PHYSICOCHEMICAL STUDIES OF BOREHOLE WATER IN ENUGU NORTH SENATORIAL DISTRICT, ENUGU STATE, NIGERIA.

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PHYSICOCHEMICAL STUDIES OF BOREHOLE WATER IN ENUGU NORTH SENATORIAL DISTRICT, ENUGU STATE, NIGERIA.

CERTIFICATION

This is to certify that NGANG, BENEDICT UGBOJI of the Department of Pure and Industrial Chemistry, Faculty of Physical Sciences, University of Nigeria Nsukka, with Reg. No. PG/MSc./13/65107 carried out this research project as part of the requirements for the award of Masters of Science (M.Sc.) Degree in Analytical Chemistry.

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External Examiner Date

DEDICATION

To every chemist inclined to seek for sustainable scientific solutions to challenges facing Africans and nations of the world;

To every citizen and organised group implementing useful national and international science policies;

To God who is the Supreme Intelligence.

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Finally, I will not hesitate to recognise that my academic success has been a tribute to my late mother's care during my childhood days.

Abstract

The groundwater quality indices of 12 randomly selected boreholes in Enugu North Senatorial District in Enugu State, south-east Nigeria have been studied. Using standard methods by American Public Health Association, American Water Works Association; World Environmental Federation (APHA-AWWA-WEF) and the Association of Official Analytical Chemists (AOAC), 22 physicochemical parameters were determined in triplicates at monthly intervals for three months in dry season and then repeated in rainy season. The parameters and the range of values obtained during dry season include: BOD_5(3.14–6.37 mg/L), COD(5.8–10.51 mg/L), temperature(29.0-31.9 ◦ C), phosphate(0.12-0.87 mg/L), nitrate(1.24-8.72 mg/L), sulphate(20.10-24.34 mg/L), pH(4.900-7.500), E.C(10.0–410.0 µS/cm), total acidity(0.06 – 1.24 mg/L), total alkalinity(28.0–22.10 mg/L), total hardness (100.0 – 140.1 mg/L), TSS(70.0–270.0 mg/L), TDS(0.00–210.0 mg/L), TS(70.0–390.0 mg/L), turbidity(3.4 –50.0 mg/L), Na(0.0–21.28 mg/L), K(0.0–12.03 mg/L), Cu(0.0–23.01 mg/L), Fe(0.0–11.03 mg/L), and Zn(0.01–3.00 mg/L). During rainy season, the parameters in the 12 samples revealed the following ranges: BOD_5(2.88 – 6.10 mg/L), COD(3.49–7.45 mg/L), temperature(29.0-31.9 ◦ C), phosphate(0.30–10.60 mg/L), nitrate(1.20–120.0 mg/L), sulphate(0.0–100.0 mg/L), pH(4.900-7.500), E.C(10.0-360.0 µS/cm), total acidity(0.10-10.5 mg/L), total alkalinity(10.0-52.1 mg/L), total hardness(100-130 mg/L), TSS(100.0-280.0 mg/L), TDS(0.0-260.0 mg/L), TS(110.0-560.0 mg/L), turbidity(3.80-56.0 mg/L), Na(0.0-21.28 mg/L), K(1.32-15.11 mg/L), Cu (0.03-28.37 mg/L), Fe(0.0-12.29 mg/L), and Zn(0.02-3.61 mg/L). The mean values of the parameters were compared with standard guideline values recommended by World Health Organisation (W.H.O.), Nigerian Standard for Drinking Water Quality (NSDWQ), National Agency for Food and Drug Administration and Control (NAFDAC) and the European Union (EU) for drinking water. Seasonal variations of the parameters in the samples were observed. The mean values of BOD_5 and temperature in all the samples were above the standard values. The rainy season nitrate values in some samples and phosphate mean values were higher than recommended values. There was a drop in pH during rainy season with the range generally acidic in both seasons. Turbidity in some samples was above the guideline value. A rainy season increase in total acidity (with a corresponding rainy season drop in total alkalinity), total hardness; sulphate and Zn values was observed. Cd and Pb were not detected in all the samples studied. The mean values of Cu and Fe increased in rainy season and were above the recommended guideline values in both seasons. K mean value increased in rainy season slightly above the standard guideline value. Recovery analyses were performed for the metals to validate the accuracy of the methods and instruments as well as the reliability of the results obtained. A two-way analysis of variance (ANOVA; using SPSS Windows Version 20) performed on the data obtained showed statistically significant variations between the 12 borehole water physicochemical parameters in dry season as well as in rainy season. Post hoc tests of multiple comparisons were conducted to specify the patterns of variability between the samples. An overall physicochemical Water Quality Index (WQI) for each borehole was computed and used in the groundwater rating. Levene's T3 test revealed no significance difference between the dry season overall physicochemical WQI and rainy season overall physicochemical WQI $t(18.67) = -1.27$, $p = .22$. Pearson correlation coefficient showed linear relationships in some of the physicochemical parameters studied.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Water is fundamental to life as well as nature. It is not just an important natural resource, it is also essential to all life forms. Its use and effects on life, environment, agriculture and industry are extensive so much so that they may never be exhausted. Starting with a few of the critical roles water performs in life for instance, one can say that water is one of the vital forces that drive life. This is evident in its critical functions in life producing (as well as furnishing) processes such as organic reactions in the body leading to cell replication and metabolism, respiration (in plants and animals) and photosynthesis in plants which provides the oxygen for animal respiration, including man. Also, water is a habitat for all aquatic life forms-plankton, amphibians, fish (most of which exclusively live in water), even some mammals like whales and dolphins (marine mammals). Since it is a basic requirement for plant photosynthesis, water is widely used for irrigation in agriculture.[1] Apart from its key role in biological (and biochemical) processes and agriculture, water finds its application in industry to be as central as it is in other spheres of life on earth. It is used in hydro-electric-power generation which is a renewable source of clean energy, food processing, fire extinguishing, transportation recreation (such as swimming), laundry and even chemical uses. It suffices to say that being a universal solvent [2]; and with its vast uses, one can say that water is an essential driver of global economy. It is said to be the most abundant chemical compound on the earth surface, covering about three quarters of the earth surface (the total volume of water on earth has been given as approximately 1,338,000,000 km^3). [3- 5]

