enugu. At present, it serves as an alternative for Port Harcourt Airport but not yet international purposes. Some major roads that go through the area include; Port Harcourt and Aba Road.

3.2. Research Design

This study is an experimental research design with aim to determine the physiochemical and biological properties of surface and ground water in suburban area of Owerri. Samples were collected from Uramiriukwa and borehole water and analyzed in the laboratory. Results were compared to the Federal Ministry of Environment (NESREA) standard for drinking water.

3.3. Sampling Techniques

3.3.1. Collection of Water samples

3.3.1.1. Collection of River Water samples

The samples were collected from Uramiriukwa River at three sampling points using a grab sampling method. The sampling areas were at three points including, the upstream, the middle-stream and the downstream. The points were at least 8km apart from each other. The sampling materials used were sterile screw capped bottles and the water samples were collected from about 4-6cm below the water surface using sterile disposable hand glove.The process of opening of bottle caps was quickly done to avoid contamination. Samples for the biological oxygen demand were collected 250mls bottles, while samples for other parameters were collected 500ml bottles. The bottles containing the samples were labeled, indicating source, date, and time of collection. A GPS was used to take the coordinates of the various sampling points.

3.3.1.2.Borehole sample collection

The procedure for data collection started with a reconnaissance survey to the area. This enabled functional boreholes to be identified. Functional borehole was conceptualized as one that is frequently in use with level of patronage (use) greater than 50 persons per day. Through this approach, 8functional boreholes were identified, after which 4 boreholes were randomly selected without replacement, at different distance to eliminate biases. The borehole at the Federal University of Technology (FUTO) served as the control point.

Water samples were collected in 1litre plastic bottles; before the collection of water samples, the boreholes were allowed to pump for 5 minutes so that water with a constant temperature and pH, representing that from the aquifer was collected. Water samples were collected at the borehole heads.

Prior to sample collection, all plastic bottles were first washed with de-ionized water, and then several times with the sample water before collection in order to avoid any contamination. After sampling, the containers were tightly covered with tightly fitting covers wrapped in a black polyethylene plastic bag labeled 1-4 and put in a cooler to ensure constant temperature.

All the samples were preserved by refrigeration and analyzed within24hours of collection. The analyses were carried out in accordance with American Public Health Association Standard (1998). The approach ensures that the samples collected were tested in accordance with agreed requirements using competent personnel as well as appropriate equipment and materials.

3.3.2. Selection of Sampling Points.

Considering the purpose and the study area, the surface water sampledwas the Uramiriukwastream, which runs a 14-kilometre (9 mi) course through Agbala communities in Owerri.

The borehole water samples were collected from three different points, in Agbala, in Owerri-north, and then FUTO (control point). Each of the sampling point were chosen such that they were at least 8 km apart.

The sampling points with coordinates are as follows:

i. Sampling points for ground water (borehole) include:

B1 Borehole (Wire crossing, Agbala)

Elevation:283ft

5.424908°N
7.112554°E

B2 Borehole (Emeke, Agbala)
Elevation:131ft
5.432978°N
7.096745°E

B3 Borehole (Egbelu, Agbala)
Elevation:131ft
5.432978°N
7.096745°E

B4 Borehole (FUTO) (control point)
Elevation:
5.05°N
7.036827°E

The sample points for surface water (Uramiriukwa river)include:

S1 5.424225°N 7.112554°E	Surface Uramiriukwa upstream River
S2 5.421028°N 7.113758°E	Surface Uramiriukwa middle stream river
S3 5.424908°N 7.112554°E	Surface Uramiriukwa downstream river

3.2.2. Procedure for samples collection

One liter polyethylene bottles were used for collection of the samples. The bottles were washed and rinsed thoroughly with distilled water to ensure the absence of contaminants. At the point of collection of the samples, the bottles were once again rinsed with the water sample before collection of the actual sample used for the experiment, and labeled immediately.

The groundwater samples were collected from four different boreholes, three from Agbala community in Owerri-north, and one point in FUTO, Owerri-west LGA.Two replicates of each of the borehole water sample, designated as B1, B2, B3 and B4, were obtained, and two replicates were also collected for the surface water samples, designated as S1, S2 and S3, for upstream, middle stream and downstream, respectively. The samples obtained were immediately sent to the laboratory for physicochemical and biological tests.

3.3. Laboratory Analysis

3.3.1 Instruments and Reagents Used

3.3.1.1. Instrumentation

Sampled bottled borehole water, autoclave, incubator, spatula, petri dish, pH meter, thermometer, conductivity meter, beaker, evaporating dish, desiccator, hot plate, measuring cylinder weighing balance, watch glass, microscope, atomic absorption spectrophotometer, culture media (Chromocult agar and Centrimide agar), masking tape, conical flask,

3.3.1.2. Reagents

Phosphoric acid and sodium periodate, Ammonia buffer solution, 0.01N EDTA (Ethylenediamine tetra acetic acid), Erichrome black T indicator, Buffer solution (NaOH solution), 0.01N EDTA (Ethylenediamine tetra acetic acid), and muroxide indicator, 0.02N H_2SO_4, Methyl Orange, Potassium Chromate indicator and 0.0141N $AgNO_3$, phenoldisulphonic acid reagent and 10 % ammonia solution, Powder MacConkey agar, Barium Chloride salt and conditioning reagent.

3.3.2. Physicochemical Analysis

3.3.2.1. Physical parameters

i) **Temperature:** Mercury-in-glass thermometer was used to determine the temperature at the site of collection of the water samples. The reading was taken after dipping the thermometer in the water and allowed to stabilize for about 2 minutes.

ii) **Turbidity:** The instrument used was the Spectrophotometer. About 10ml of the water sample was poured inside cuvette and reading was taken at 425nm. The absorbance reading obtained was the turbidity level of the water sample.

iii) **Electrical Conductivity Test:** Conductivity meter was used. 250 ml beaker was filled with distilled water and the electrode was inserted into the beaker so as to wet it thoroughly. Then the conductivity meter was switched on and the zero error was corrected. Later, the distilled water was replaced with the sample water and the electrode was carefully inserted into the sample. I observed that the readings were fluctuating and took the readings when stable.

iv) **Total Dissolved Solids (TDS) Test:** The total dissolved solid was determined by evaporation method. The evaporating dish was weighed while empty and 100cm^3 of the sample was poured into the evaporating dish and placed in the oven at 120^{O}C for proper drying for 2hours. After drying the evaporating dish and its contents were transferred into the desiccator to cool for 1hour. The evaporating dish and its contents were weighed. The difference in their weight gives the weight of the total dissolved solids of the water sample.

3.3.2.2. Chemical Parameters

i. **pH:** A pH meter (Tensway method) was used to determine the pH of all water samples. It was carried out in situ that is at the site of collection of the water samples. 20ml of water sample solution was poured inside a 50ml beaker. The electrode of the pH meter was put inside the water sample after standardization with buffer solutions and reading off the value on the digital display board.

ii. **Total Hardness Test:** Total hardness is due to both calcium and magnesium expressed as mg/l$CaCO_3$ Reagents used were Eriochrome black T, N/50 Ethylene Diamine Tetra acetic acid (EDTA). Prepare 0.01m or 0.02N EDTA by dissolving 3.7225g/l of the salt (mol. Wt. 372.25) and Ammonia Buffer solution (pH 10). Add 142ml conc. NH_3 solution (specific gravity 0.88 – 0.90) to 17.5g of AR Ammonium Chloride (NH_4Cl) and dilute to 250ml with distilled water. Method: 100ml of filtered sample was put into a conical flask and 2ml of ammonia buffer solution was added. Total hardness indicator tablet, Eriochrome black T was added by crushing and N/50 (0.02N) EDTA was added from the burette with stirring until the color changes from wine red to blue color attained as the end point.

iii. **Nitrate Test:** Nitrate was determined by the spectrophotometric sodium salicylate method. Standard solution of potassium nitrate was present (0 to 5 mg/l) and 10ml of Sodium Salicylate solution, 2ml of conc. Sulphur acid and allowed to stand for 15mins. A 15ml volume of distilled water and 15ml of sodium titrated solution were added to each sample and absorbance of the yellow color developed was read at 420nm. A calibration curve was plotted with the absorbance values of the standard and the concentration (mg/l) of nitrate in the sample was extrapolated from the standard curve.

Calculation: Total Hardness [$CaCO_3/MgCO_3$ (Mgl^{-1})] = (ml of 0.02N EDTA × 1000ml) ÷ Vol. of sample

iv. **Chloride Test:**The Silver nitrate titrimetric method described by APHA(1998)was used. A 100ml vol. of each sample in a conical flask was mixed with 3 drops of 10% potassium chromate indicator and a filtrate against 0.05N Silver Nitrate solution until a pink color was obtained.

Calculation: Cl (mg/l) = A – B × N × 35.45 × 100/Vol. of sample

Where A = Titre value of sample
B = Titre value of distilled water
C = Normality of Silver Nitrate

v. **Dissolved oxygen:** About 100ml of the water samples was pipetted. 250ml conical flask 2ml of Manganous Sulphate solution was added by 2ml of alkaline iodine reagent. 2ml of conc. Sulphuric acid was added and shaked. 4 drops of freshly prepared starch solution was added and bluish black color was obtained and titrated with 0.025N sodium thiosulphate until solution turns to a pale straw to colorless end point at the first disappearance of the blue color.

Calculation:

DO (mg/l) = T × 0.025 × 8 × 1000/vol. of sample

vi. **Biological Oxygen Demand determination:** This was determined by incubating the sample solution for 5 days under the 20°C because most of the oxygen that is going to be used up by the bugs has been used up that time.

BOD = $DO_1 - DO_f$that is initial DO_1 minus the final DO_f

vii. **Determination of Chemical Oxygen Demand:** This was determined by titration method described by APHA (1998).

About 100ml of the water sample was pipetted inside a conical flask. 10ml of 0.0125N $KMnO_4$ was added followed by 10ml of 20% H_2SO_4. The mixture was gently shaked and incubated at 27°C for 4 hours. At the end of incubation period the mixture was added with 1ml potassium iodine and titrated against 0.0125N $Na_2S_2O_2$ using starch indicator until the blue color appeared.

Calculation

T – B × 1000/a × vol. of sample

T = titre of sample

B = blank titre

V = volume of sample used a = volume of $KMnO_4$ added

viii. **Sulphate Test:** Reagents used were Barium Chloride salt and conditioning reagent by Barium Sulphate. 1 ml of conditioning reagent was first added to 50ml of sample of the raw water. This was stirred for 2 minutes and then used to correct the zero error of the turbidity meter. Further, a spoon of barium chloride salt was added to the sample solution and stirred. The sample solution was then inserted into the turbidity meter and its reading was taken.

ix. **Alkalinity:** This was determined by titration method. About 150 sample solution was pipetted inside a conical flask and 10 drops of phenolphthalein indicator was added and titrated against 0.02N until a pink color appears.

Calculation

Alkalinity = Titration × 10

x. **Iron Test**: Spectrophotometer method was applied. About 10ml of the water sample was pipetted inside 50ml beaker. 1ml of 10 % hydroxylamine Hydrochloride was added followed by addition of 1ml Orthophenanthroline solution. 1ml of Ammonium acetate was diluted to 50ml mark, the absorbance readings were taken at 510nm after 1hour. Standard solutions were also prepared in this manner using 100ppm of ferrous Ammonium Sulphate from 0, 2 to 10ppm.

Calculation

Fe (ppm) = Absorbance × slope ratio × Vf × Df / vol. of sample

Where Vf = total vol. of the sample solution

Df = dilution factor

3.3.3. Biological Parameters

i.Coliform count

For this test,5.25g powder of the MacConkey agar was dissolved to 1000ml of distilled water. Mix and heat until dissolved. Sterilize by autoclaving for 15minutes at 121^{o}C and poured into petri dishes. Aliquots 10ml of each sample were used to inoculate on MacConkey agar by spread plate method.The plates were incubated at 37°C for 24hours in an incubator. After incubation, colonies were observed on the different plate, counted and recorded.

Calculation: fecal coliform cfu/ml = colony observe× dilution factor (if any) × volume used.

ii. Determination of Total bacteria count

MEDIA PREPARATION (Nutrient agar)

This is a basic media mostly used for culturing, subculturing and for total viable bacterial count.

Procedure

Dissolve 28.0gm in 100ml distilled water, gently heat to dissolve the medium completely sterile by autoclaving at 15psi (1210c) for 15 minutes. Dispense the medium as desired in the plate

Mac-conkey Agar

This is a differential, medium best for total coliform counts.

Procedure

Dissolve 52.5g powder of the mac-conkey agar to 1000ml of distilled water. Mix and heat until dissolved. Sterilize by autoclaving 15minutes at 121 0c and pour into petri dishes.

iii. Determination of total klebsiella

Eosin Methylene Blue (EMB) Agar

It is used for differential isolation of gram –negative ereteric bacterial and total faecal count.

Procedure

Suspend 36grms in 1000ml distilled water, Heat to dissolve the medium completely. Dispense and sterilize by autoclaving at 15ibs pressure (1210c) for 15 minutes. Pour to petri dishes (plates).

iv. **Determination of *e.coli*.**

A mixture of the culture broth, enzyme inducer and E- Coli was injected into the chambers on the top layer. A mixture of the substrate and lysis solution was injected into the chambers on the bottom layer. Then the slipchip was slide to make each chamber independent. *E. coli* was cultured in the chamber in the LB broth for 2.5h. After that the slipchip was slide again to introduce the lysis solution into the culture solution for GUS release and enzyme reaction and then incubated in the plate reader at 24°c for another 2.5h. During incubation, the fluorescence intensity of each chamber was record.

3.4. Sources of Data

Data were sourced from both the primary and secondary form in order to get a reliable result for this research. Therefore, it is important that the necessary data were collected and analyzed. The research is based on first hand observation, gathering of data, description, explanation and prediction of events.

3.4.1. Primary Data

The primary data were obtained from the field study such as data on samples collected and laboratory analysis. It is the raw and original research data that was generated for analysis and interpretation.

3.4.2 Secondary Data

This form of data was obtained from past literatures including, journals, magazines, text books, and information from various agencies, including, National Population Commission (NPC), and Ministry of Lands, Survey and Urban Planning, Owerri, Imo state, World Health Organisation (WHO) published in the internet.

3.54.Techniques for Data Analysis

The ANOVA statistical analysis was used to determinethe means, and standard error mean of the physiochemical and biological parameters of the two water sources, for the objective 1, 2 and 3, using the IBM SPSS software.

A Duncan post-hoc test was carried out to compare the spatial variations of the physiochemical and biological parameters of the two water sources as in objective 4, using the IBM SPSS software, while a T-test was caried out to compare the physiochemical and biological parameters of the two water sources, as in objective 5, using the excel spread sheet.

The excel spreadsheet was also used to calculate Water Quality Index (WQI) of the two water sources, as in objective 6, by applying the weighted arithmetic method according to Lumb *et al*., 2011, using the formula as follows:

WQI $= \sum qnWn \big/ \sum wn$ ……………………….equation 3.1

Where:

qn = Quality rating of nth water quality parameter.

Wn= Unit weight of nth water quality parameter.

The quality rating (qn) is calculated using the expression:

qn = [(Vn – Vid) / (Sn- Vid)] x 100 ……………….. equation 3.2

Where:

Vn = Estimated value of nth water quality parameter at a givensample location.

Vid = Ideal value for n th parameter in pure water.

Note: (Vid is 0 for all other parameters except the parameter pH = 7.0 and DO 14.6mg/l)

The unit weight (Wn) is calculated as:

Wn = k / Sn …………………… equation 3.3

Where:

Sn = Standard permissible value of nth water quality parameter.

k = Constant of proportionality and it is calculated as:

k = [1 / ($\sum 1/\,\mathrm{Sn} = 1,2,..\,\mathrm{n}$)]………………..equation 3.4

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1. Spatial variations of the physiochemical and biological properties of the surface water samples.

Table 4.1: Physiochemical and biological characteristics of Uramiriukwa River water samples.

Parameters	URAMIRIUKWA RIVER WATER SAMPLES		
	Point 1 (Upstream)	Point 2 (Middle stream)	Point 3 (Downstream)
Temperature (°C)	26.25 ± 0.05^{a}	26.25 ± 0.15^{a}	26.25 ± 0.05^{a}
TSS (mg/l)	152.85 ± 2.00^{a}	157.1 ± 17.1^{a}	121.85 ± 9.0^{a}
TDS (mg/l)	7.15^{a}	7.8^{a}	7.15^{a}
Odour	unobjectionable	unobjectionable	unobjectionable
Colour (CP)	125^{a}	155 ± 1^{b}	82.5 ± 2.5^{c}
Appearance	turbid	turbid	turbid
Turbidity (NTU)	53.5 ± 0.10^{c}	24.65 ± 0.05^{a}	33.5 ± 0.6^{b}
EC (µs/cm)	11^{a}	12^{a}	11^{a}
pH	7.25 ± 0.05^{ab}	7.4 ± 0.1^{b}	7.05 ± 0.05^{a}
Alkalinity (mg/l)	7.00 ± 1.00^{a}	10^{b}	5.5 ± 0.5^{a}
DO (mg/l)	14.6^{c}	12.85 ± 0.05^{a}	13.1^{b}
BOD (mg/l)	1.35 ± 0.05^{a}	1.7^{b}	3.3 ± 0.05^{c}
COD (mg/l)	208^{a}	472 ± 8.0^{c}	280 ± 8^{b}
Total acidity (mg/H+)	0.22 ± 0.02^{a}	0.3 ± 0.02^{a}	0.3 ± 0.02^{a}
Nitrate (NO3) (mg/l)	31.70 ± 0.16^{c}	25.535 ± 0.16^{a}	28.08 ± 0.08^{b}
Phosphate (PO4) mg/l	0.675 ± 0.02^{c}	0.58^{b}	0.5 ± 0.005^{a}
Chloride (mg/l)	29.99 ± 2.00^{ab}	32.99 ± 1.00^{b}	25.99^{a}
Total Hardness, mg/l	85.47^{a}	115.26 ± 3.89^{b}	161.88 ± 3.89^{c}
sulphate SO4 (mg/l)	1.64 ± 0.01^{a}	1.84 ± 0.02^{b}	15.87 ± 0.01^{c}
Iron (Fe) mg/l	1.98^{a}	2.27 ± 0.02^{b}	2.3 ± 0.01^{b}
Total bacteria count Cfu/100 ml	$2.59\text{x}10^{5}\pm2.41\text{x}10^{5\ a}$	$2.95\text{x}10^{4}\pm2.05\text{x}10^{4\ a}$	$3.65\text{x}10^{5\ a}$
Total coliform count Cfu/ 100 ml	$8.67\ \text{x}10^{5}\pm8.33\text{x}10^{5\ a}$	$5.4\text{x}10^{5}\pm4.6\text{x}10^{4\ a}$	$2.065\text{x}10^{4\ a}$
Klebsiella count cfu/ 100 ml	NG	NG	NG
e. coli (cfu/100ml)	NG	NG	NG

Source: Field work by author,

Values = mean±SEM

ANOVA result showed that water samples at the three points are not significantlydifferent ($p>0.05$).

Subscript a-c, indicates least to highest value, and values with same superscript along a row are not significantly different ($p>0.05$)

SEM=Standard Error of Mean, TSS = Total Suspended Solid, TS= Total Solid, TDS=Total Dissolved Solid, EC= Electric Current, COD = Chemical Oxygen Demand, BOD=Biological Oxygen Demand, DO=Dissolved Oxygen, NG=No Growth

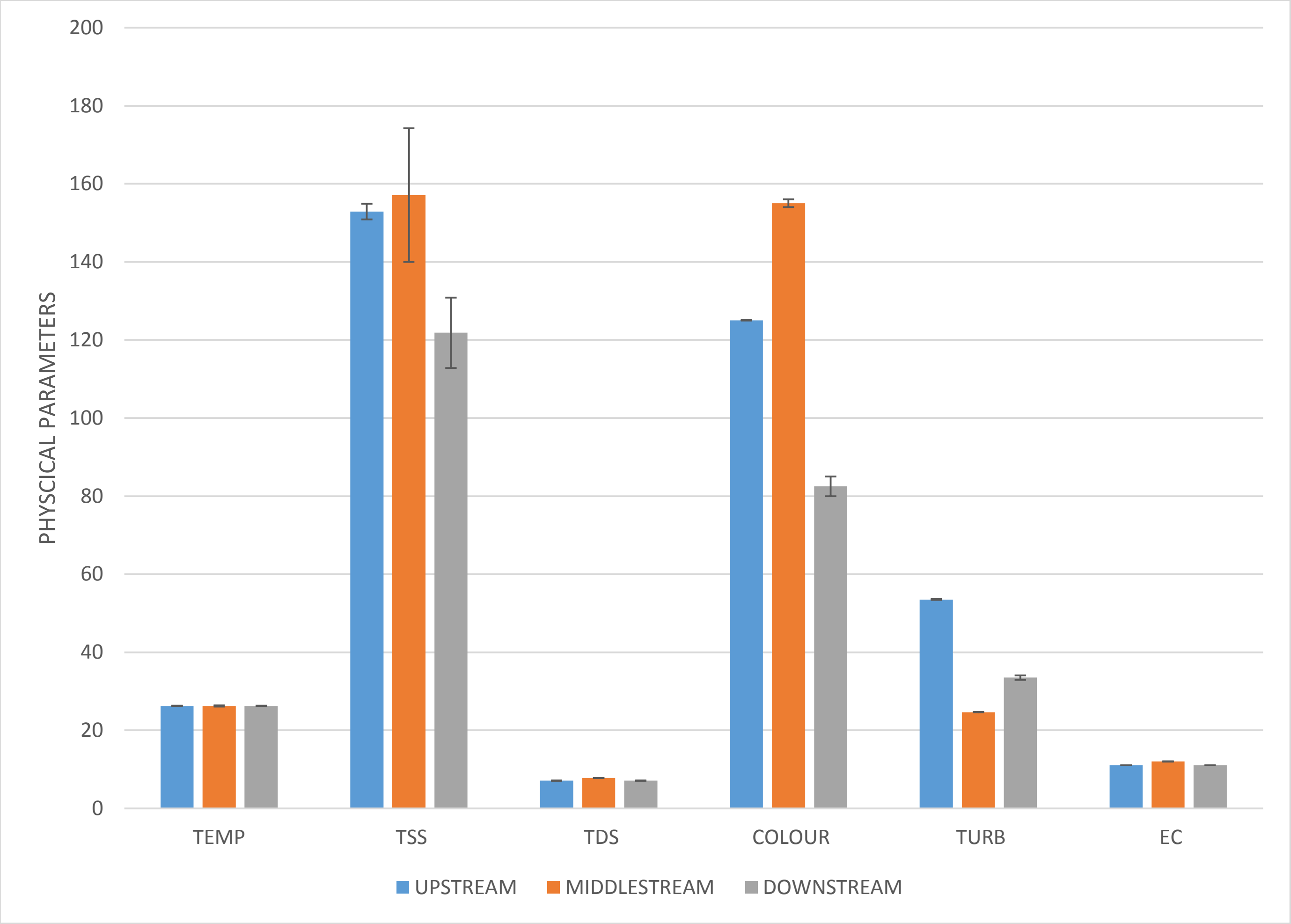

*Figure 4.1: Graph comparing spatial variation of*mean ± SEM *temperature, TSS, TDS,colour turbidity and EC of the Uramiriukwa river water samples.*

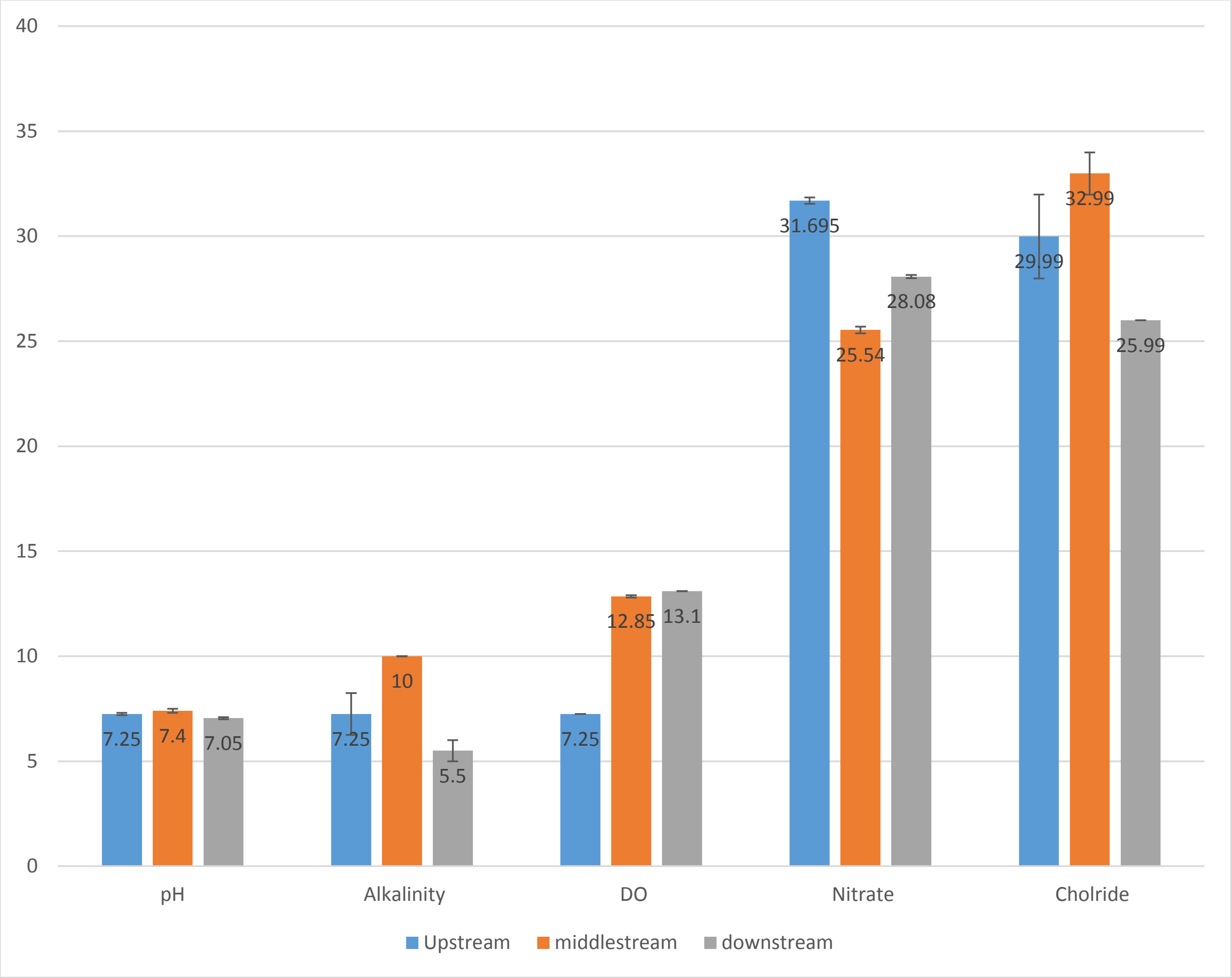

*Figure 4.2: Graph comparing spatial variation of*mean ± SEM *pH, alkalinity, DO, Nitrate and cloride of the Uramiriukwa river water samples.*

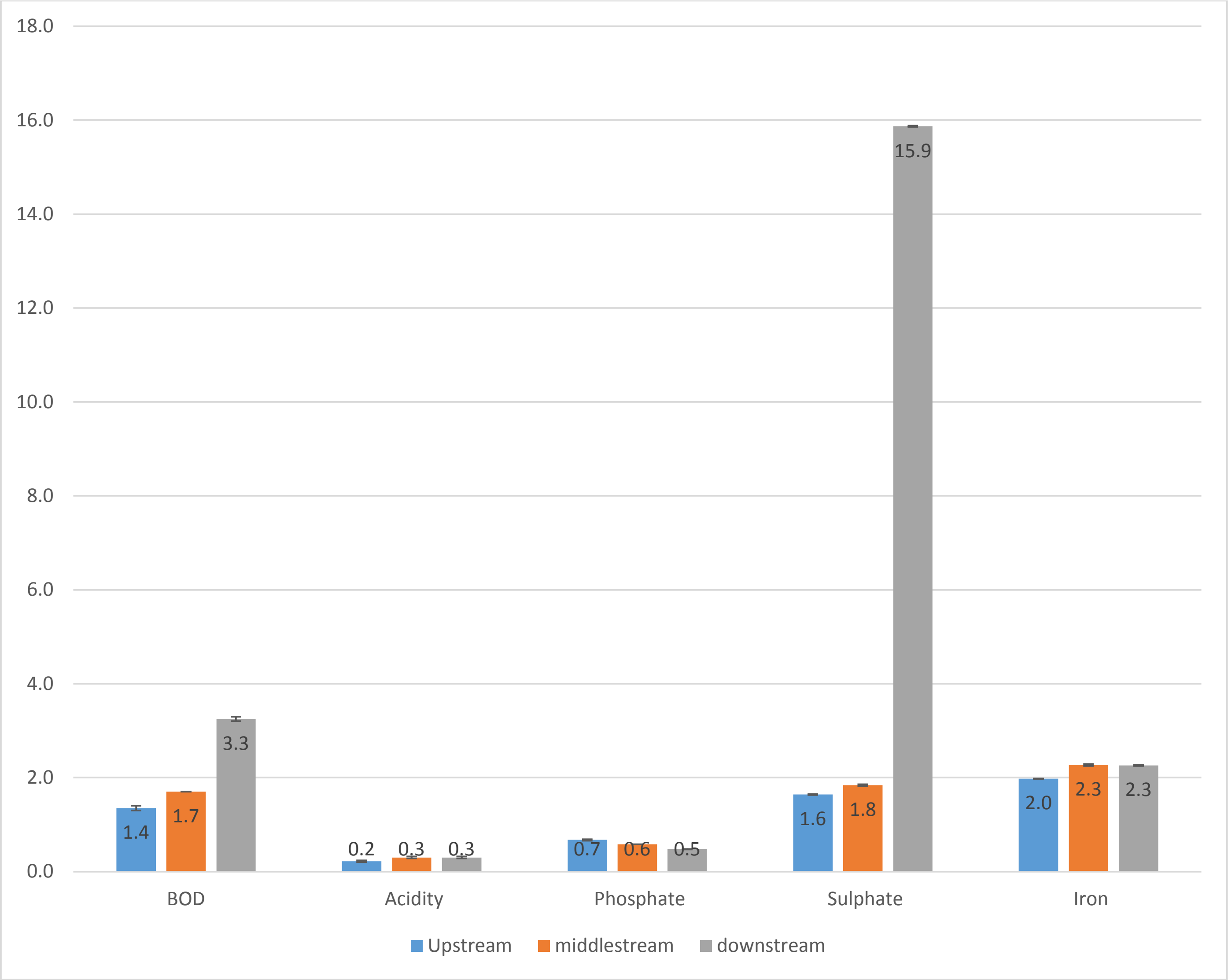

*Figure 4.3: Graph comparing spatial variation of*mean ± SEM *BOD, acidity, phosphate, sulpahte, and iron, of the Uramiriukwa river water samples.*

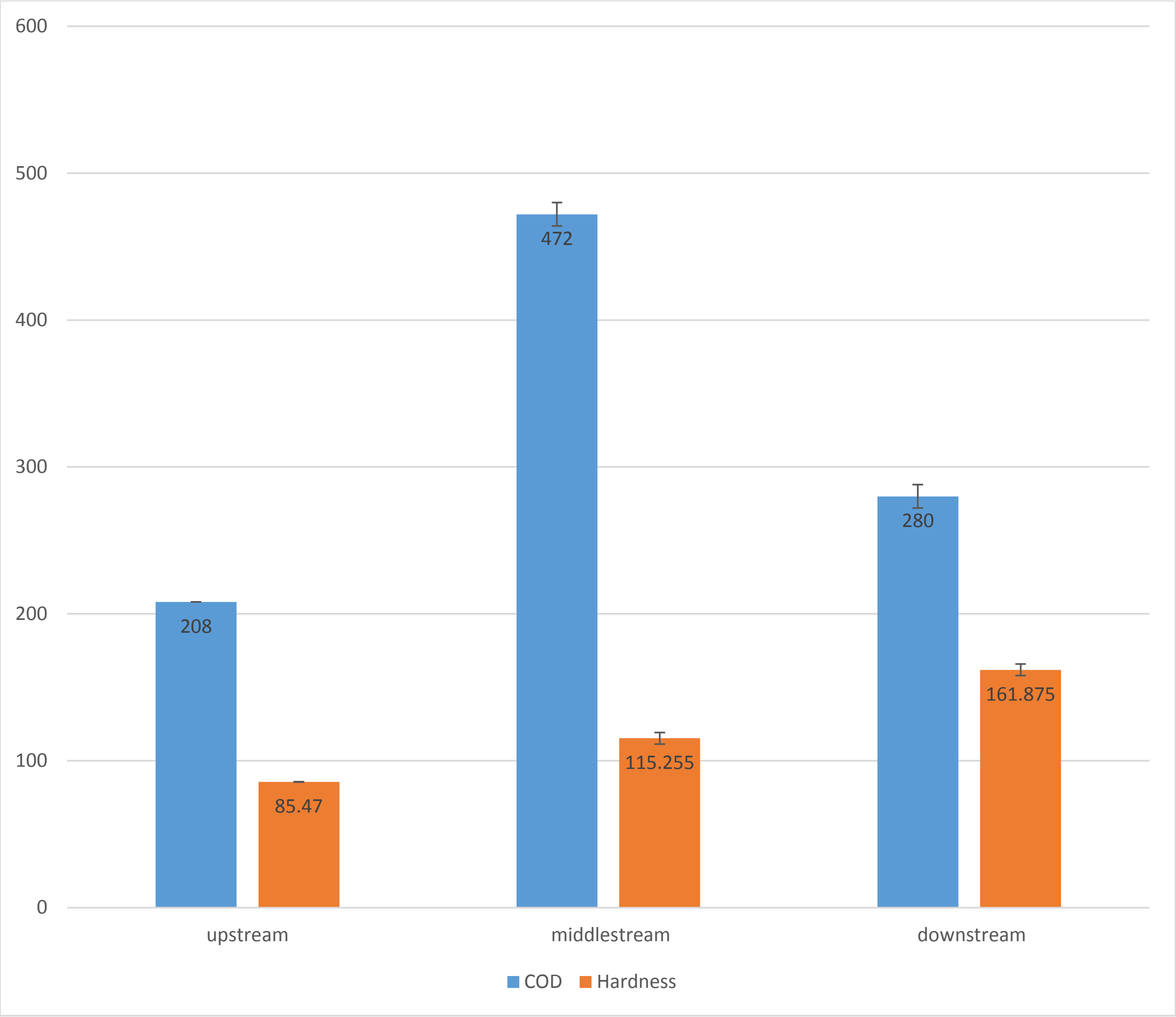

*Figure 4.4: Graph comparing spatial variation of*mean ± SEM *COD and hardness of the Uramiriukwa river water samples.*

The spatial variation of the physiochemical and biological parameters of Uramiriukwa river water samples at different points, including the upstream, middle stream and downstream are shown in Table 4.

The result for the physical properties of the river shows that, the temperatures, total suspended solids, total suspended solids, and electric current, were not significantly different at the upstream, middle stream and downstream at ($p>0.05$), while colour and turbidity, were significantly different at the three points at ($p<0.05$). the appearance of the river water samples was turbid at the three points.

The result for the chemical properties of the river water sample showed significant differences ($p<0.05$) for pH, dissolved oxygen, BOD, COD, nitrate, phosphate, chloride, total hardness, sulphate at the three points, while there was no significant difference ($p>0.05$) in the total acid at the three points. Furthermore, there was no significant difference ($p>0.05$) in the total alkalinity at the upstream and downstream, while the result showed a significant difference ($p>0.05$) at the middle stream. Also, a significant difference ($p<0.05$) was observed in the iron content at the upstream, but no significant difference ($p>0.05$) in the middle stream and downstream.