Despite its abundance, only three percent of water (which exists as fresh water and partly as ponds, rivers and streams; most of which are trapped in glaciers and polar caps) is potable for human use and consumption since the other bulky 97 percent exists as ocean which is highly saline.

Naturally, water is a unique substance that can exist as solid, liquid and gas forms. [2] At standard temperature and pressure, water is liquid (density: 1,000 kg/m^3); it freezes into solid ice at 0^oc (density of 917 kg/m^3) and at sea level, it boils at 100^oc (specific heat capacity: 4181.3 $J/(kg \cdot K)$ and heat of vaporization: 40.65 $kJ \cdot mol^{-1}$). The maximum density of water occurs at 3.98 °C. [6] Its molecule is polar and composed of a single oxygen atom (^{16}O) and two hydrogen atoms (^{1}H and a little of ^{2}H depending on natural source) with an H-O-H bond angle of about 105^{0} [2].

It has been said that the human body needs between one to seven litres of water per day to avoid dehydration, [7] depending on factors such as humidity, temperature, body activity, [8] and so on. Pregnant and breastfeeding women need extra fluid to keep them hydrated. [9] Water meant for drinking should be safe by being free of contaminants. It is said to be polluted if foreign substances (oxygen demanding substances, diseases causing agents, inorganic chemicals, synthetic organic chemicals such as pesticides and industrial wastes, sediments from land erosion, radioactive wastes or energy such as waste heat) are present in such a degree that it can not be used for a specified purpose. [2] Sources of these pollutants have been classified as resulting from Municipal waste (or domestic effluents), agricultural discharge, and mining and industry. [3] It is thus imperative to check the various sources of water supply for drinking and domestic purposes so as to analyse for their purity.

Natural sources of water include rain-water, surface water (streams, rivers, sea, etc) and groundwater. Water supply facilities include water purification facilities, water tanks, water towers, water pipes including old aqueducts, water wells, cisterns for rainwater harvesting, water supply networks, etc. Borehole water, (which is obtained from ground source) is one of the common sources of water for drinking and other domestic and industrial purposes around the world.