Result for biological parameters of Uramiriukwa river showed no significant difference ($p>0.05$) for total bacteria count, and total coliform count at the three points, while no growth were detected for klebsiella and *e.coli*, at the three point

4.1.2. Spatial variations the Physiochemical and biological parameters of the ground water sample.

Table 4.2: physiochemical and biological characteristics of borehole water samples.

Parameters	**OWERRI-NORTH (AGBALA) BOREHOLE WATER SAMPLES**			
	Point 1	**Point 2**	**Point 3**	**FUTO (Control point)**
Temperature (°C)	30.3 ± 0.1^{a}	30.6^{b}	31.35 ± 0.10^{c}	30.7
TSS (mg/l)	105.6 ± 4.0^{b}	62.93 ± 44.5^{a}	55.57 ± 0.70^{a}	9.53
TDS (mg/l)	8.4^{5b}	23.08 ± 16.3^{c}	**5.53**$\pm 0.33^{a}$	**7.475**
Odour	unobjectionable	unobjectionable	unobjectionable	unobjectionable
Colour (CP)	2.50 ± 0.5^{b}	0^{a}	5^{c}	0
Appearance	clear	clear	clear	clear
Turbidity (NTU)	5.52 ± 0.01^{b}	0^{a}	0^{a}	4.28 ± 0.01
EC (µs/cm)	13^{b}	**35.5**$\pm 0.71^{c}$	8.50 ± 0.50^{a}	11.5±0.35
pH	6.05 ± 0.1^{a}	6.4^{b}	6.15 ± 0.05^{a}	6.15
Alkalinity (mg/l)	$6a^{b}$	5.5 ± 0.71^{a}	7.50 ± 0.50^{b}	10.5
DO (mg/l)	14.1 ± 0.1^{b}	10.70 ± 0.01^{a}	14.2^{b}	10.2
BOD (mg/l)	8.45 ± 0.05^{c}	5.71 ± 0.13^{a}	6.62 ± 0.02^{b}	5.15
COD (mg/l)	640 ± 16^{c}	488 ± 11.31^{b}	160^{a}	248
Total acidity (mg/H+)	0.28^{a}	0.38 ± 0.03^{b}	0.34 ± 0.02^{ab}	0.42
Nitrate (NO3) (mg/l)	7.85^{b}	82.845 ± 0.11c	0a	ND
Phosphate (PO4) mg/l	0.45 ± 0.1^{b}	0.585 ± 0.01^{c}	0.34^{a}	0.69
Chloride (mg/l)	19.10 ± 2^{a}	24.99 ± 1.41^{a}	23.99 ± 2^{a}	18.99
Total Hardness, mg/l	90.65^{a}	124.32 ± 7.32^{c}	108.78 ± 2.59^{b}	103.6
sulphate SO4 (mg/l)	4.48 ± 0.09^{c}	0.35^{a}	1.67 ± 0.01^{b}	1.23
Iron (Fe) mg/l	0.31c	0.27b	0.135 ± 0.0^{2a}	0.3
Total bacteria count Cfu/100 ml	$1.9\times10^{3} \pm 100^{a}$	$5.0\times10^{3} \pm 3.5 \times 10^{3c}$	3.0×10^{3b}	1.8×10^{4}
Total coliform count Cfu/ 100 ml	$1.88\times10^{4} \pm 250^{c}$	$1.5\times10^{4} \pm 1.1 \times 10^{4b}$	2.0×10^{3a}	3.5×10^{3}
Klebsella count cfu/ 100 ml	1.8×10^{4b}	$2.1\times10^{4} \pm 1.5\times 10^{4c}$	0^{a}	1.2×10^{4}
e. coli (cfu/100ml)	3.0×10^{3b}	0^{a}	0^{a}	2.0×10^{3}

Source: Field work by author,

Values: Mean ± SEM

ANOVA result showed that water samples at the three points are significantly different ($p<0.05$).

Subscript a-c, indicates least to highest value, and values with same superscript along a row are not significantly different ($p>0.05$)

SEM=Standard Error of Mean, TSS = Total Suspended Solid, TS= Total Solid, TDS=Total Dissolved Solid, EC= Electric Current, COD = Chemical Oxygen Demand, BOD=Biological Oxygen Demand, DO=Dissolved Oxygen, NG=No Growth,NESREA= Federal Ministry of Environment, WHO=World Health Organization.

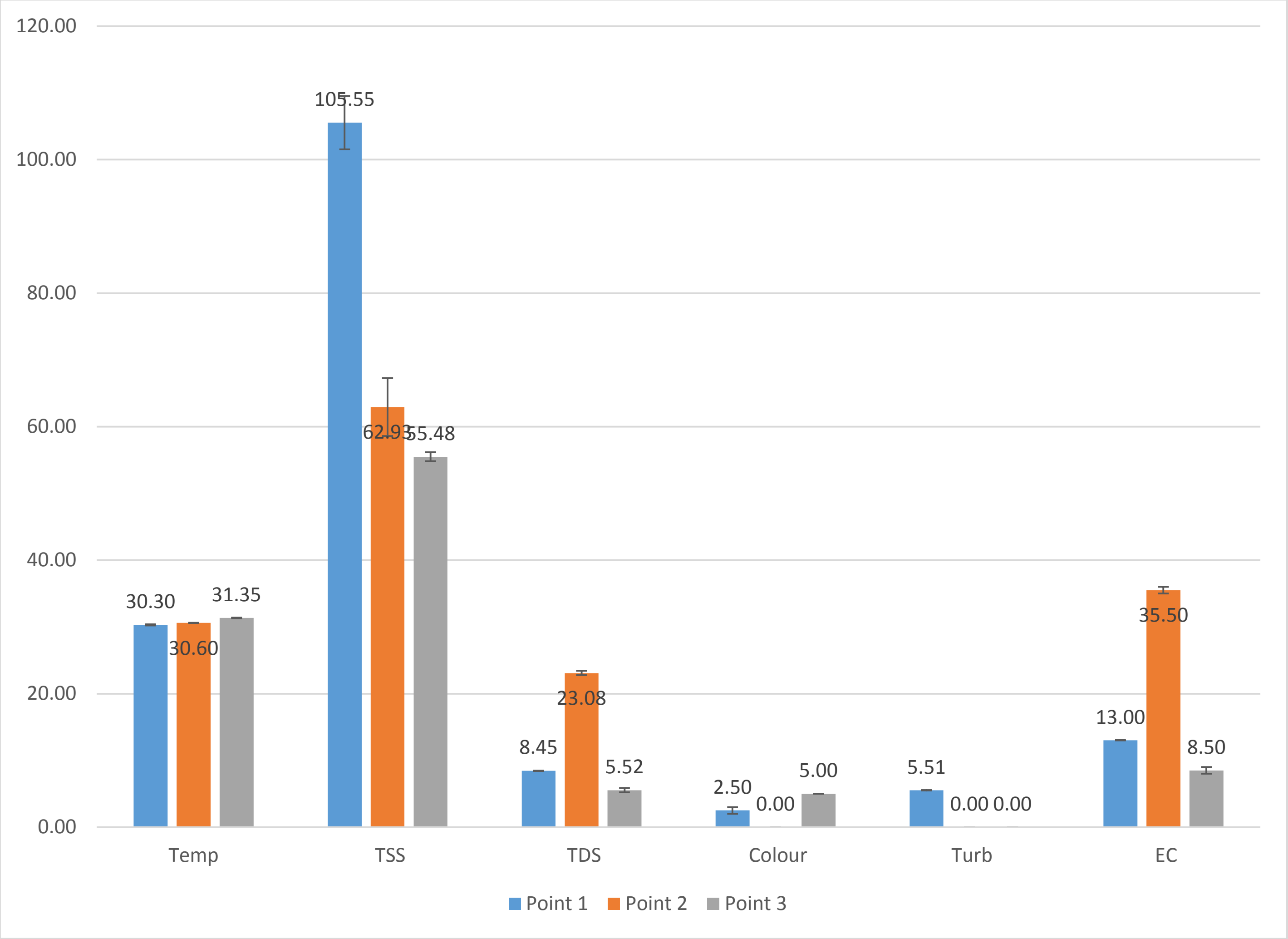

*Figure 4.5: Graph comparing spatial variation of*mean ± SEM *temperature, TSS, TDS,colour turbidity and EC of the borehole water samples*

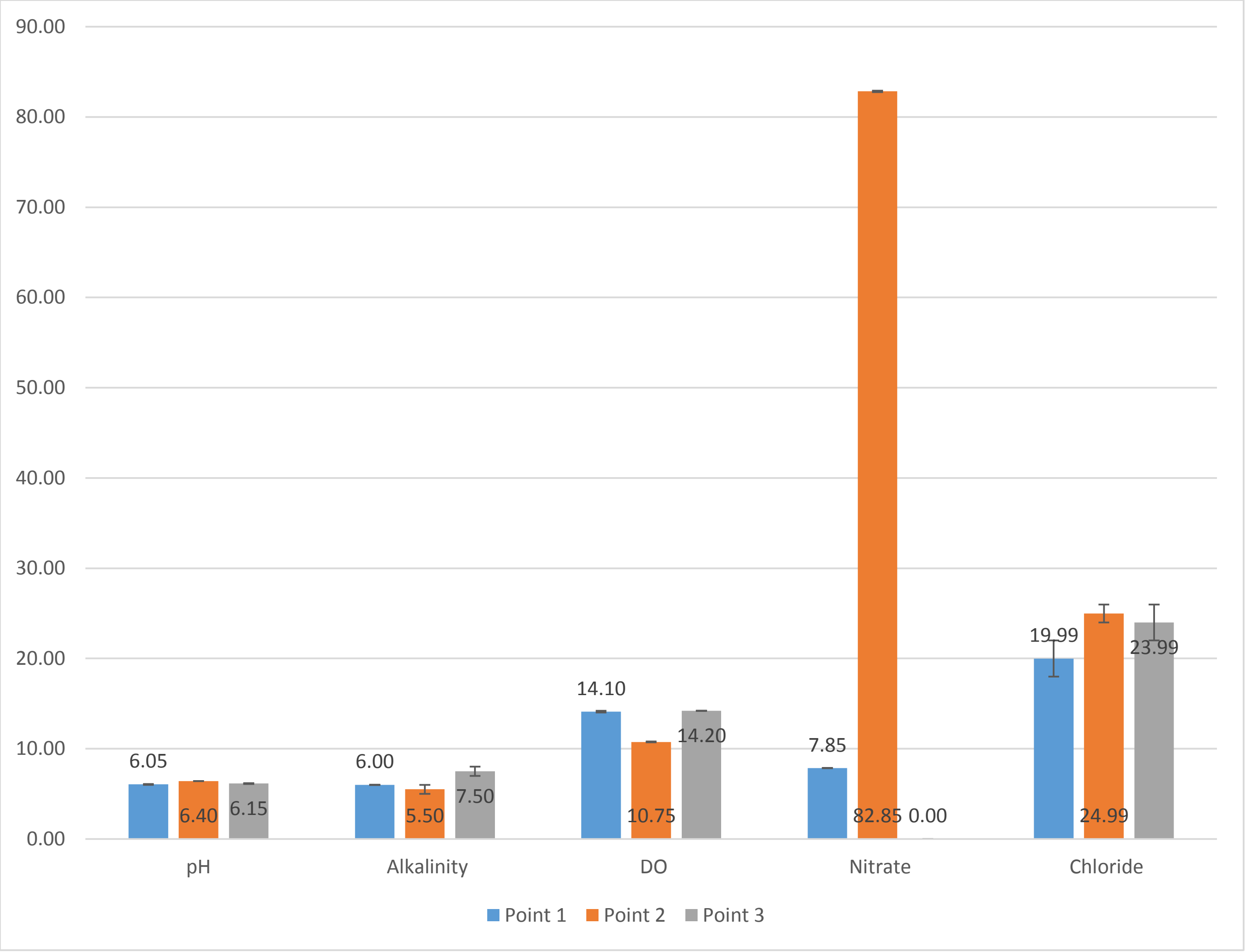

*Figure 4.6: Graph comparing spatial variation of*mean ± SEM *pH, alkalinity, DO, Nitrate and chloride of the borehole water samples.*

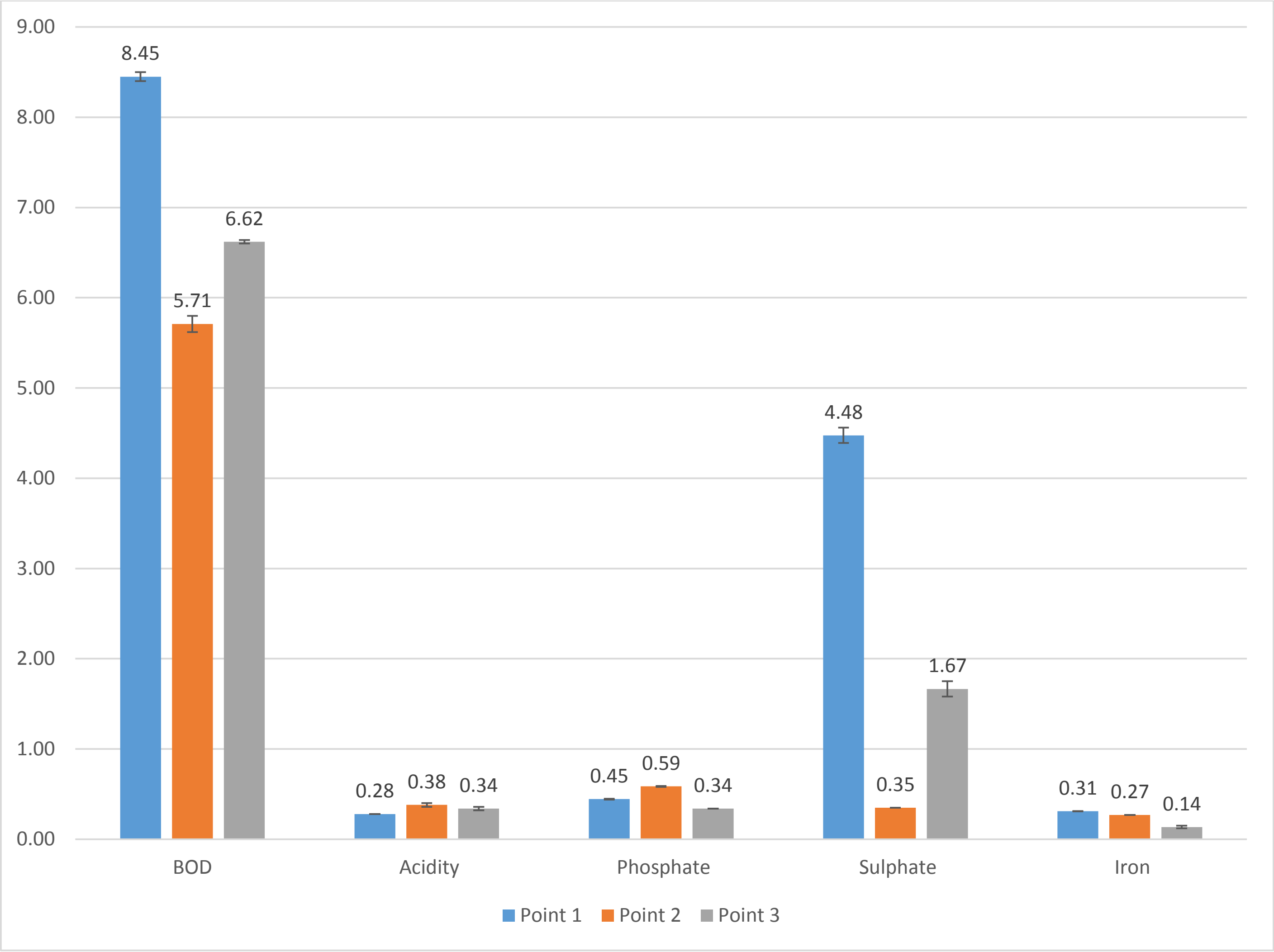

*Figure 4.7: Graph comparing spatial variation of*mean ± SEM *BOD, acidity, phosphate, sulphate, and iron, of the borehole water samples.*

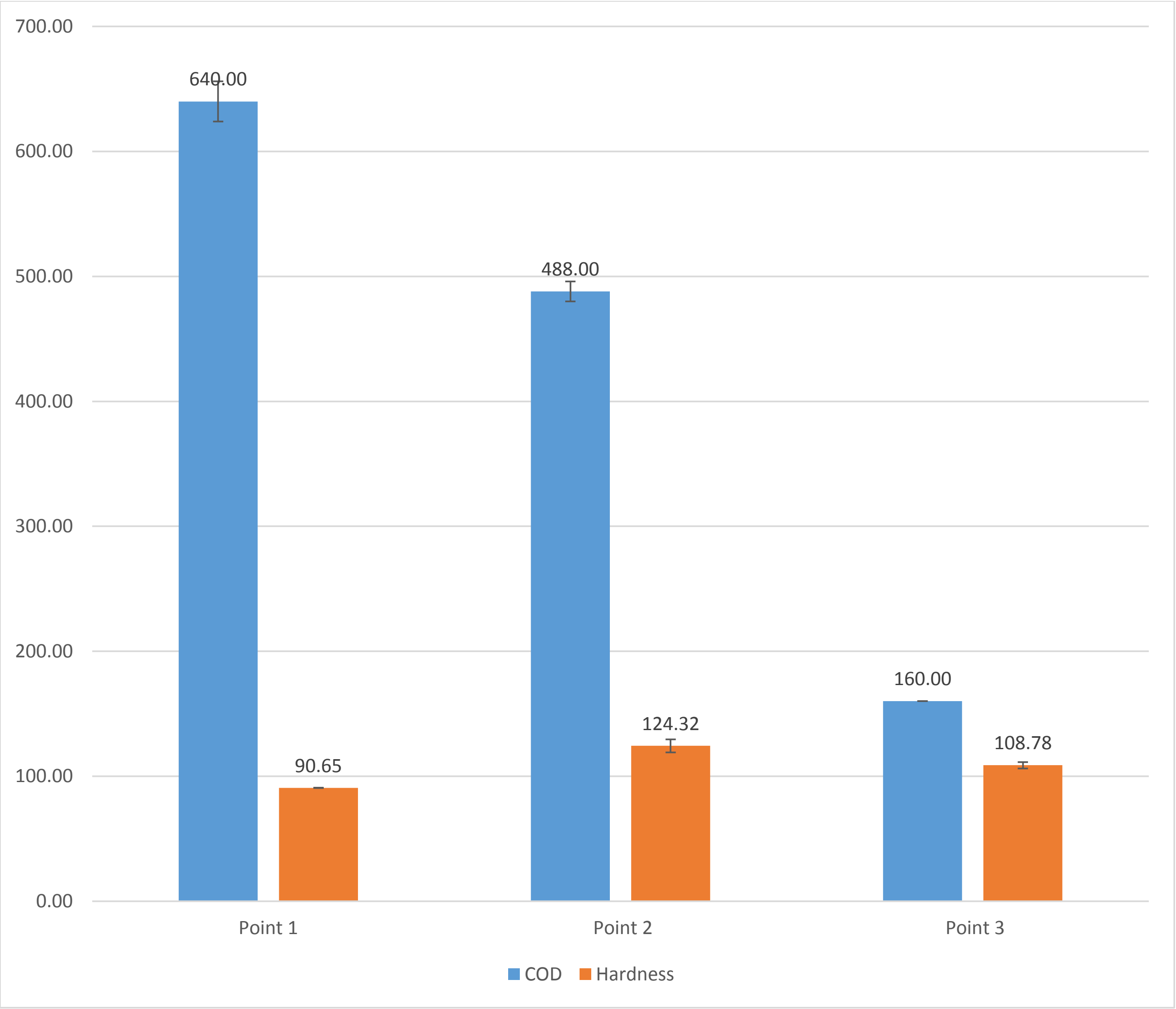

*Figure 4.8: Graph comparing spatial variation of*mean ± SEM *COD and hardness of the borehole water samples.*

Table 4.2 shows the physical, chemical, and biological properties of the borehole water samples from three different points in the Owerri-north local government areas of Imo State. The temperatures of the three borehole water samples were 30.3 ± 0.1 ºC, 30.6 ºC, and 31.35±0.10 ºC for points 1, point 2, and point 3, respectively, and were significantly different ($p<0.05$). Total suspended solids (TSS) for the three spatial points were 105.64.0 mg/L, 62.930.45 mg/L, and 55.57 mg/L respectively. TSS at point 2 and 3 showed no significantly difference ($p>0.05$) but showed a significant difference ($p<0.05$) from point 1. Total dissolved solids at all three points were significantly different ($p<0.05$). Colour was not detected at points 2, but was detected at points 1 and 3, with values of 2.500.5 CP and 5 CP, respectively, and significantly different ($p<0.05$) at all three points. The appearance at the three points was clear,while turbidity showed no detection in water samples from points 2 and 3, but was detected in points 1 with value of 5.520.01 NTU. Turbidity at point 2 and 3 were significantly similar, but different from that of point 1. The electric current of the water samples from the three spatial points were 13 µs/cm, 35.5±0.71 µs/cm, and 8.50±0.50 µs/cm, respectively, and were significantly different ($p<0.05$) at all points. Also, as shown in Table 4.2, the chemical parameter tests of the boreholes from the three spatial points show that the pH was 6.05±0.1, 6.4, and 6.15 ± 0.05, for points 1, 2, and 3, respectively. The pH at point 1 and 3 were not significantly different ($p>0.05$), but different significantly ($p>0.05$) from point 2. Total alkalinity was 6 mg/L, 5.5 0.71 mg/L, and 7.50±0.50mg/L, respectively, for points, 1, 2 and 3. Like the pH level, the alkalinity levels at point 1 and 3 were not significantly different ($p>0.05$) but significantly different ($p<0.05$) from point 2. The dissolved oxygen at the three points were 14.1 ± 0.1, 10.70 ± 0.01, and 14.2, for points 1, 2, and 3 respectively. Dissolved oxygen at point 1 and 3 were not significantly different ($p>0.05$) but significantly different ($p<0.05$) from point 2. The BOD of water samples at the three points were all were 8.45±0.05, 5.71±0.13, and 6.62±0.02, for points 1, 2 and 3 respectively, and were significantly different ($p<0.05$) at all points, while the COD of borehole water samples from all three points with values of 640 mg/L, 488 11.31 mg/L, and 160 mg/L, for points 1, 2, and 3 respectively, and also significantly different ($p<0.05$) at all points. Nitrate was not detected in the borehole water samples from points 3, but was detected in samples from points 1 and 2, with values of 7.85 mg/L and 82.85 mg/Lrespectively. Nitrate at all three points were also significantly different ($p<0.05$). The phosphate content of the borehole water samples from the three points were 0.45±0.1 mg/L, 0.59±0.01 mg/L, and 0.34 mg/L for points 1, 2, and 3, respectively,and significantly different at the three points. The chloride content of the borehole water samples from the three points had values of 19.10±2 mg/L, 24.99±1.41 mg/L, and 23.99±2 mg/Lfor points 1, 2, and 3, respectively,and showed no significantly difference ($p<0.05$) at all points. The total hardness of borehole water samples from the three spatial points were 9.065 mg/L, 124.32±7.3 mg/L, and 108.78±2.59 mg/Lfor points 1, 2, and 3, respectively, and were all significantly different ($p<0.05$). The iron contents of the borehole water samples from the three spatial points were, 0.31 mg/L, 0.27 mg/L, and 0.140.02 mg/Lfor points 1, 2, and 3 respectively, and were also significantly different ($p<0.05$) at the three points. Table 4.2 also shows the result of the biological properties test of the borehole water sampled from the three spatial points of the study area. The result showed that bacteria count of the three borehole water samples were, $1.9x10^3$, $5.0x10^3$, and 3.0×10^3Cfu/100 ml for points 1, 2, and 3 respectively, and significantly different at all points. The coliform counts were 1.88×10^4, 1.5×10^4, and 2.0×10^3, Cfu/100 ml for points 1, 2, and 3 respectively, and were also significantly different. Klebsiella counts were $1.8x10^4$, $2.1x10^4$, and 0 for borehole water sampled from points 1, 2, and 3, respectively, and also significantly different at all points. *E.coli* was detected in the borehole water samples from points 1 only, with values of 3.0x103 cfu/100, while *e.coli* growths were not observed in borehole water sampled from points 2 and 3.

4.1.3. The mean physiochemical and biological properties of boreholeand Uramiriukwa river water samples, compared to the NESREA Standards.

Table 4.3.: Comparing the mean of physiochemical and biological parameters of borehole water and Uramiriukwa rivers in Owerri-North with the NESREA standards for drinking water.

Parameter	**Boreholes and Uramiriukwa River Water Samples**		
	Borehole (Mean ±SEM)	**Uramiriukwa River (Mean ±SEM)**	**NESREA Standards**
Physical Properties			
Temperature (°C)	30.74±0.22	26.25 ± 0.00	30.00
TSS (mg/l)	58.37±19.67	143.93 ± 11.11	10.00
TDS (mg/l)	11.13±4.03	7.37 ± 0.22	500
Odour	Unobjectionable	Unobjectionable	Unobjectionable
Colour (CP)	3.75±1.25	120.83 ± 21.03	15
Appearance	clear	Turbid	clear
Turbidity (NTU)	4.90±0.62	37.22 ± 8.53	10
EC (µs/cm)	17.13±6.20	11.33 ± 0.33	1000
Chemical Properties			
pH	6.19±0.07	7.23 ± 0.10	6.50-8.50
Alkalinity (mg/l)	7.38±1.13	7.50 ± 1.32	150
DO (mg/l)	12.31±1.07	13.52 ± 0.55	>7.50
BOD (mg/l)	6.48±0.72	2.10 ± 0.58	15
COD (mg/l)	384±109.93	320 ± 78.79	40
Total acidity (mg/H+)	0.36±0.03	0.27 ± 0.03	NS
Nitrate (NO3) (mg/l)	45.35±37.50	28.44 ± 1.79	50
Phosphate (PO4) mg/l	0.52±0.08	0.58 ± 0.06	5
Chloride (mg/l)	21.99±1.47	29.66 ± 2.03	250
Total Hardness, mg/l	106.84±6.96	120.87 ± 22.2	150
sulphate SO4 (mg/l)	1.93±0.89	6.45 ± 4.71	200-400
Iron (Fe) mg/l	0.25±0.04	2.17 ± 0.10	1.00
Biological Properties			
Total bacteria count Cfu/100 ml	6.975 x 10^3	2.18 x 10^7	0-30
Total coliform count Cfu/ 100 ml	9.813 x 10^3	3.76 x 10^7	0.10
Klebsella count cfu/ 100 ml	1.7 x 10^7	NG	0
e. coli (cfu/100ml)	2.5x 103	NG	0

Source: Field work by author, 2023

The means of the borehole and Uramiriukwa river water samples are significantly different (P<0.05)
SEM=Standard Error of Mean, TSS = total suspended solid, TS= total solid, TDS=Total Dissolved Solid, EC= electric current, COD=Chemical Oxygen Demand, BOD=Biological Oxygen Demand, DO=Dissolved Oxygen, NESREA= Federal Ministry of Environment, WHO=World Health Organization.

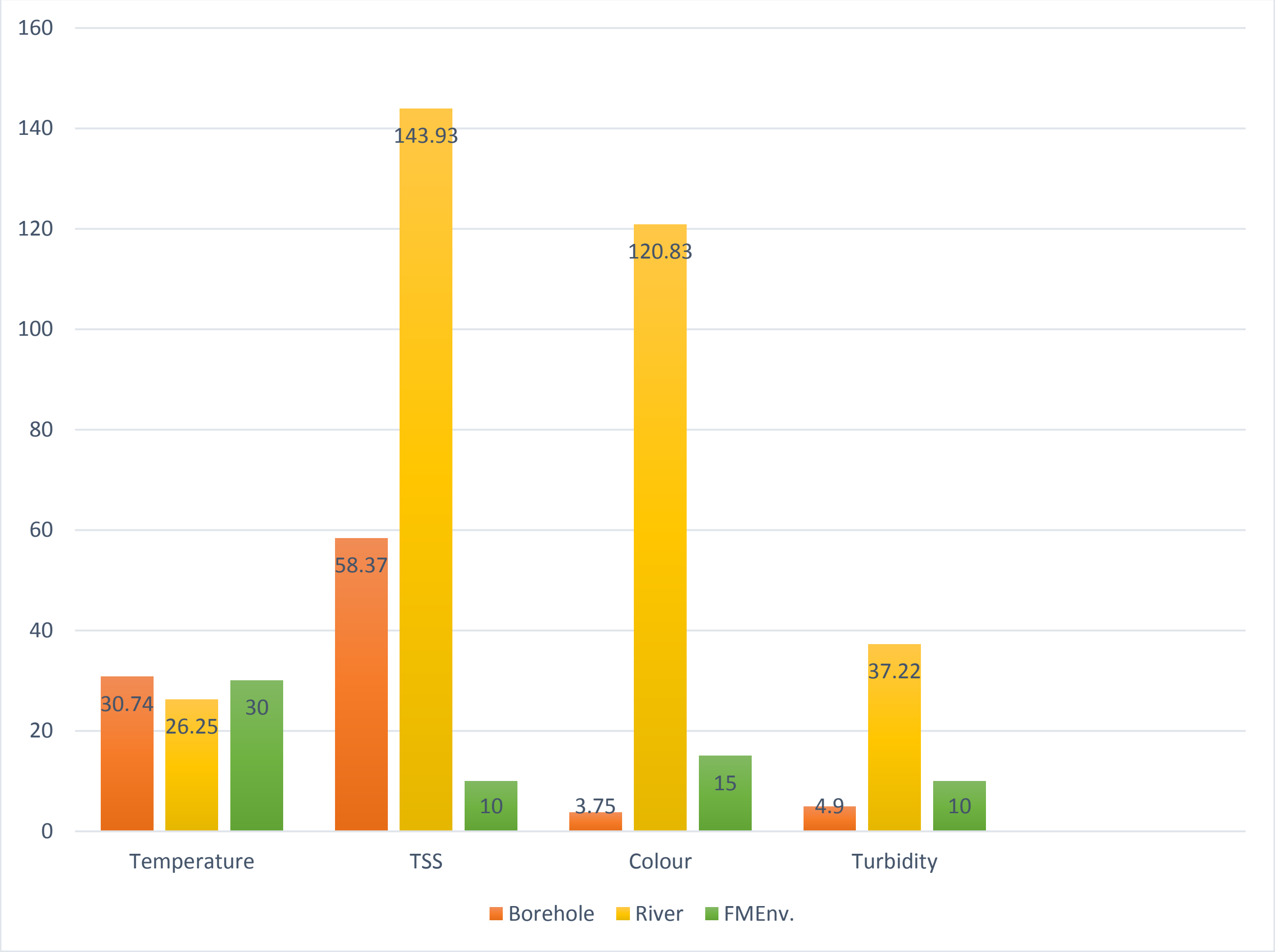

Figure 4.9: Graph comparing the mean temperature, TSS, colour and turbidity of the borehole and river water samples to the NESREA standards for drinking water.

Figure 4.9 compares some physical properties, including temperature, TSS, colour and turbidity, of the borehole and river water samples to the NESREA standards for drinking water. The result shows that the mean temperature for the borehole water was 30.74 ºC, above the NESREA standard of 30ºC for drinking water, while that of the Uramiriukwa River was 26.25ºC and below the NESREA standard. The mean total suspended solids were 58.37 mg/L and 143.93 mg/L for the borehole and river, respectively, both of which were above the NESREA permissible limit of 10 mg/L. The mean value of colour for the borehole water samples was 3.75 cp, below the NESREA permissible limit of 15 cp, while the mean colour value of the river water samples was 120.83 cp, against the NESREA limit. The mean turbidity value of the borehole water samples was 4.9 NTU, which is low compared to the NESREA standard of 10 NTU, while the turbidity of the river was 37.22 NTU, which is higher than the NESREA.

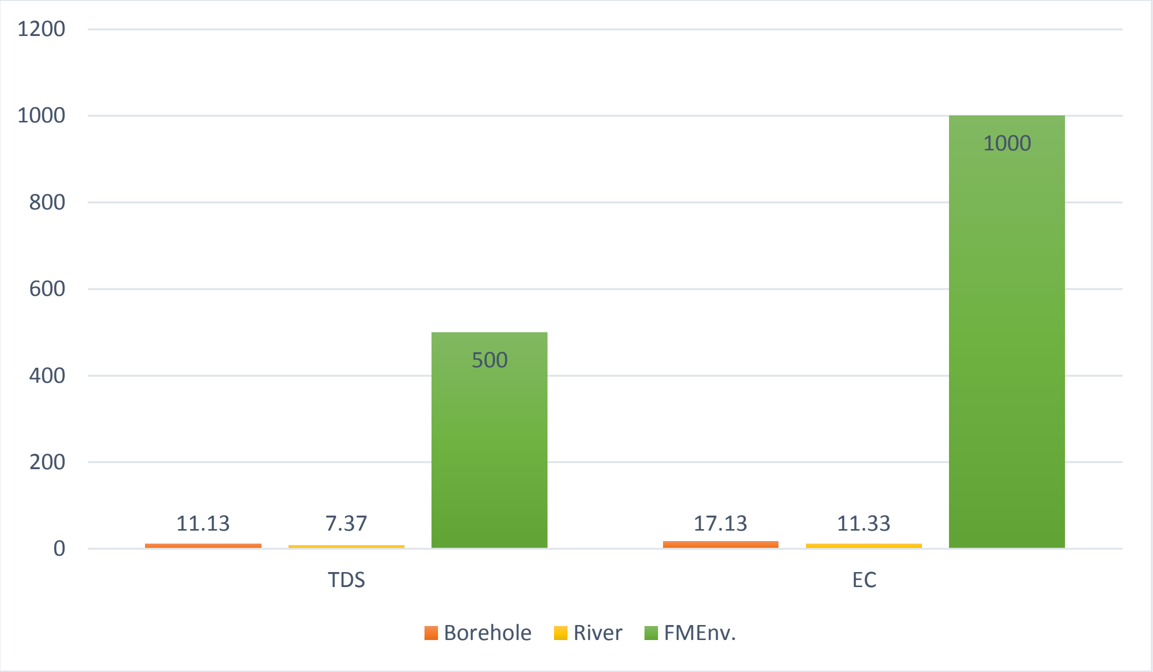

Figure 4.10: Graph comparing the mean TDS, and electric current of the borehole and river water samples to the NESREA standards for drinking water.

The result in Figure 4.10 shows that the mean total dissolved solid and electric current, for the borehole and river water samples were below the NESREA permissible levels of 500 mg/L and 1000 µs/cm for total dissolved solid and electric current respectively. The mean total dissolved solid was 11.13mg/L, and 7.37mg/L for the borehole and river water samples respectively, while the mean electric current were 17.13 µs/cm and 11.33 µs/cm respectively.