In Nigeria, there are laws governing the use of water resources. These are contained in the Constitution of the Federal Republic of Nigeria 1999 as "Nigerian Laws Governing the water sector. They include among others: The Water Resources Act 1993, The National Water Resource Institute Act, River Basins Development Authorities Act, National Inland Waterways Authority Act, The Various State Water Board Acts, The National Resources Conservation Council Act, etc. For instance, the "Water Resources Act 101 of 1993" vests on the Federal Government of Nigeria through the Federal Ministry of Water Resources, the rights to regulate, develop, and license all water operators in Nigeria. This includes planning, development, and usage of Nigeria's water resources, ensuring quality, quantity, distribution, use and management of water, ensuring application of appropriate standards and techniques for investigation, use control, protection, management and administration of water resources, facilitating technical assistance and rehabilitation for water supplies etc. [10] It is therefore important to constantly investigate the quality of water from various sources around us as this will serve as a contribution towards national development.

1.2 Drinking Water Quality

The characteristic of water supply that will influence its suitability for a specific use is referred to as water quality. Quality is defined by certain physical, chemical and biological characteristics. These characteristics provide the basic

parameters for the analysis of water for various purposes. In Nigeria and other parts of the world, these parameters provide a basic framework for references to be made to globally approved standards. Stakeholders in the water sector and outside the country have reached a consensus on the parameters and standard for water quality (including drinking water and water for agricultural and industrial purposes). For example, the Nigerian Standard for Drinking Water Quality (NSDWQ) established in 2007 was developed with reference to World Health Organisation (WHO) guidelines for drinking water quality (3rd Edition), Nigeria Industrial Standard for Potable Water and Natural Mineral Water and the National Guidelines and standards for Water Quality in Nigeria. NSDWQ which was approved by the Standards Organisation of Nigeria (SON) subdivided the parameters for determining water quality into physical/organoleptic, chemical organic and inorganic constituents, disinfectants and disinfectant by-products, radionuclide and microbial parameters. [11] These parameters and their allowable limits (maximum permitted limits) are tabulated below:

1.2.1 Parameters and Maximum Allowable Limits

Table 1.1 Physical / Organoleptic Parameters

Parameter	Unit	Maximum Permitted Levels	Health Impact
Colour	TCU	15	None
Odour	-	Unobjectionable	None
Taste	-	Unobjectionable	None
Temperature	0^{o}Celsius	Ambient	None
Turbidity	NTU	5	None

1.2.2 Chemical Parameters

Table 1.2 - Inorganic Constituents

Parameter	**Unit**	**Maximum Permitted**	**Health Impact**	**Notes**
Aluminium (Al)	mg/L	0.2	Potential Neuro-degenerative disorders	Note 1
Arsenic (As)	mg/L	0.01	Cancer,	

Barium	mg/L	0.7	Hypertension	
Cadmium (Cd)	mg/L	0.003	Toxic to the kidney	
Chloride (Cl)	mg/L	250	None	
Chromium (Cr^{6+})	mg/L	0.05	Cancer	
Conductivity	µS/cm	1000	None	
Copper (Cu^{2+})	mg/L	1	Gastrointestinal disorder,	
Cyanide (CN^-)	mg/L	0.01	Very toxic to the thyroid and the nervous system	
Fluoride (F^-)	mg/L	1.5	Fluorosis, Skeletal tissue (bones and teeth) morbidity	
Hardness (as $CaCO_3$)	mg/L	150	None	
Hydrogen Sulphide (H_2S)	mg/L	0.05	None	
Iron (Fe^{2+})	mg/L	0.3	None	
Lead (Pb^{2+})	mg/L	0.01	Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems	
Magnesium (Mg^{2+})	mg/L	0.20	Consumer acceptability	
Manganese (Mn^{2+})	mg/L	0.2	Neurological disorder	
Mercury (Hg^+)	mg/L	0.001	Affects the kidney and central nervous system	
Nickel (Ni)	mg/L	0.02	Possible carcinogenic	
Nitrate (NO_3^-)	mg/L	50	Cyanosis, and asphyxia („blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months	
Nitrite (NO_2^-)	mg/L	0.2	Cyanosis, and asphyxia ('blue-baby syndrome') in infants under 3 months	
pH	-	6.5-8.5	None	
Sodium (Na^+)	mg/L	200	None	
Sulphate (SO_4^{2-})	mg/L	100	None	
Total Dissolved Solids	mg/L	500	None	
Zinc (Zn)	mg/L	3	None	