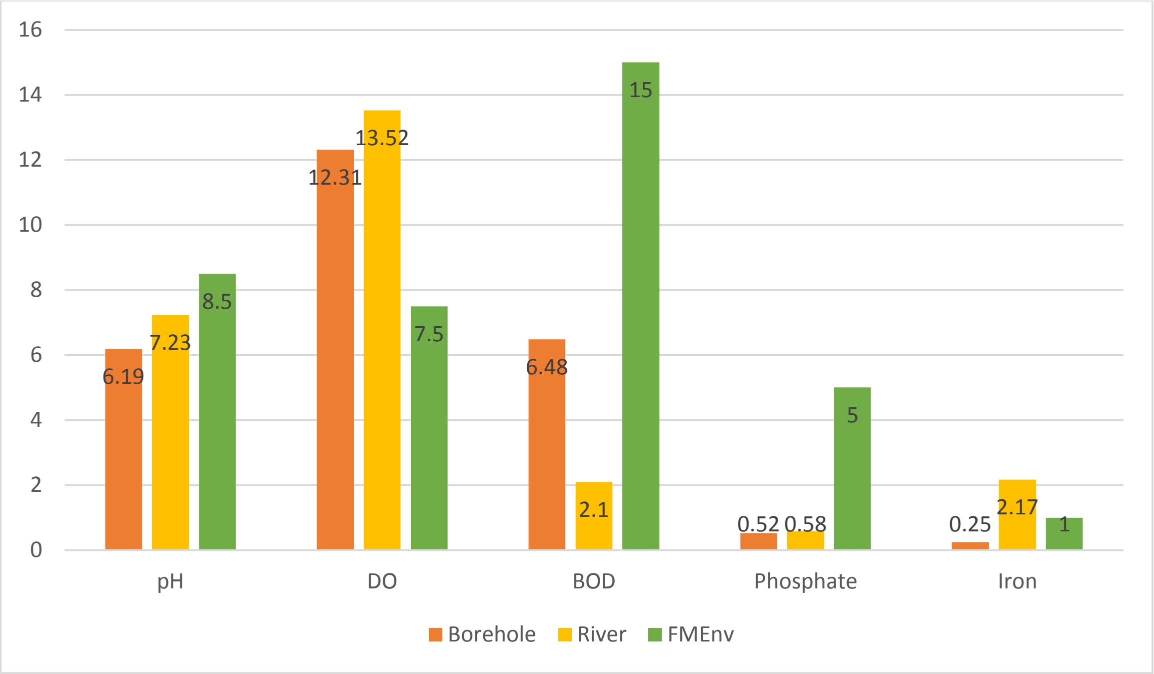

Figure 4.11.: Graph comparing the mean temperature, pH, dissolved oxygen, biological oxygen demand, phosphate and iron content of the borehole and river water samples to the NESREA standards for drinking water.

Figure 4.11 compares some chemical properties, including temperature, pH, dissolved oxygen, biological oxygen demand, phosphate, and iron content, of the borehole and river water samples to the NESREA standards for drinking water. The mean pH values of the borehole and the river water were 6.19 and 7.23, respectively, and below the NESREA maximum permissible limit of 8.5. The NESREA standard for DO is set at > 7.5 mg/L, while the results show that the mean DO for the borehole and the river water samples were 12.31 mg/L and 13.52 mg/L respectively, and were greater than 7.5mg/L as set by NESREA standards. The mean BOD of the borehole and the river water samples were 6.84 mg/L, and 2.1 mg/L respectively, and were lower than the NESREA permissible limit of 15 mg/L. Mean phosphate contents were 0.52 mg/L and 0.58 mg/L, for the borehole and the river water sample respectively, and lower than the NESREA permissible limit of 5 mg/L. The mean iron content of the borehole water sample at 0.25 mg/L was lower than the NESREA permissible limit of 1.00mg/L, while that of the river water sample at 2.17 mg/L was higher than the NESREA permissible limit.

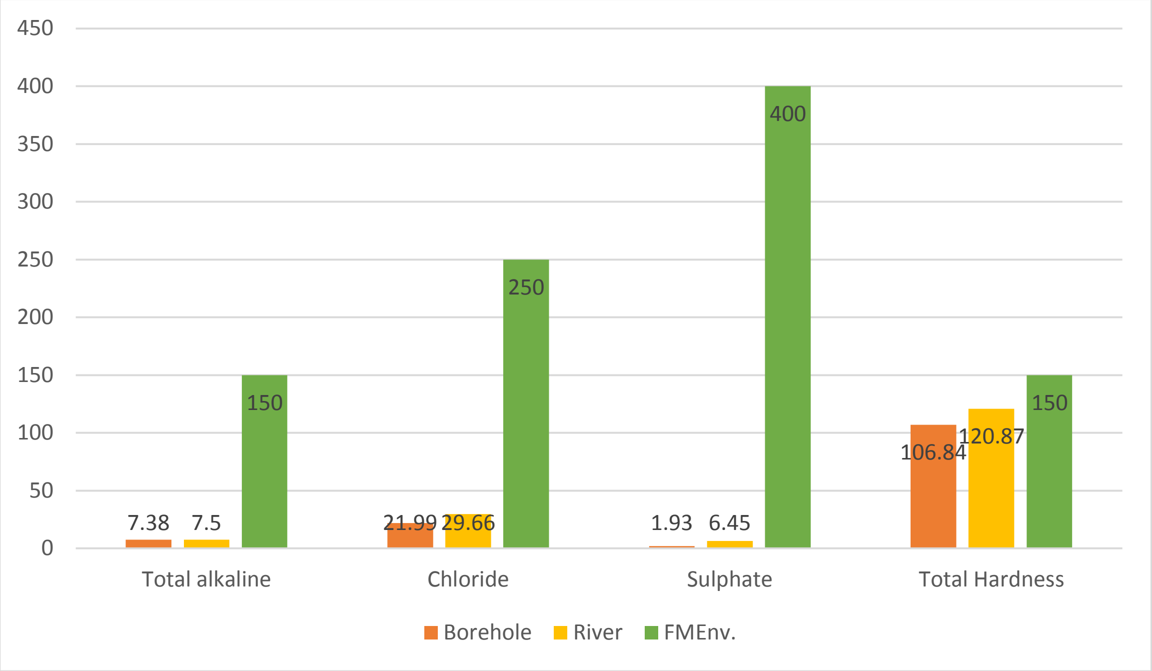

Figure 4.12.: A plot comparing the mean total alkalinity, chloride, sulphate, and total hardness of the borehole and river water samples to the NESREA standards for drinking water.

The Figure 4.12shows mean total alkaline contents of the borehole and Uramiriukwa river water samples were 7.38 mg/L and 7.5mg/L respectively, and were both below the NESREA permissible of 150mg/L. Also, the mean chloride, sulphate, and total hardness were 21.99mg/L and 29.66mg/L, 1.93mg/L and 6.45mg/L, 106.84mg/L, and 120.87mg/L for the borehole and the river water samples respectively, and were all below the NESREA permissible levels as shown in the Figure 4.12.

The biological properties of the boreholes and river water samples in table 4.3 shows that the mean total bacteria counts were 6.975 x 10^3cfu/100ml, and 2.18 x 10^7 cfu/100ml respectively, much higher than the NESREA permissible limit of 0.30 cfu/100ml. Mean total coliform counts were 9.813 x 10^3 cfu/100ml, and 3.76 x 10^7cfu/100ml for the borehole and river water samples respectively, which were higher than the NESREA permissible limit of 0.10 cfu/100ml. Mean total klebsiella and *e.coli* were 1.7 x 10^7 cfu/100ml, and 2.5 x 10^3respectively, for the borehole water samples, against the NESREA standard of 0 cfu/100ml for klebsiella and *e.coli*, while there was no detection of klebsiella and *e.coli* for the river water sample.

4.1.4. Water Quality Index of the two water sources in sub-urban area of Owerri

Table 4.4: Water quality index value for the borehole water sample

Parameters	NESREA STD (sn)	wn =k/sn	ideal value (vo)	mean conc. Value (vn)	vn/sn	vn/sn x 100=qn	WnQn
DO	7.5	0.078601	14.6	12.31	0.322	32.2	2.530949
pH	7.5	0.078601	7	6.19	1.62	162	12.73335
e.coli	0	0	0	25000	0	0	0
BOD	15	0.0393	0	6.48	0.432	43.2	1.69778
TEMP	30	0.01965	0	30.74	1.024667	102.4666667	2.013493
PHOPHATE	5	0.117901	0	0.52	0.104	10.4	1.226174
NITRATE	50	0.01179	0	45.35	0.907	90.7	1.069365
TDS	500	0.001179	0	11.13	0.02226	2.226	0.002624
TUR	10	0.058951	0	4.9	0.49	49	2.888583
EC	1000	0.00059	0	17.13	0.01713	1.713	0.00101
ALKALINITY	150	0.00393	0	7.38	0.0492	4.92	0.019336
IRON	1	0.589507	0	0.25	0.25	25	14.73767
				WQI	= $\sum qnWn / \sum wn$		**38.92**

$K = 0.589507, \sum \boldsymbol{wn} = \mathbf{1}$

The water quality index value of the mean borehole water samples parameter Table 4.4 was found to be 38.92, and in relative to the WQI rating in table 4.4., the borehole water is rated “good” for drinking.

Table 4.5: Water quality index value of the UramiriukwaRiver water sample

Parameters	**NESREA STD (sn)**	**wn =k/sn**	**ideal value (vo)**	**mean conc. Value (vn)**	**vn/sn**	**vn/sn x 100=qn**	**WnQn**
DO	7.5	0.078601	14.6	13.52	0.322	32.2	2.530949
pH	7.5	0.078601	7	7.23	1.62	162	12.73335
e.coli	0	0	0	0	0	0	0
BOD	15	0.0393	0	2.1	0.14	14	0.550206
TEMP	30	0.01965	0	26.25	0.875	87.5	1.719395
PHOPHATE	5	0.117901	0	0.58	0.116	11.6	1.367656
NITRATE	50	0.01179	0	28.44	0.5688	56.88	0.670623
TDS	500	0.001179	0	7.37	0.01474	1.474	0.001738
TUR	10	0.058951	0	37.22	3.722	372.2	21.94144
EC	1000	0.00059	0	11.33	0.01133	1.133	0.000668
ALKALINITY	150	0.00393	0	7.5	0.05	5	0.01965
IRON	1	0.589507	0	2.17	2.17	217	127.923
				WQI	= $\sum qnWn / \sum wn$		**169.46**

The water quality index value of the mean Uramiriukwa river water parameters was found to be 169.46, and in relative to the WQI rating in Table 4.5, the borehole water is rated “unfit” for drinking.

4.2 Discussion

The mean total suspended solids (TSS) in the water samples from the borehole and the river were 58.37±1.97 mg/L and 143.93±11.11 mg/L, respectively. Total suspended solids are particles smaller than 2 microns that do not dissolve in water and cannot be filtered out (Campbell, 2021). The water sample from the borehole has obviously less TSS than the water sample from the river, but neither water source met the NESREA threshold of 10.00 mg/L. It is general knowledge that ground water sources, such as boreholes, are devoid of pollutants,because of the fact that ground water travels through microscopic aquifers of soil particles and rocks (Famiglietti, 2014) aids in particle removal. According to Akhionbare (2015), long-distance soil filtration often eliminates practically all suspended particles, and reduce turbidity. On the other hand, surface water sources are exposed to pollution and anthropogenic activities, such as dredging, municipal waste disposal, industrial waste water, and urban runoff, to name a few, resulting in a high TSS concentration.

The mean temperature of the borehole water samples, 30.74^{o}C, was slightly higher than the NESREA standard of 30^{o}C, whereas the mean temperature of the river, 26.25 ^{o}C, was lower than the NESREA standard. Temperature has a significant impact on the physiochemical and biological qualities, as it affects the growth and proliferation of microorganisms as well as chemical reactions in water. Total suspended solids concentrations are frequently correlated with water turbidity (cloudiness). If TSS is high and the water is cloudy, sunlight will not transmit properly through the water, resulting in a decrease in temperature. Therefore, it would be accurate to assume that the high TSS and turbidity of the Uramiriukwa river are responsible for its lower temperature compared to the borehole water sample.

TDS is the combined concentration of dissolved organic and inorganic minerals in water and is a function of pH and temperature (Agbaire and Oyibo, 2009). According to the USGS (2018), temperature can impact the chemistry of water, as chemical reactions can speed up as the temperature rises and vice versa. This suggests that the rate of mineral dissolution in water will increase as water temperature rises. Additionally, pH is a significant component that influences TDS. Water with a low pH value dissolves more minerals than water with a high pH value (Goel, 2009). Agbaire and Oyibo (2009) explained further that ground water with a low pH and high temperature typically dissolves minerals in rocks, resulting in elevated TDS concentrations. This explains why the river water sample has a lower TDS concentration than the borehole water sample with greater temperature and pH.

Turbidity of the borehole water sample was 4.90±0.62 mg/L, which is lower than the NESREA permissible limit of 10mg/L, and therefore met the turbidity standard for drinking water. While the mean turbidity value of the Uramiriukwa river water sample was 37.22±8.3mg/L, and they did not pass for the NESREA standard, as it was above the permissible limit. Turbidity (cloudiness) of water values is often related to total suspended solids (TSS), such that the higher the TSS, the more turbid. This explains why the river water sample has higher turbidity than the borehole sample, given than the river has a TSS value of 143.93±11.11 mg/L, which is more than two times greater than that of the borehole water sample with TSS value of 58.37±1.97mg/L. The TSS contents also accounts for the appearance of the water samples. The appearance of the borehole water was clear because of lower TSS, and pass the NESREA standard for drinking water, while the river water sample was turbid and below the standard for drinking water. it is a common knowledge that high TSS results in murky water while low TSS increases water clarity.

The electrical conductivity of water is determined by the presence of salts, acids, and bases, known as electrolytes, which are capable of creating cations and anions. As conductivity is directly proportional to the amount of dissolved salts, its magnitude can provide a reasonable estimation of the concentration of dissolved solids. Accordingly, there was a higher record of electric current in the borehole water, as a result of its higher dissolved solids, while the electric current in the river water sample was lower, giving it a lower dissolved solid. The mean electric current values for the two water sources were 17.13±6.20 µs/cm, and 11.33±0.33 µs/cm for the borehole and river water samples, respectively, which are record lows compared to the NESREA standard value of 1000 µs/cm for drinking water. Several studies, including Bayode, Lurunfemi&Ojo. (2012), who assessed the impact of some waste dumpsites on groundwater quality in some parts of Akure metropolis, also linked pollution from dumpsite leachate to high dissolved solids and electric current in groundwater. Similarly, Odukoya*et al* (2010) have linked industrial effluent discharge to increased dissolved solids and electric current in groundwater. Hence, the low dissolved solids and electric current in the water samples in this study, may be an indication of low contamination.

The mean pH values for the borehole and Uramiriukwa river were 6.19 and 7.23, respectively, the borehole water was lower than the NESREA minimum permissible level of 6.5 while the mean pH value for the river was between the NESREA permissible range of 6.50-8.50. The mean pH value of the river water sample shows that the river is higher than the borehole and also alkaline, while that of the borehole is slightly acidic. This may be due to dredging activities and excavation of earth for coarse soil and river gravels for building construction purposes, going on around the river. When water comes into contact with the soil, there is a higher tendency for its pH to shift towards alkalinity by displacing the positively charged ions in the soil, replacing them with hydrogen ions. Studies show that this displacement is increased with coarse soil types and more resisted in percolated soil types due to the presence of a higher number of colloids. On the other hand, alkaline water has a higher buffering capacity and tends to resist any change in pH (Fernandez, 2018).

A study carried out in Omoku, a suburban area in River state of Nigeria, by Dirisu*et al.,* (2016), shows that the river had mean pH of 5.54+0.035, while borehole was 4.74+0.49. Compared with the result in this study, water samples from borehole and streams in Omoku have lower pH and are acidic, which may be as a result of acid rain from gas flaring. Kolo *et al.,* (2009) reported borehole water mean pH value of 6.296 and 6.143 respectively, in Polo and Bulumkutu suburban communities in Maiduguri State, Nigeria, which are similar to the result obtained in this study.

Fagorite, Ahamefule &Onyekuru, 2019 reported a maximum pH value of 6.5 at the downstream (Mberichi) of Otamiri river, in the same study area as the present study. The result shows that the pH value of Uramiriukwa river is higher than that of Otamiri River and therefore more alkaline.

The mean total alkalinity of the water sources in the present study were 7.38 and 7.50 for the borehole and river, respectively. The alkalinity of the river was slightly above that of the borehole; however, both were below the NESREA permissible level of 150 mg/L. The alkalinity of water is related to pH, such that the higher the alkalinity, the higher the pH and vice versa. As mentioned earlier, alkalinity is due to the presence of these forms of the carbonate anions (HCO3-), (CO32-) and (OH-) that act as buffer systems (Chris, 2012), neutralizing acids by accepting hydrogen ions (H+) and preventing sudden changes in the acidity levels of water. Therefore, it can be inferred that the higher alkalinity of the river can be connected to the type of soil and the interaction of the soil and the river, due to excavation and dredging activities. Dissolved oxygen is a function of temperature and microbial activity in a water sample (Premlata, 2009). Dissolved oxygen is inversely proportional to temperature and bacterial activities, such that the higher the water temperature and bacterial activities, the lower the dissolved oxygen. Furthermore, with an increase in water temperatures towards the optimum temperature that supports the stability of microbial life, dissolved oxygen is expected to increase significantly (Krishnamurthy, 1990). The mean dissolved oxygen of the borehole and Uramiriukwa river water samples was 12.31 and 13.52 mg/L, respectively, and was > 7.50 as set by NESREA. The higher dissolved oxygen in the river water sample correlated with the lower temperature and bacterial activities, while the lower dissolved oxygen in the borehole water sample also correlated with the higher temperature and bacterial activities, as shown in Table 4.3.

BOD is a function of dissolved oxygen required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials and can represent organic matter contamination in water. the BOD of the borehole and river water samples in the present study were 6.48 15mg/L and 2.10 15mg/L respectively. Although it is a common believe that ground water is often free from contamination, however leakage form septic tanks, and underground tanks, coupled with land use, municipal waste leachate can lead to significant contamination of ground water. This could explain the higher detected in the borehole. However, compared to the NESREA. permissible limit of 15mg/L, it can be said that the two water sources in this present study, are safe for drinking, relative to their BOD contents.

Chemical oxygen demand (COD) is a function of the oxygen required for the oxidation of organic chemical materials, e.g. petroleum. It is a measure of wastewater and aqueous hazardous waste pollution in water. The values of COD in the two water samples were 384 mg/L and 320 mg/L for the borehole and Uramiriukwa river water samples, respectively. These values were very close to the NESREA permissible limit of 40 mg/L. The high level of COD in the water samples in the present study is an indication of significant contamination by organic chemical waste, which may be due to indiscriminate municipal or wastewater waste discharge in the river or waste dumping on land, in the case of the borehole. Ikem, Osibanjo, Sridhar &Sobande, (2002) evaluated groundwater quality characteristics near two waste sites in Ibadan and Lagos and reported similar results for chemical oxygen demand. Results in the present study showed that nitrate values were 45 mg/L and 28.44 mg/L, respectively, and were below the NESREA standards of 50 mg/L. Although natural water free from significant contamination has a low nitrate content of about 5 mg/L, contamination from fertilizer leachate, septic tank leachate, unsewered sanitation, pit latrines, animal waste, or human waste can lead to increased nitrate levels in the water. Similar to the concentration of nitrate obtained in the present study, Akakuru, Akudinobi&Aniwetalu(2015) also reported nitrate concentration levels below the WHO (2006) recommended highest permissible limit in groundwater in Owerri, thus indicating good drinking water quality relative to nitrate content.

The chloride concentration of the borehole and river water samples were below the NESREA permissible levels. This also is an indication of good drinking water. However, the values were higher than the results obtained by Akakuru*et al*(2015), provided an insight on some groundwater results in Owerri as Chloride concentration ranges from 0.04mg/l – 5.2 mg/l, and also, by the study of Fagorite, Ahiarakwem, Ibeneme,Chinemelu, Ukwajiunor, Abiahu&Poopola(2019) who reported 5.27mg/L as the highest concentration of chloride for Otamiri river, in suburban area of Owerri-west LGA, Imo state.

Hardness of water is an indication of mineral content. It is formed when water percolates through deposits of limestone, chalk or gypsum, which are largely made up of calcium and magnesium carbonates, bicarbonates and sulfates. According to WHO, hard water may have moderate health benefits, since it contains some dietary mineral like calcium and magnesium. In the present study, the hardiness concentrations were, 106.84±6.96mg/L and 120.87±22.2, for borehole and the river water samples respectively, and were lower than the NESREA permissible limits, but much higher than that reported by Fagorite, *et al*., 2019, for Otamiri river which is 13.20mg/L. Studies has shown that water hardness can be affected by seasonal variations, such that hardness increases in the dry seasons and decreases in the rainy seasons as a result of dilution and runoff. Nwafor *et al*. (2013) analyzed the seasonal influence on the physico-chemical concentrations in hand dug wells in Akure town, and reported higher concentrations of hardness in dry season. The total hardness difference reported in the present study and Fagorite*et al*., 2019, may be due to seasonal variation in the time of study. The sulfate concentrations of the water sources were 1.920.89 mg/L and 6.45 mg/L for the borehole and river, respectively, and were much lower than the NESREA permissible limits of 200–400 mg/L. Fagorite*et al*. (2019) reported a sulphate concentration of 4.83 mg/L for the Otamiri River, which is below the result reported in the present study.The hardness of water is an indication of mineral content. It is formed when water percolates through deposits of limestone, chalk, or gypsum, which are largely made up of calcium and magnesium carbonates, bicarbonates, and sulfates. According to the WHO, hard water may have moderate health benefits since it contains some dietary minerals like calcium and magnesium. In the present study, the hardiness concentrations were, 106.84 ± 6.96 mg/L and 120.87±22.2, for borehole and river water samples, and were lower than the

NESREApermissible limits, but much higher than that reported by Fagorite, *et al*., 2019, for the Otamiri river, which is 13.20mg/L. Studies have shown that water hardness can be affected by seasonal variations, such that hardness increases in the dry seasons and decreases in the rainy seasons as a result of dilution and runoff. Nwafor *et al*. (2013) analyzed the seasonal influence on the physico-chemical concentrations in hand dug wells in Akure town, and reported higher concentrations of hardness in dry season. The total hardness difference reported in the present study and Fagorite*et al*., 2019, may be due to seasonal variation in the time of study. The sulfate concentrations of the water sources were 1.920.89 mg/L and 6.45 mg/L for the borehole and river, respectively, and were much lower than the NESREA permissible limits of 200–400 mg/L. Fagorite*et al*. (2019) reported a sulphate concentration of 4.83 mg/L for the Otamiri River, which is below the result reported in the present study.

The iron content of the borehole water sample was 0.25±0.04mg/L and was found to be below the NESREA permissible limit of 1mg/L. While that of the river was higher, with concentration of 2.17±0.10mg/L. The highest value report by Fagorite*et al*., 2019, for Otamiri was 0.23mg/L, which is similar to the iron content levels of borehole in the present study.

Studies shows that optimum temperature for klebsiella and *e.coli* is 37 ºC, and this implies that on one hand, temperature much higher or lower than 37 ºC, may negatively affect their activities, and on the other hand, temperature near 37ºC improve their activities. This correlates with the facts that klebsiella and *e.coli* were detected in the borehole water sample which has a temperature near 30.74ºC while the organisms were not detected in the river water sample with much lower temperature of 26.25ºC. The level of klebsiella and *e.coli*present in the borehole water were 1.7 x 10^7cfu and 2.5 x 10^3 cfu respectively, which is an indication of serious contamination compared to the NESREA standard of 0. klebsiella and *e.coli*are serious pathogenic bacteria and are subgroup of faecal coliforms. Although most *e.col*i is harmless, some cause diseases. The presence of these bacteria in a drinking water sample almost always indicates recent fecal contamination, meaning there is a greater risk that pathogens are present (WSDH, 2021).

The two water sources had a high coliform and bacteria counts compared to the NESREA standards. However, the borehole water had higher total coliform and total bacteria counts compared to the river water sample, which could be due to the fact that the borehole water has temperature value suitable for proliferation of bacteria, also considering the possible of fecal contamination through leachate from underground septic tanks located around the two of the borehole points. Notwithstanding the difference in the coliform and bacteria population in the borehole, and river the two water sources had high coliform and bacteria counts compared to the NESREA standards.

However, the borehole water had higher total coliform and total bacteria counts compared to the river water sample, which could be due to the fact that the borehole water has a temperature value suitable for the proliferation of bacteria, as well as the possibility of fecal contamination through leachate from underground septic tanks located around the two borehole points.

Although coliform bacteria are not normally causes of serious illness, they are easy to culture, and their presence is used to infer that other pathogenic organisms of fecal origin may be present in a sample, or that said sample is not safe to consume (Liu *et al*., 2019).Notwithstanding the difference in the coliform and bacteria populations in the borehole and river water samples, both water sources could be considered heavily polluted by microbes of fecal origin and thus, may pose danger to human health.

Furthermore, the T-test result showed that there is a significant difference in the mean physiochemical and biological properties of the borehole water sample and the Uramiriukwa water sample. The result of the water quality index test (Tables 4.4 and 4.5) showed WQI vales of 38.92 and 169.46 for the borehole and river water samples respectively, which indicates that while the borehole water samples are good for drinking, the Uramiriukwa river water samples are unfit. The WQI result of the Uramiriukwa river water samples maybe due to its physical properties, in respects its high contents of suspended solids, which resulted in turbidity and high colour value, which are very important factors to consider for drinking water.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings:

The following are the major findings of the study

Study of the physical parameters of both water sources shows that the borehole water has better physical properties compared to the Uramiriukwa river. Indiscriminate solid waste disposal and anthropogenic activities resulted to its high total suspended solid, which in turn results to the increase in turbidity, and color index, and then low temperature owing to low penetration of sunlight into the river. Although the borehole had far better physical properties, none of the water sources m*et al*l the NESREA standard for physical properties of drinking water.

The COD of both water sources were very high compared to the NESREA standard, which is an indication of the presence of chemical pollutants. Only the pH of the borehole water was out of the NESREA permissible range. The level of ferrous iron in the river was higher than the NESREA permissible levels, while that of the borehole was lower. The high levels of iron may be due to industrial activities.

The high total bacteria count, total coliform count, klebsiella and *e.coli* in the borehole water is an indication of heavy microbial contaminations, probably from sewer leachates. Less total bacteria count, and total coliform count, with the absence of *e.coli* and klebsiella in the river, maybe due to the fact that surface water are flowing, unlike groundwater. However, none of the water sources met the NESREA standards, in terms of their biological properties, but the borehole was found to be more polluted, and poses higher health risks.

Spatialvariations analysis showed that there is no significant difference ($p>0.05$) in the river water samples at upstream, middle stream and downstream, while there was significant difference in the three borehole water samples.

The T-test result showed significant difference ($p<0.05$)between the means of the river and borehole water samples.

Calculation for WQI showed that the borehole water was good for drinking, while the Urumiriukwa water samples were unfit for drinking.

5.2 Conclusion

Findings from the physiochemical properties of Uramiriukwa river and boreholes in the suburban area of Owerri, including Owerri. Agbala precisely, shows that the river is polluted with solid and chemical wastes as a result of anthropogenic activities, including dredging, industrial activities, laundry, and indiscriminate municipal waste disposal, as observed during field study. The presence of high level of coliform in the borehole and river water samples is an indication of fecal contamination, which is an indication of possible health risk.

In conclusion, given the result of the physiochemical and biological properties of the two major sources of water for drinking and domestic use, are below the NESREA standards. However, result showed that the borehole water was good for drinking, while the Urumiriukwa river is unfit for drinking.

5.3 Recommendations

Considering the findings from this study, the following recommendations are made:

i. The borehole water should at leastbe passed through a filter and boiled or treated with a disinfectant e.g., **5.25% solution** sodium hypochlorite (NaOcl), in order to remove excess suspended solids and microbial contaminants respectively before drinking or use for domestic purposes.
ii. The water from the Uramiriukwa river should be press filtered through activated charcoal in order to remove excess suspended solid and color. The water should also be passed through an iron removal filter and also disinfected before drink or used domestically.
iii. Despite being another source of revenue to the government, the dredging and excavation work going on in the river should be monitored and supervised regularly so that the impact on the water body will not be enormous in order not to alter the parameters negatively and to an extent that water consumed can cause harm to human.
iv. All the sources of water supply in the area should be purified before drinking despite the borehole water seen as being more potable.
v. Government should provide water treatment facilities and also rehabilitate the water scheme for proper treatment and adequate distribution for the populace consumption.

5.4 Suggestion for further research

For further research the duration of the sampling should be put into consideration, such that the seasonal variation of the physiochemical and biological properties of the water samples can be understood.

The heavy metal and hydrocarbon contents of the water samples should also be studied, in order to understand which chemicals contributes to the high COD.

5.5 Contribution to knowledge

The study has given an insight on the vulnerability of the groundwater and surface water structure and the prevailing conditions of the quality of the two sources of water supply in suburban areas of Owerri-north.

REFERENCES

Adah, P.D. and Abok G. (2013), Challenges of Urban Water Management in Nigeria: The Way Forward, J. of Environmental Sciences and Resource Management, Vol.5, No.1, Pp. 111-121.

Adeboyejo, O. A., Clarke, E.O. and Olarinmoye, M.O. (2011). Organochlorine Pesticide Residues in water, sediments, Fin and Shell-fish samples from Lagos Lagoon Complex, Nigeria. Researcher, Vol. 3, pp. 38-45. www.sciencepub.net/researcher/research0303/06_4630research0303

Adejuwon, J. O. and Mbuk, C. J. (2011).Biological and Physiochemical Properties of shallow wells in Ikorodu town, Lagos Nigeria.*Journal of Geology and Mining Research* 3.6:161-168.

Adewuyi, G. O. Oputu, O. U and Opasina, M.A. (2010).Assessment of Groundwater Quality and saline intrusions in Coastal Aquifers of Lagos Metropolis, Nigeria.*J. of Water Resource and Protection* 2: 849-853.

Adeyemi, D., Anyakora, C., Ukpo, G. and Adedayo, A.and Darko, G. (2011). Evaluation of the levels of organochlorine pesticide residues in water samples of Lagos Lagoon using solid phase extraction method. Journal of Environmental Chemistry and Ecotoxicology, Vol. 3, No. 6, (June 2011), pp. 160-166. ISSN-2141-226 X

Afolabi, T. A., Ogbuneke, C. C., Ogunkunle, O. A., Bamiro, F. O. (2012) "Comparative assessment of the potable quality of water from industrial, urban and rural parts of Lagos, Nigeria", Ife Journal of science vol. 14 (2), p221

Agbaire, P.O and Oyibo, P. I. (2009) "Seasonal variation of some physico-chemical properties of borehole water in Abraka, Nigeria" African Journal of Pure and Applied Chemistry Vol.3 (6), pp 116-118. ISSN 1996-0840

Ahmed, H. (2003). Effect of sanitation on groundwater quality. International Conference on Towards the Millennium Development Goal, pp.183-185.

Akakuru, O.C., Akudinobi, B.E.B., and Aniwetalu, E.U, (2015) "Qualitative Evaluation and Hydrogeochemical Attributes of Groundwater in Owerri Capital Territory, Southeastern Nigeria" IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 3, Issue 2 Ver. I (Mar Apr. 2015), PP 12-18 www.iosrjournals.org

Akakuru, O.C., Maduka, E.C., and Akakuru, O.U. (2013). Hydrogeochemical characterization of surface water sources in Owerri Capital Territory, Southeastern Nigeria, IOSR journal of Applied Geology and Geophysics, Vol.1, Issue 2, July – August 2013. www.iosrjournals.org.Pp.32-38.

Akhionbare S.M.O. (2015). The Environment: Concepts, Issues and Control of Pollution. Springfield Publishers Ltd, second edition.

Akpoveta O.V., Okoh B.E., and Osakwe S.A. (2011). Quality Assessment of Borehole Water used in the Vicinities of Benin, Edo State and Agbor, Delta State of Nigeria. Current Research in Chemistry, 3: 62-69.

Allaq, A. A., Mahid, P., Yahya, M. et al (2023) Emerging Drinking Water Borne Diseases: A review on types, sources and health precautions. Journal of Pharmacetuical Research, 35 (31), 1-7 doi: 10.9734/jpri/2023

Amadi, A.N., Ameh, M.I and Olasehinde, P.I. (2010). "Effect of urbanization on groundwater quality within Makurdi Metropolis, Benue State". Proceedings, Annual Conference of the Nigerian Association of Hydrogeologists on Water Resources Development and Climate Change.p49.

Andricevic, R., Srzic, V. and Gotovae, H. (2011). Risk characterization for toxic chemicals transported in aquifers. Adv water Resourdoi: 10.1016/j.advwatres.2011.04.009

Anyanwu, B.O., Ezejiofor, A.N., Igweze, Z.N. and Orisakwe, O.E. (2018). Heavy Metal Mixture Exposure and Effects in Developing Nations: An Update. *Toxics*. 2;6(4):65.

APHA, (1992), Standard Methods for Examination of Water and Water, 18th Edition. American Public Health Association (APHA), American Water Works Association (AWWA), Washington D.C., pp.50-54.

Ayenimo, J. G., Adeeyinwo, C. E. and Amoo, I. A. (2005). Heavy metal pollutants in Warri River, Nigeria. *Kragujevac Journal of Science*, Vol. 27, pp. 43-50. ISSN 1450-9636.

Banerjee, S. Skilling, H. Forster, V. Briceno-Garmen-dia, C. Morella E. and Chfadi, T. (2008) "Africa Infrastructure Country Diagnostic: Urban Water Supply in SubSaharan Africa," Report by the World Bank and the Water and Sanitation Programme, Washington DC.

Bayode, S., M.Olurunfemi., and J.S.Ojo. 2012. Assessment of impact of some waste dumpsite on groundwater quality in some parts of Akure metropolis southwestern Nigeria. *Pacific Journal of Technology*, Vol.13, No.2, pp.528-536.

Burke, J. J. and Moench, M. H., (2000). "Groundwater and Society: Resources, Tensions and Opportunities," United Nations Publication, New York.

Calow C. Roger, Alan M. McDonald, Alan L. Nicol and Nick S. Robins, (2011). Groundwater Security and Drought in Africa. Linking Availability, Access and Demand.

Chris, W.P. (2012). *Water Quality: Alkalinity and Hardness.* University of Florida. http://edis.ifas.ufl.edu/ss540. Retrieved on 25th July 2011 at 1:00pm

Craun, M.F., Gunther, F.C., Rebecca, L.C. and Michael J.B. (2006), Waterborne outbreaks reported in the United States *Journal of Water and Health* | 04.Suppl 2 | 2006. Pp 19 – 22.

Dege, (2011), Technology of Bottled water third edition March 2011.

Di Baldassarre, G., Sivapalan, M., Rusca, M., Cudennec, C., Garcia, M., Kreibich, H., ... &Blöschl, G. (2019). Sociohydrology: scientific challenges in addressing the sustainable development goals. *Water Resources Research, 55*(8), 6327-6355.

Dlamini, C., Fadiran, A. and Thwala, J. (2013), "A Study of Environmental Assessment of Acid Mine Drainage in Ngwenya, Swaziland," Journal of Environmental Protection, Vol. 4 No. 11B, 2013, pp. 20-26 .doi: 10.4236/jep. 2013.411B003

Datsuke Sakai, Jill Dixon, Annita Achilleos, Micheal Dixon, Paul A. Trainer, (2016) Prevention of Treacher Collins Syndrome Craniofacial anomalies in mouse models via maternal antioxideant supplementation.

Dorevitch, S., Panthi, S., Huang, Y., LI, H., Michalek, A.M., Pratap, P., Wroblewski, M., LIU, L., Scheff, P.A. and LI, A. (2011). Water ingestion during water recreation. Water Research, vol. 45, no. 5, p. 2020-2028 . PMid:21227479 . http://dx.doi.org/10.1016/j.watres.2010.12.006

Edet, A. and Worden, R. H. (2009). Monitoring of the physical parameters and evaluation of the chemical composition of river and groundwater in Calabar (Southeastern Nigeria). *Environmental Monitoring and Assessment*, 157, Issues 1-4, 243-258. ISSN: 0167-6369.

Ekiye, E. and Zejiao, L. (2010). Water quality monitoring in Nigeria; Case Study of Nigeria's industrial cities. *Journal of American Science*, Vol. 6, No. 4, pp. 22-28. ISSN: 1545-1003.

Eni, D.V., J.Obiefuna., C. Oko., and I. Ekwok. 2011. Impact of urbanization on sub-surface water quality in Calabar municipalty, Nigeria. *International Journal of Humanities and Social Sciences*, Vol.1, Issue 10, pp.167-172.

Espejo, L, Krestschner, N, Oyarzun, J, Meza, F, Nunez, J., Maturana, H, Soto, G, Oyanzo, P. Garrida, M, Suckel, F, Amegaza, J, and Oyarzu R. (2012) Application of Water quality indices and analysis of the surface water quality monitoring network in semi arid North-central, Chile. Environmental monitoring and Assessment, Vol. 1814, No. 9 p, 55571-5588.