Table 1.3 Organic Constituents

Parameter	**Unit**	**Maximum Permitted Levels**	**Health Impact**
Detergents	mg/L	0.01	Possibly carcinogenic
Mineral oil	mg/L	0.003	Possibly carcinogenic

Pesticides	mg/L	0.01	Possibly carcinogenic
Phenols	mg/L	0.001	Possibly carcinogenic
Poly Aromatic Hydrocarbons	mg/L	0.007	Possibly carcinogenic
Total Organic Carbon or Oxidisability	mg/L	5	Cancer

1.2.3. Disinfectants and their By-products

Table 1.4 Disinfectants and their by-products

Parameter	**Unit**	**Maximum Permitted Levels**	**Health Impact**	**Note**
Free residual chlorine	mg/L	0.2 - 0.25	None	Note 2
Trihalomethanes Total	mg/L	0.001	Cancer	Note 2
2,4,6-trichlorophenol	mg/L	0.02	Cancer	Note 2

Note 2: For chlorinated water only.

Drinking water providers shall increase the amount of residual chlorine during epidemics or special cases according to instructions of Ministry of Health.

1.2.4 Radioactive Constituents

The presence of the following contaminants shall not exceed limits specified in Table 1.5.

Table 1.5 - Radioactive Limits

Parameter	**Unit**	**Maximum Permitted Levels**	**Health Impact**	**Notes**
Radionuclides	Bq/L	0.1	Cancer	

1.2.5. Microbiological Requirements

Table 1.6 Microbiological Limits

Parameter	Unit	Maximum Permitted Levels	Health Impact
Total Coliform count	cfu/mL	10	Indication of faecal contamination
Thermo tolerant Coliform or *E.coli*	cfu/100 mL	0	Urinary track infections, bacteraemia, meningitis, diarrhea, (one of the main cause of morbidity and mortality among children), acute renal failure and haemolytic anaemia
Faecal streptococcus	cfu/100 mL	0	Indication of recent faecal contamination
Clostridium perfringens spore	cfu/100 mL	0	Index of intermittent faecal contamination

SOURCE: Nigerian Standard for Drinking Water approved by Standard Organisation of Nigeria, 2007.

Over a billion people worldwide do not have access to safe water [2] and some of the problems facing the Nigerian water sector include poor water quality due to pollution and sanitation issues. [3] The Federal Government of Nigeria through the Millennium Development Goals (MDGs) Programme is partnering with State Ministry of Water Resources, e.g. the Enugu State Rural Water and Sanitation Agency (ENRUWSA) as well as other organisations such as the United Nations International Children Emergency Fund (UNICEF), in finding lasting solutions to the menace of safe water scarcity. Through this partnership, borehole water schemes are being carried out in different parts of the country. For instance in Nsukka, the electro-mechanical systems of the urban water boreholes have been rehabilitated and one new borehole has been drilled along Enugu Road, Nsukka. Enugu State government is committed to water and environmental sanitation to such a degree as to compel companies producing toxic waste water to mount plants that will treat their waste water. A United Nations (UN) report observed that water-borne diseases are endemic in certain parts of Africa's most populous country (Nigeria) [4] but UNICEF

emphasizes that the occurrence of diarrhoea, a major childhood killer in Nigeria, could decline by 15 percent if water quality was improved. It is pertinent therefore to conduct research in the water sector to provide data on the quality of water in parts of the state.

1.3. STATEMENT OF PROBLEMS

- In the bid to meet the water demand of the ever-growing population in Enugu North Senatorial District and its environs, efforts without substantial impact have been made by individuals, governments, and corporate bodies towards supply of potable water for the masses. Some of these efforts include the construction of borehole water supply systems (whose purity is seldom taken serious [4]) in communities and urban towns (and as such close to anthropogenic contamination source).
- Many people within the urban towns and rural communities in Enugu North Senatorial District still suffer from lack of stable potable water supply.
- In 2006, United Nations report stated that "there is enough water for everyone[4] unfortunately, only a few have access to good quality water.
- It has been estimated that by 2025 more than half of the world population will be facing water-based vulnerability. [3]

1.4 SIGNIFICANCE OF THE STUDY

The significance of this study includes provision of:

- Baseline information on borehole water quality for Enugu North Senatorial District catchment area.
- A framework to assess the on-going study of vulnerability of borehole water supply in Enugu State to contamination and the major operational or infrastructure problems that may make future contamination likely. This will

help to enhance substantial impact in efforts made towards supply of potable water to the ever-growing population in Enugu State.

- A reference for future planning, assessment and monitoring of progress made in the water sector in Nigeria.
- More insight into the existing water safety parameters with the view to facilitate disease surveillance due to possible water toxins. This will help to reduce the number of people dying of water related diseases as more than 25,000 people are said to die daily due to water related diseases.[6]
- Supportive information towards the ongoing Environment Impact Assessment (EIA) with the view to reducing indiscriminate contamination of natural waters.

1. 5 OBJECTIVES OF THE STUDY

- The general purpose of this study is to assess the quality of borehole water in Enugu North Senatorial District, Enugu State, Nigeria. To achieve this aim, the objectives of the study shall be to:
- Determine twenty-two physicochemical parameters in water samples collected from twelve boreholes selected from the seven Local Government Areas (LGAs) in the study area in dry season and rainy season.
- Compare the results obtained with the World Health Organisation (WHO) standard for potable water and/or Nigerian Standard for Drinking Water quality (NSDWQ).
- Establish the comparative ground water qualities of various towns and communities in the study area.
- Measure the strength of association of the water quality parameters.
- Make necessary recommendations based on the findings of the research.

1.6 SCOPE OF STUDY

- Borehole water samples collected from twelve different towns/communities covering seven LGAs in Enugu North Senatorial District at different times during the research period.
- A total of twenty-two physicochemical parameters determined in the samples based on the specific objectives of this study. These parameters were carefully selected to cover the following:

► General degree of water pollution,

► Pollution due to agricultural/fertilizer inputs,

► Parameters due to soil types and geological differences,

► Heavy Metals: possible inputs from water sources especially waste-water percolation from industrial processes.

CHAPTER TWO

2.0 LITERATURE REVIEW

Qualitative and quantitative measurements are needed from time to time to constantly monitor the quality of water from the various sources of supply. This is because water may contain some elements (all mineral elements, whether considered to be essential or potentially toxic, can have an adverse effect upon the humans and animals if consumed at excessively high concentrations) [12]. Studies have shown that approximately 3.1% of deaths (1.7 million) and 3.7% of 'Disability-Adjusted-Life-Years' (DALYs) (54.2 million) worldwide are attributable to unsafe water, poor sanitation and hygiene. [13]. There is an increasing recognition that the provision of quality water is central to any meaningful human development. [14]. Water is the most important of all public services. It is the most essential necessity of life after oxygen. Anything that disturbs the provision and supply of water therefore tends to disturb the very survival of humanity. The challenges facing many countries in the world today in their struggle for economic and social development is increasingly related to water. One of the international goals set for the year 2015 in the United Nations Millennium Declaration and in the plan of implementation of the world summit on sustainable development is reducing the proportion of people without adequate access to water and basic sanitation by one-half. While access to sufficient and clean drinking water may be taken for granted in the developed world, problems with access are most severe in the developing world, where more than 5 million people perish every year from water-related diseases, and more than 1 billion people suffer without access to water for their basic needs. [15]

Africa has the lowest water supply and sanitation coverage of any region in the world. More than 30% of Africans residing in urban areas currently lack access to adequate water services and facilities. In the year 2000, World Health Organisation (WHO) estimated that Africa contains 28% of the world's population without access to improved water supplies, and 13% of the world's population without access to improved sanitation. Only 62% of the people in African countries have access to improved water supplies, and only 60% have access to improved sanitation. [13]