Fagorite, V. I..,Ahiarakwem, C. A., Ibeneme, S. I., Chinemelu,E. S., Ukwajiunor, J. I., Abiahu, C.M., &Poopola, J. O. (2019). Microbial Assay of Otamiri River and Its Sediments in Parts of Owerri. Journal of Geoscience and Environment Protection, 7 ,
155-166. https://doi.org/10.4236/gep.2019.78011

FAO (2010). *Corporate Document Repository*. Fishery Harbour Manual on the Prevention of Pollution.

Federal Ministry of Water Resources (FMWR), (2000) "National Water Supply and Sanitation Policy Document," Abuja.

Federal Republic of Nigeria (2009). Report of the Vision 2020 National Technical Working Group on Water and Sanitation. http://www.ibenaija.org/uploads/1/0/1/2/10128027/watersanitation_ntwg_report.pdf, accessed 26th September, 2014.

Federal Republic of Nigeria (FRN), (2004), “National Water Policy Document, Abuja, Nigeria”,.

Federal Republic of Nigeria, (2009). Federal Republic of Nigeria Official Gazette:Supplement to the Gazette, Government*Notice*No.2, Vol.96 FGP16122009/10,000(0L020) Federal Government Printer, Abuja.

Galadima, A., Garba, Z. N., Leke, L., Almustapha, M. N. and Adam, I. K. (2011).Domestic water pollution among local communities in Nigeria - causes and consequences. *European Journal of Scientific Research*, Vol.52, No.4, pp. 592-603. ISSN 1450216 X.

Geetha, T.S., Challaswammy, L. Venkatachalam, K. (2024) Deeper learning for river water quality monitoring: A CANBILSTM Approach Along Kaveri River. Sustainable Water Resources Management, 10:125 (2024).

Gharibi, H., Sowlat, MH.,Mahvi, AH., Mahmoudzadeh, H., Arabalibeik, H., Keshavarz, M., Karimzadeh, N.and Hassani, G. (2012) . Development of a dairy cattle drinking water quality index (DCWQI) based on fuzzy inferences systems. *Ecological Indicators*, vol. 20, p. 228-237. http://dx.doi.org/10.1016/j.ecolind.2012.02.015

Goel P.K., (2009) *Water Pollution Causes, Effect and Control*, Revised 2nd Edition, New Age International (P) Ltd. Publisher, 223.

Goldface andIrokalibe I.J. (2008), *Water Management in Federal and Federal –Type Countries: Nigerian Perspectives*, Ahmadu Bello University, Zaria Nigeria. http://www.dsi.gov.tr/english/congress2007/chapter_3/84.pdf.

Hadipuro W. and Indriyanti N. Y.(2009), “Typical Urban Water Supply Provision in Developing Countries: A Case Study of Semarang City, Indonesia,” *Water Policy*, Vol. 11, No. 1, pp. 55-66 . doi :10.2166/wp.2009.008

Hansen, J. (2020). Borehole clean: should i clean my borehole? From: https://www.aquify.co.za/borehole-clean-does-your-borehole-need-to-be-cleaned/. Retrieved, June 14, 2023

Hellström G. (2008). Large-Scale Applications of Ground-Source Heat Pumps in Sweden. IEA HP Annex 29 Workshop, Zurich, May 19, 2008.

Hobson, J.M. (2004). The Eastern Origins of Western Civilization. Cambridge University Press. p. 215.

Ikem, A., Osibanjo, O., Sridhar, M.K.C. and Sobande, A. (2002). Evaluation of groundwater quality characteristics near two wastes sites in Ibadan and Lagos, Nigeria. *Journal of Water, Air and Soil pollution*, Vol.140, No.1-4, pp.307-333.

Imo State Government Ministry of Works and Transport, (1984). Atlas Map of Imo State. Department of Lands, Survey and Urban Development, G & G s p a Italy.

Jing-Jing Huang, Hong-Ying Hu, Yin-Hu Wu, Bin Wei, Yun Lu, (2013). "effect ofchlorination and ultraviolet disinfection on TetA mediated tetracycline resistance of*Eschericha coli*" chemosphere 2013, vol 90(8) 2247-2253 , doi:10.1016 /j.chemosphere. 2012.10.008.

Kelechi, O. J., Nnawuike, A. J., Kelechi, I. S., Emmanuel, E. J. &Odinaka, N. P. (2021). Assessment of Microbial Load in Water and Sediments of Rivers Otamiri and Nworie in Owerri, South Eastern Nigeria. International Journal of Pathogen Research, 27–39.

Kolo, B. Dibal, J.M and Ndakawa, I.I (2019). Elemental Analysis of Tap and Borehole Waters in Maiduguri, Semi-Arid Region, Nigeria European Journal of Applied Sciences 1 (2): 26-29, 2019.

Khan, N., Hussain, S. T., Hussain, J., Jamila, N., Ahmed, S., Riaz, U., Zain, U., &Saboor, A. (2012).Physiochemical Evaluation of the Drinking Water Sources from District Kohat, Khyber Pakhtunkhwa, Pakistan. *International Journal of Water Resources and Environmental Engineering*, 4(10), 302-313.

Lenntech, (2009). Iron in groundwater, Lenntech water treatment and purification holding B.V, Rotterdamseweg, Netherlands

Longe, E.O., and L.O. Enekwechi (2007).Investigation on potential groundwater impacts and influence of local hydrogeology on natural attenuation of leachates at municipal landfill. *International Journal of Environmental Science and Technology*, Vol.4,No.1, pp.133-140.

Lumb, A, Sharma, TC, and Bibeault, J.F. (2011). A review of genesis and evolution of water quality index (WQI) and some future direction. Water quality, exposure AND Health, vol. 3, No. 1, p. 11-24.

Magesh, N.S. and Chandrasekar, N. (2013).Evaluation of spatial variation in groundwater quality by WQI and GIS technique: a case study of Virudunagar District, Tamil Nadu, India. *Arabian Journal of Geosciences*, vol. 6, no. 6, p. 1883-1898. http://dx.doi.org/10.1007/s12517-011-0496-z

Mark, W., Pximing, C, and Sarah, A.C. (2002). *World water and food to 2015: dealing with scarcity*. International Food Policy Research Institute NW, Washington DC USA.

Mbuka-Nwosu, I. E., Muoghalu, L. N., & Okonkwo, A. U. (2022, July 31). Sources and Functionality of Rural Water Supply in Communities from three Senatorial Zones of Imo State, Nigeria. Journal of Applied Sciences and Environmental Management, 26(7), 1283–1288. https://doi.org/10.4314/jasem.v26i7.15.

McDowell R.W., Nobel, A. Kittridge, M. et al (2024) Monitoring to detect changes in water quality to meet policy objectives. Sci Rep, 14, 1914 (2024).

Minh Phung T. Pham, James W. Castle and John H. Rodgers Jr., (2011). Application of water quality guidelines and water quantity calculations to decisions for beneficial use of treated water.

Muthukumaravel, K. (2010) Evaluation of Ground Water Quality in Perambalur, *Indian Journal of Environmental Sciences*, 14(1), 47-49

National Archives of Scotland (NAS),(2009). Sustainable Development and Environmental Policy Document.

National Bureau of Statistics (2009). Social Statistics in Nigeria. 399 p. http://www.nigerianstat.gov.ng/ext/latest_release/ssd09.pdf.Accessed: 10/10/2011.

National geographic (2022). Surface Water. https://education.nationalgeographic.org/resource/surface-water/. Retrieved, June 14, 2023.

Nikolaidis, C., Mandalos, P., &Vantarakis, A. (2008). Impact of intensive agricultural practices on drinking water quality in the EVROS Region (NE GREECE) by GIS analysis. *Environmental monitoring and assessment*, *143*, 43-50.

Nola, M., Noah, O.V., Ewoti, M., Nougang, F., Krier, N.E. Chihib, J., Hornez, P. and Njiné, T. (2011). Assessment of the hierarchical involvement of chemical characteristics of soil layer particles during bacterial retention in central Africa. *Int. J. Environ. Poll*., pp: 46.

Nwafor, E.K., Okoye, C.J. and Akinbile, O.C. (2013). *Seasonal assessment of groundwater quality for domestic use in Akure Metropolis, Ondo State, Nigeria*. Proceeding, Nigerian Association of Hydrological Sciences conference on Water Resources and National Development in: Mbajiorg, C.C; Obeta,M.C and Anyanwu, C(eds),pp.3842.

Nwankwoala, H.O. (2015), "Hydrogeology and Groundwater Resources of Nigeria". N Y Sci J 2015;8(1):89-100]. (ISSN: 1554-0200). http://www.sciencepub.net/newyork.

Obasohan, E. E., Agbonlahor, D. E. and Obano, E. E. (2010). Water pollution: A review of microbial quality and health concerns of water, sediment and fish in the aquatic African ecosystem. *Journal of Biotechnology*, Vol. 9, No. 4, (January 2010) pp. 423427.ISSN 1684-5315.

Obilonu, A.N., Chijioke, C., Igwegbe, W.E., Ibearugbulem, O.I. Y., AbubakarF. (2013). "Water quality challenges and impact" *International Letters of NaturalSciences* Vol. 4 pp 44-53 Sci Press Ltd., Switzerlanddoi:10.18052/www.scipress.com/ILNS.4.44 Online: 2013-11-03.

Ocheri, M.I., Odoma, L. A. and Umar, N. D. (2014), "Groundwater Quality in Nigerian Urban Areas: A Review" *Global Journal of Science Frontier Research: H Environment & Earth Science* Volume 14 Issue 3 Version 1.0 Global Journals Inc. (USA) Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Okeke, P.N. and Adinna, E.N. (2013) "Water Quality Study of Otamiri River in Owerri, Nigeria" *Universal Journal of Environmental Research and Technology* e-ISSN 2249 0256 Volume 3, (6): 641-649, www.environmentaljournal.org

Okeola, F.O., Kolawole, O.D. and Ameen, O.M. (2010) Comparative study of physicchemical parameters of water from a River and its surrounding wells for possible interactive effect. *Advances in environmental Biology*. 4(3):336-344.

Oloruntade, A.J., Konyeha, S. and Alao, F. (2014), "Assessing the sustainability of borehole for portable water supply in selected communities in Akoko area of Ondo stateNigeria" Ethiopian Journal of Environmental Studies & Management 7 Suppl.: 881 – 889,ISSN:1998-0507 doi: http://dx.doi.org/10.4314/ejesm.v7i2.8S

Oluyemi, A.S. (2013) , Determination of water quality of selected public wells in Ekiti state, south-western Nigeria Department of Chemistry, Ekiti State University,Ado-Ekiti, Nigeria. *Scientific Journal of Environmental Sciences* (2013) 2(3) 70-79 ISSN 23225017 p 70-79 p 70 – 71

Onunkwo .A.A (2015), "Alternative Source of Water Supply for Owerri Area" Journal of Environment and Earth Science www.iiste.org ISSN 2224-3216 (Paper) ISSN 22250948 (Online) Vol.5, No. 16

Osibanjo, O., Daso, A. P. and Gbadebo, A.M. (2011).The impact of industries on surface water quality of River Ona and River Alaro in Oluyole Industrial Estate, Ibadan, Nigeria. African Journal of Biotechnology, Vol. 10, No. 4, (January 2011), pp. 696702. ISSN 1684–5315.

Pfister, S., Bayner. P., Kochler, A. and Hellweg, S. (2011). Environmental impacts of water use in global crop production: hotspots and trade-offs with land use. *Environmental Science and Technology*, vol. 45, no. 13, p. 5761-5768 .PMid :21644578. http://dx.doi.org/10.1021/es1041755

Pradhan, B. and Pirasteh, S. (2011). Hydro-Chemical Analysis of the Ground Water of the Basaltic Catchments: Upper Bhatsai Region, Maharastra. *The Open Hydrology Journal*. 5:51-57

Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils Agriculture Handbook. USDA and IBH Pub. Coy. Ltd., New Delhi, India, 354-378

Sarah Jones (2020). Odour. from: https://www.h2olabcheck.com/blog/view/odour. Retrieved, July 3, 2023.

Saxena, P. (2016). Acidity in Water. https://www.slideshare.net/purvasaxena1/acidity-in-water. Retrieved, July 3, 2023

SGS (2012). *Groundwater Analysis. SGS Environmental Services*-ENV 068: www.environment.sgs.ca or www.environment.sgs.ca/fr-FR/ Retrieved April 5 , 2013.

Singh, B., Khurana, S.C., Manish, K., Tadav, N. and Yadav, R. (2012). Seasonal Variation of Coliforms and Nitrate in Groundwater Quality in Kanpur Metro. India. *International Journal of Research in Chemistry and Environment* Vol. 2 Issue 2 April (207-209)ISSN 2248-9649

Singh, CK., Shashtri, S., Mukherjee, S., Kunari, R., Avatar, R., Singh, A. and Singh, RP. (2011). Application of GWQI to asses' effect of land use change on groundwater quality in lower Shiwaliks of Punjab: remote sensing and GIS based approach. *Water Resource Manage*, vol. 25, no. 7, p. 1881-1898. http://dx.doi.org/10.1007/s11269011-9779-0

Spitsov, D., Nekrasova, L., Kondratenko, L., Pushkin, S., &Klyuchnikov, D. (2020). The effect of agricultural practices on the drinking water quality: a case study. *Asian Journal of Water, Environment and Pollution*, *17*(2), 73-80.

Stiles, Lynn (1998). "Underground thermal energy storage in the US". IEA Heat Pump Centre Newsletter. 16 (2): 22–23.

Stoler, J., Weeks, J.R. and Fink, G. (2012b) Sachet drinking water in Ghana's Accra-Tema metropolitan area: past, present, and future. *Journal of Water, Sanitation and Hygiene for Development* 2, 223–240.

Stoler, J. (2012) "Improved but unsustainable: accounting for sachet water in post-2015 goals for global safe water". *Tropical Medicine and International Health* Vol. 17 (12) pp. 1506-1508.

Sullivan, P., Agardy, F. J., & Clark, J. J. (2005). *The environmental science of drinking water*. Elsevier.

Suthra, S., Bishnoi, P., Singh, S., Mutiyar, P.K., Nema, A.K. and Patil, N.S. (2009). Nitrate contamination in groundwater of some rural areas of Rajasthan, Department of Civil Engineering, Indian Institute of Technology New Delhi India.

Taiwo, A. M. (2010). Environmental impact of poultry farm operations on Alakata Stream at Isolu in Abeokuta, Nigeria.Unpublished Master's Thesis. University of Agriculture, Abeokuta.108 p.

Taiwo, A. M., Adeogun, A. O., Olatunde, K. A., Adegbite, K. I. (2011). Analysis of groundwater quality of hand-dug wells in peri-urban areas of Obantoko, Abeokuta, Nigeria for selected physico-chemical parameters. Pacific Journal of Science and Technology, Vol. 12, No. 1, (May 2011), pp. 527-534. www.akamaiuniversity.us/PJST12_1_527.pdf

Taiwo, A.M., Olujimi, O.O., Bamgbose O., and Arowolo T.A., (2012). Surface Water Quality Monitoring in Nigeria: Situational Analysis and Future Management Strategy, Water Quality Monitoring and Assessment, Dr. Voudouris (Ed.), ISBN: 978-953-51-0486-5, In Tech, Available from: http://www.intechopen.com/books/waterquality-monitoring-and-assessment/surfacewater-quality-monitoring-in-nigeria-situational-analysis-and-futuremanagementstrategy.

Tsani, S., Koundouri, P., &Akinsete, E. (2020). Resource management and sustainable development: A review of the European water policies in accordance with the United Nations' Sustainable Development Goals. *Environmental Science & Policy*, *114*, 570-579.

Tse, A.C. and Adamu,C.I. (2012). Assessment of anthropogenic influence of groundwater in hand dug wells in Makurdi Metropolis in North central Nigeria. *Ife Journal of Science*, Vol.14, No.1, pp.

Turbidity and Water | U.S. Geological Survey. (2019, October 22). https://www.usgs.gov/special-topics/water-science-school/science/turbidity-and-water

Udoh, F. (2012) Nigeria: sachet water business generates N7 billion daily – NAFDAC. All Africa. http://allafrica.com/stories/201204200996.html (accessed April 20 2012).

UNESCO/UNEP (2009). United Nations World United Assessment programme. The United Nations World Water Development Report 3: Water in Changing World. UNESCO, Paris, and Earthscan, London (http://webworld.unesco.org/water/wwap/wwdr/wwdr3/

United Nations (2010) World Urbanization Prospects: The 2009 Revision. United Nations Population Division, Department of Economic and Social Affairs, New York, NY.

United State Geological Survey (USGS), (2012). http://www.usgs.gov08/ 06/2012 11:45 AM.)

UN-Water (2011). UN Water Policy Brief. Water Quality. http:/www.unwater.org

UN-Water (2021) Summary Progress Update, 2021 SDG6.Water and Sanitation for All. http://www.unwater.org.version July 2021a.pdf

USEPA2015,http://www2.epa.gov/sites/production/files/2015-03/documents/pmdefinitions.pdf 1

Wakawa, R. J ., Uzairu, A., Kagbu, J. A. and Balarabe, M. L. (2008). Impact assessment of effluent discharge on physico-chemical parameters and some heavy metal concentrations in surface water of River Challawa Kano, Nigeria. African *Journal of Pure and Applied Chemistry*, Vol. 2, No 9, (October 2008), pp. 100-106 . ISSN 1996 –0840.

Water Global Annual Assessment of Sanitation and Drinking- water (WGAASD) (2010).

Water Initiative.(2010). UN water global annual assessment of sanitation and drinking water (2010 report).Implemented by World Health Organization. Geneva: United Nations. http://www.who.int/water_sanitation_health/glaas/en/.Accessed January 2011

WHO (2010).*Water for Health; Guideline for drinking water quality, incorporating 1st and 2nd agenda to 3rd edition.*Volume 1 recommendations.

WHO/UNICEF.(2013). Progress on Sanitation and Drinking Water 2013. Update. Joint Monitoring Programme. http://www.budapestwatersummit.hu/data/images/Budapest_Water_Summit_ Statement___Final___11_October_2013.pdf.)