The Water Utility Partnership, an organisation that deals with capacity building of water supply and sanitation utilities in Africa, has noted that: "public water services in many African countries have been assigned to a single water authority and the abilities of governments to deliver water adequately have been negatively affected by a number of factors. Thus urban water systems are characterised by heavy losses both financially and of water itself. Africa is also noted as urbanizing more than any other region in the world. Between 1995 and 2005, the urban population was expected to grow from 300 to 700 million and by 2020 it is expected that over 50% of the population in African countries will reside in urban areas". [13]

Borehole water (which is a form of underground water source) has become a popular alternative to other major sources of water supply for domestic and private use. It serves as a modern equivalent to the century old well water. A single borehole is reported to have over forty times the water capacity that an average home would need (500–600 litres of water a day) [14]. Borehole water contamination may arise from pollutants entering the water table some distance from the port or from sewage entering the borehole itself in the port area through cracked or corroded casings.

Boreholes are more susceptible to contamination. This is particularly widespread and acute in the developing world where unchecked industrial growth, lack of monitoring facilities and failure to enforce environmental regulations add to the severity of the situation [15].

2.1 Borehole and Ground Water Quality

"A borehole is simply a deep narrow well usually driven by an electric pump that taps into the underground stores of water held in permeable rock known as aquifers." [16] Groundwater is defined as subsurface water that occurs beneath the water table and flows through voids in soils and permeable geologic formations that are fully saturated. [17-18] In other words groundwater is found under the ground in soil or rocks and the use of borehole is a method of collecting groundwater. Below is a picture of a typical borehole.

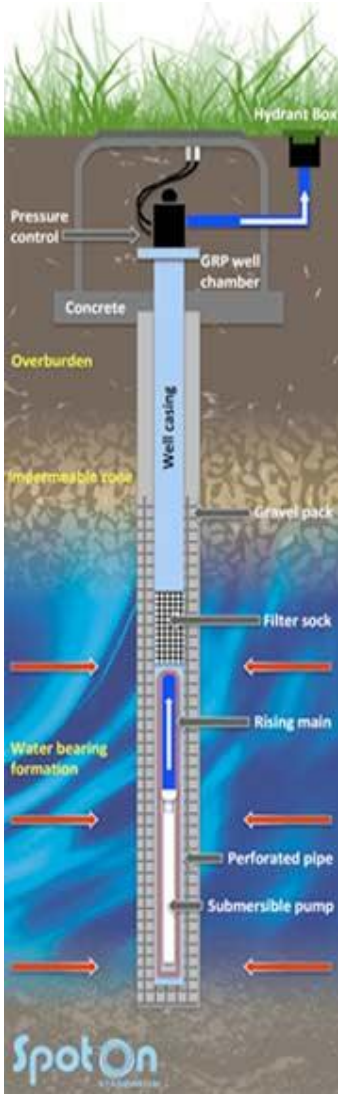

Fig. 2.1a: Typical Borehole (underground feature).

Fig. 2.1b: Typical Borehole (underground feature).

Source: www.spotonstandards.com (accessed on 9th May, 2014).

According to the Guidelines issued by the National Agency for Food and Drug Administration and Control (NAFDAC) in 1999, "the depth of the drilled borehole must be below the sea level and it should be equipped with a submersible pump. The borehole must be suitably positioned topographically from the septic tank and there must be a good distance (e.g. 30 meters) separating the two of them. The minimum depth of the borehole should be 150 ft (45.72 meters). Well water and deep water having depth lower than that specified for borehole are not acceptable as potable water. This is because in most Nigerian cities, the general mode of disposal of sewage is by the use of cesspools, septic tanks and pit latrines. Except for very few factories now, there are no sewer and modern sewage treatment plants. Consequently, ground water is polluted to a high degree by seepage from various sources (i.e. sewage ponds, refuse dumps, leaching of fertilizers, pesticides from agriculture, detergent, radioactive wastages, etc)." [19]