Winter, T.C. Harvey, J.W. Franke, O.L. and Alley, W.M (2013)., 'Ground Water and Surface Water A Single Resource'' http://pubs.water.usgs.gov/cir1139 (2013)

World Economic Forum. (2013). Global Risks 2013: Eighth Edition. Davos.

World Health Organization (WHO) (2004). Water, Sanitation and Hygiene links to Health: Facts and Figures. Updated November 2004.WHO, Generva, 2004. http://www.who.int/water_sanitation_health/publication/facts2004/en/

World Water Day Report (WWDR), (22 March 2011): Water for Cities: Responding to the Urban Challenge.

World Health Organization (2013). Technical notes on drinking-water, sanitation and hygiene in emergencies. www.cdn.who.int. Retrieved, June 14, 2023.

World Health Organization. (2021) Hardness.from: https://www.who.int/water_sanitation_health/dwq/chemicals/hardness.pdf. Retrieved, June 14, 2023.

Zeenat, A., Hatha, A. A. M., Viola, L. and Vipra, K. (2009).Bacteriological quality and risk assessment of the imported and domestic bottled mineral water sold in Fiji. Journal of Water and Health Vol.7 (4), 642 – 649.

APPENDICES

ANOVA FOR BOREHOLE WATER SAMPLES

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	1.170	2	.585	70.200	.003
	Within Groups	.025	3	.008		
	Total	1.195	5			
TSS	Between Groups	2919.933	2	1459.966	62.283	.004
	Within Groups	70.322	3	23.441		
	Total	2990.255	5			
TDS	Between Groups	353.633	2	176.816	1255.500	.000
	Within Groups	.422	3	.141		
	Total	354.055	5			
COLOUR	Between Groups	25.000	2	12.500	75.000	.003
	Within Groups	.500	3	.167		
	Total	25.500	5			
TURBIDITY	Between Groups	40.554	2	20.277	1216609.000	.000
	Within Groups	.000	3	.000		
	Total	40.554	5			
EC	Between Groups	837.000	2	418.500	1255.500	.000
	Within Groups	1.000	3	.333		
	Total	838.000	5			
pH	Between Groups	.130	2	.065	19.500	.019
	Within Groups	.010	3	.003		
	Total	.140	5			
ALKALINITY	Between Groups	4.333	2	2.167	6.500	.081
	Within Groups	1.000	3	.333		
	Total	5.333	5			
DO	Between Groups	15.423	2	7.712	925.400	.000
	Within Groups	.025	3	.008		
	Total	15.448	5			
BOD	Between Groups	7.790	2	3.895	531.118	.000
	Within Groups	.022	3	.007		
	Total	7.812	5			
COD	Between Groups	240725.333	2	120362.667	564.200	.000
	Within Groups	640.000	3	213.333		
	Total	241365.333	5			
Acidity	Between Groups	.010	2	.005	9.500	.050
	Within Groups	.002	3	.001		
	Total	.012	5			
NITRATE	Between Groups	8366.111	2	4183.056	1115481.471	.000
	Within Groups	.011	3	.004		
	Total	8366.122	5			

PHOSPHATE	Between Groups	.060	2	.030	906.500	.000
	Within Groups	.000	3	.000		
	Total	.061	5			
CHLORIDE	Between Groups	28.000	2	14.000	2.333	.245
	Within Groups	18.000	3	6.000		
	Total	46.000	5			
HARDNESS	Between Groups	1135.905	2	567.952	25.400	.013
	Within Groups	67.081	3	22.360		
	Total	1202.986	5			
SULPHATE	Between Groups	17.761	2	8.880	921.832	.000
	Within Groups	.029	3	.010		
	Total	17.790	5			
IRON	Between Groups	.034	2	.017	112.111	.002
	Within Groups	.000	3	.000		
	Total	.034	5			
TOTAL BACTERIA	Between Groups	9880000.000	2	4940000.000	741.000	.000
	Within Groups	20000.000	3	6666.667		
	Total	9900000.000	5			
TOTAL COLIFORM	Between Groups	309083333.333	2	154541666.667	3709.000	.000
	Within Groups	125000.000	3	41666.667		
	Total	309208333.333	5			
KLEBSIELLA	Between Groups	516000000.000	2	258000000.000	.	.
	Within Groups	.000	3	.000		
	Total	516000000.000	5			
e.coli	Between Groups	12000000.000	2	6000000.000	.	.
	Within Groups	.000	3	.000		
	Total	12000000.000	5			

POST HOC TEST FOR BOREHOLE

Temp

Duncan[a]

		Subset for alpha = 0.05		
SAMPLE POINTS	N	1	2	3
POINT 1	2	30.3000		
POINT 2	2		30.6000	
POINT 3	2			31.3500
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TSS

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2
POINT 3	2	55.4750	
POINT 2	2	62.9250	
POINT 1	2		105.5500
Sig.		.221	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TDS

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 3	2	5.5250		
POINT 1	2		8.4500	
POINT 2	2			23.0750
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

COLOUR

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 2	2	.0000		
POINT 1	2		2.5000	
POINT 3	2			5.0000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 2.000.

TURBIDITY

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2
POINT 2	2	.0000	
POINT 3	2	.0000	
POINT 1	2		5.5150

Sig.		1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

EC

Duncan[a]

		Subset for alpha = 0.05		
SAMPLE POINTS	N	1	2	3
POINT 3	2	8.5000		
POINT 1	2		13.0000	
POINT 2	2			35.5000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

pH

Duncan[a]

		Subset for alpha = 0.05	
SAMPLE POINTS	N	1	2
POINT 1	2	6.0500	
POINT 3	2	6.1500	
POINT 2	2		6.4000
Sig.		.182	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

ALKALINITY

Duncan[a]

		Subset for alpha = 0.05	
SAMPLE POINTS	N	1	2
POINT 2	2	5.5000	
POINT 1	2	6.0000	6.0000
POINT 3	2		7.5000
Sig.		.450	.081

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

DO

Duncan[a]

		Subset for alpha = 0.05	
SAMPLE POINTS	N	1	2
POINT 2	2	10.7500	
POINT 1	2		14.1000
POINT 3	2		14.2000

Sig.		1.000	.353

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

BOD

Duncan[a]

		Subset for alpha = 0.05		
SAMPLE POINTS	N	1	2	3
POINT 2	2	5.7100		
POINT 3	2		6.6200	
POINT 1	2			8.4500
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

COD

Duncan[a]

		Subset for alpha = 0.05		
SAMPLE POINTS	N	1	2	3
POINT 3	2	160.0000		
POINT 2	2		488.0000	
POINT 1	2			640.0000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

Acidity

Duncan[a]

		Subset for alpha = 0.05	
SAMPLE POINTS	N	1	2
POINT 1	2	.2800	
POINT 3	2	.3400	.3400
POINT 2	2		.3800
Sig.		.081	.182

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

NITRATE

Duncan[a]

		Subset for alpha = 0.05		
SAMPLE POINTS	N	1	2	3
POINT 3	2	.0000		
POINT 1	2		7.8500	
POINT 2	2			82.8450
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

PHOSPHATE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 3	2	.3400		
POINT 1	2		.4450	
POINT 2	2			.5850
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

CHLORIDE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1
POINT 1	2	19.9900
POINT 3	2	23.9900
POINT 2	2	24.9900
Sig.		.134

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

HARDNESS

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 1	2	90.6500		
POINT 3	2		108.7800	
POINT 2	2			124.3200
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

SULPHATE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 2	2	.3500		
POINT 3	2		1.6650	
POINT 1	2			4.4750
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

IRON

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 3	2	.1350		
POINT 2	2		.2700	
POINT 1	2			.3100
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TOTAL BACTERIA

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 1	2	1900.0000		
POINT 3	2		3000.0000	
POINT 2	2			5000.0000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TOTAL COLIFORM

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
POINT 3	2	2000.0000		
POINT 2	2		15000.0000	
POINT 1	2			18750.0000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

ANOVA FOR THE URAMIRIUKWA RIVER WATER SAMPLES

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	.000	2	.000	.000	1.000
	Within Groups	.055	3	.018		
	Total	.055	5			
TSS	Between Groups	1481.083	2	740.542	2.943	.196

	Within Groups	754.820	3	251.607		
	Total	2235.903	5			
TDS	Between Groups	.563	2	.282	.	.
	Within Groups	.000	3	.000		
	Total	.563	5			
COLOUR	Between Groups	5308.333	2	2654.167	549.138	.000
	Within Groups	14.500	3	4.833		
	Total	5322.833	5			
TURBIDITY	Between Groups	873.763	2	436.882	1759.255	.000
	Within Groups	.745	3	.248		
	Total	874.508	5			
EC	Between Groups	1.333	2	.667	.	.
	Within Groups	.000	3	.000		
	Total	1.333	5			
pH	Between Groups	.123	2	.062	6.167	.087
	Within Groups	.030	3	.010		
	Total	.153	5			
ALKALINITY	Between Groups	21.000	2	10.500	12.600	.035
	Within Groups	2.500	3	.833		
	Total	23.500	5			
DO	Between Groups	3.583	2	1.792	1075.000	.000
	Within Groups	.005	3	.002		
	Total	3.588	5			
BOD	Between Groups	4.090	2	2.045	613.500	.000
	Within Groups	.010	3	.003		
	Total	4.100	5			
COD	Between Groups	74496.000	2	37248.000	436.500	.000
	Within Groups	256.000	3	85.333		
	Total	74752.000	5			
Acidity	Between Groups	.009	2	.004	5.333	.103
	Within Groups	.002	3	.001		
	Total	.011	5			
NITRATE	Between Groups	38.334	2	19.167	535.646	.000
	Within Groups	.107	3	.036		
	Total	38.442	5			
PHOSPHATE	Between Groups	.040	2	.020	120.100	.001
	Within Groups	.000	3	.000		
	Total	.041	5			
CHLORIDE	Between Groups	49.333	2	24.667	7.400	.069
	Within Groups	10.000	3	3.333		
	Total	59.333	5			
HARDNESS	Between Groups	5932.196	2	2966.098	147.389	.001
	Within Groups	60.373	3	20.124		

	Total	5992.569	5			
SULPHATE	Between Groups	266.249	2	133.125	332811.500	.000
	Within Groups	.001	3	.000		
	Total	266.250	5			
IRON	Between Groups	.108	2	.054	162.600	.001
	Within Groups	.001	3	.000		
	Total	.109	5			
TOTAL BACTERIA	Between Groups	1176443333333333.200	2	588221666666666.600	.517	.641
	Within Groups	3414525000000000.000	3	1138175000000000.000		
	Total	4590968333333333.000	5			
TOTAL COLIFORM	Between Groups	7469903333333333.000	2	3734951666666666.500	.764	.539
	Within Groups	14668945000000000.000	3	4889648333333333.000		
	Total	22138848333333332.000	5			
KLEBSIELLA	Between Groups	.000	2	.000	.	.
	Within Groups	.000	3	.000		
	Total	.000	5			
e.coli	Between Groups	.000	2	.000	.	.
	Within Groups	.000	3	.000		
	Total	.000	5			

POST-HOC RESULT FOR URAMIRIUKWA RIVER WATER SAMPLE

Temp

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1
UPSTREAM	2	26.2500
MIDDLESTREAM	2	26.2500
DOWNSTREAM	2	26.2500
Sig.		1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TSS

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1
DOWNSTREAM	2	121.8500
UPSTREAM	2	152.8500
MIDDLESTREAM	2	157.1000
Sig.		.113

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

COLOUR

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
DOWNSTREAM	2	82.5000		
UPSTREAM	2		125.0000	
MIDDLESTREAM	2			155.0000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TURBIDITY

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
MIDDLESTREAM	2	24.6500		
DOWNSTREAM	2		33.5000	
UPSTREAM	2			53.5000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

pH

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2
DOWNSTREAM	2	7.0500	
UPSTREAM	2	7.2500	7.2500
MIDDLESTREAM	2		7.4000
Sig.		.139	.231

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

ALKALINITY

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2
DOWNSTREAM	2	5.5000	
UPSTREAM	2	7.0000	
MIDDLESTREAM	2		10.0000
Sig.		.199	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

DO

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
MIDDLESTREAM	2	12.8500		
DOWNSTREAM	2		13.1000	
UPSTREAM	2			14.6000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

BOD

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
UPSTREAM	2	1.3500		
MIDDLESTREAM	2		1.7000	
DOWNSTREAM	2			3.2500
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

COD

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
UPSTREAM	2	208.0000		
DOWNSTREAM	2		280.0000	
MIDDLESTREAM	2			472.0000
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

Acidity

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1
UPSTREAM	2	.2200
MIDDLESTREAM	2	.3000
DOWNSTREAM	2	.3000
Sig.		.067

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

NITRATE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
MIDDLESTREAM	2	25.5350		
DOWNSTREAM	2		28.0750	
UPSTREAM	2			31.6950
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

PHOSPHATE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
DOWNSTREAM	2	.4750		
MIDDLESTREAM	2		.5800	
UPSTREAM	2			.6750
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

CHLORIDE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2
DOWNSTREAM	2	25.9900	
UPSTREAM	2	29.9900	29.9900
MIDDLESTREAM	2		32.9900
Sig.		.116	.199

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

HARDNESS

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
UPSTREAM	2	85.4700		
MIDDLESTREAM	2		115.2550	
DOWNSTREAM	2			161.8750
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

SULPHATE

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2	3
UPSTREAM	2	1.6400		
MIDDLESTREAM	2		1.8400	
DOWNSTREAM	2			15.8700
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

IRON

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1	2
UPSTREAM	2	1.9800	
DOWNSTREAM	2		2.2600
MIDDLESTREAM	2		2.2700
Sig.		1.000	.622

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TOTAL BACTERIA

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1
MIDDLESTREAM	2	2950000.0000
UPSTREAM	2	25900000.0000
DOWNSTREAM	2	36500000.0000
Sig.		.391

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TOTAL COLIFORM

Duncan[a]

SAMPLE POINTS	N	Subset for alpha = 0.05 1
MIDDLESTREAM	2	5400000.0000
DOWNSTREAM	2	20650000.0000
UPSTREAM	2	86700000.0000
Sig.		.327

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

TEST FOR MEAN OF BOREHOLES AND URAMIRIUKWA RIVER WATER SAMPLES

t-Test: Two-Sample Assuming Unequal Variances

	Uramiriukwa River	*Borehole*
Mean	2827026.291	10476227
Variance	8.59593E+13	1.45E+15
Observations	21	21
Hypothesized Mean Difference	0	
df	22	
t Stat	-0.893025309	
P(T<=t) one-tail	0.190754268	
t Critical one-tail	1.717144374	
P(T<=t) two-tail	0.381508536	
t Critical two-tail	2.073873068	

t-Test: Two-Sample Assuming Equal Variances

	Uramiriukwa River	*Borehole*
Mean	2827026.291	10476227
Variance	8.59593E+13	1.45E+15
Observations	21	21
Pooled Variance	7.7036E+14	
Hypothesized Mean Difference	0	
df	40	
t Stat	-0.893025309	
P(T<=t) one-tail	0.188592526	
t Critical one-tail	1.683851013	
P(T<=t) two-tail	0.377185052	
t Critical two-tail	2.02107539	

WATER QUALITY INDEX CALCULATIONS

WATER QUALITY INDEX VALUE FOR THE MEAN BOREHOLE WATER PARAMETERS

Parameters	NESREA STD (sn)	1/sn	wn =k/sn	ideal value (vo)	mean conc. Value (vn)	vn/sn	vn/sn x 100=Qn	WnQn
DO	7.5	0.133333	0.078601	14.6	12.31	0.322	32.2	2.530949
pH	7.5	0.133333	0.078601	7	6.19	1.62	162	12.73335
e.coli	0	0	0	0	25000	0	0	0
BOD	15	0.066667	0.0393	0	6.48	0.432	43.2	1.69778
TEMP	30	0.033333	0.01965	0	30.74	1.024667	102.4666667	2.013493
PHOPHATE	5	0.2	0.117901	0	0.52	0.104	10.4	1.226174
NITRATE	50	0.02	0.01179	0	45.35	0.907	90.7	1.069365
TDS	500	0.002	0.001179	0	11.13	0.02226	2.226	0.002624
TUR	10	0.1	0.058951	0	4.9	0.49	49	2.888583
EC	1000	0.001	0.00059	0	17.13	0.01713	1.713	0.00101
ALKALINITY	150	0.006667	0.00393	0	7.38	0.0492	4.92	0.019336
IRON	1	1	0.589507	0	0.25	0.25	25	14.73767
$\sum {}^{1}/_{sn} = 1.696333$								**38.92033**
k=1/($\sum {}^{1}/_{sn}$) = 0.589507								
				$\sum wn = 1$				

WQI = $\sum qnWn / \sum wn$ = 38.92

WATER QUALITY INDEX VALUE FOR THE MEAN URAMIRIUKWA WATER PARAMETERS

Parameters	NESREA STD (sn)	1/sn	wn =k/sn	ideal value (vo)	mean conc. Value (vn)	vn/sn	vn/sn x 100=Qn	WnQn
DO	7.5	0.133333	0.078601	14.6	13.52	0.322	32.2	2.530949
pH	7.5	0.133333	0.078601	7	7.23	1.62	162	12.73335
e.coli	0	0	0	0	0	0	0	0
BOD	15	0.066667	0.0393	0	2.1	0.14	14	0.550206
TEMP	30	0.033333	0.01965	0	26.25	0.875	87.5	1.719395
PHOPHATE	5	0.2	0.117901	0	0.58	0.116	11.6	1.367656
NITRATE	50	0.02	0.01179	0	28.44	0.5688	56.88	0.670623
TDS	500	0.002	0.001179	0	7.37	0.01474	1.474	0.001738
TUR	10	0.1	0.058951	0	37.22	3.722	372.2	21.94144
EC	1000	0.001	0.00059	0	11.33	0.01133	1.133	0.000668
ALKALINITY	150	0.006667	0.00393	0	7.5	0.05	5	0.01965
IRON	1	1	0.589507	0	2.17	2.17	217	127.923
$\sum {}^{1}/_{sn} = 1.696333$								**169.46**
k=1/($\sum {}^{1}/_{sn}$) = 0.589507								
				$\sum wn = 1$				

WQI = $\sum qnWn / \sum wn$ = 169.46