NAFDAC also adopted the approved World Health Organisation (WHO) Standards for potable water and stressed that "potable water must be free from chemical substances and micro-organisms in amounts that could be hazardous to health. It must be organoleptically acceptable and aesthetically attractive. It is expected to meet the World Health organization (WHO) standards" [19] shown in Table 2.2 below:

Table 2.1 W.H.O. STANDARD FOR DRINKING WATER [19]

Physical/Chemical Specification

Test	Specification
1. General Appearance	Clear
2. Colour	5 Hazen units
3. Odour	Odourless
4. pH	6.5-8.5
5. Total Hardness	500 mg/L
6. Calcium carbonate	100 mg/L
7. Total dissolved solid	50 mg/L dried at 180^0C
8. Chlorine (Cl)	75 mg/L
9. Residual Chlorine	200 mg/L- 600 mg/L
10. Magnesium (Mg)	30 mg/L -150 mg/L
11. Manganese (Mn)	0.05 mg/L
12. Iron (Fe)	0.03 mg/L
13. Sulphate	200 mg/L – 400 mg/L
14. Lead (Pb)	0.05 mg/L
15. Fluorides (F)	0.05 mg/L
16. Arsenic (As)	0.01 mg/L
17. Cyanides (CN)	should not be detectable by Analysis
18. Copper (Cu)	0.05 mg/L
19. Zinc (Zn)	5.0 mg/L
20. Mercury (Hg)	0.001 mg/L
21. Chromium (Cr)	0.05 mg/L
22. Cadmium (Cd)	0.01 mg/L
23. Selenium (Se)	0.01 mg/L
24. Radionuclide	1000 uC/L (gross beta 1.0 mg/L activity) 45 mg/L.
25. Barium (Ba)	0.7 mg/L
26. Nitrates.	50 mg/L

The above Standard Guidelines can be used to assess the quality of water from various sources meant for drinking and other domestic uses. The parameters are indicators of the quality of water since the later is defined by certain allowable maximum limits of the former. The Standard Organisation of Nigeria (SON) advices that the following set of simple parameters indicators of quality of drinking water should be controlled on regular basis. SON referred to these parameters as "**Minimum Parameters for Monitoring":**

Table 2.2. Routine Monitoring Parameters

Parameters	**Notes**
Taste	
Odour	
Colour	
Turbidity	
pH	
Conductivity	
Iron	
Nitrates	
Aluminium	Note 1
Residual chlorine	Note 2
E. coli	Note 3

Note 1: Parameters subject to monitoring water treated using aluminium compound

Note 2: Parameters subject to monitoring water treated using chlorine compound

Note 3: 95% compliance over a one-year period. [11]

2.2 Comparison of various Standards for Water Quality Parameters:

In a study on "Water Quality in International River Basin" it was observed that there are no universally recognised and acceptable international standards for drinking water. [20] Different countries specify standards to be applied in their own

country and the concentration of individual constituents may vary from one set of standard to another.

Below is a selection of some parameters for concentration listed by W.H.O, European Union (EU) and the United State Environmental Protection Agency (EPA).

Table 2.3 Comparison of some parametric values of international water quality standards:

Parameter	W.H.O.	EU	UNITED STATES EPA
Arsenic	10 µg/L	10 µg/L	10 µg/L
Antimony	no standard	5.0 µg/L	6.0 µg/L
Barium	700 µg/L	no standard	2 mg/L
Benzene	10 µg/L	1.0 µg/L	5 µg/L
Cadmium	3 µg/L	5 µg/L	5 µg/L
Chromium	50 µg/L	50 µg/L	0.1 mg/L
Cyanide	should not be detected	50 µg/L	0.2 mg/L
Fluoride	1.5 mg/L	1.5 mg/L	4 mg/L
Lead	0.05 mg/L	10 µg/L	15 µg/L
Nitrate	50 mg/L	50 mg/L	10 mg/L (as N)
Selenium	40 µg/L	10 µg/L	50 µg/L

Drinking water quality standards have been developed for various countries, including Nigeria. The standards are often presented as guidelines containing parametric values as shown above. A parametric value, which is usually specific, may be the concentration of a substance or a statistical value such as the average concentration, e.g. 0.2 mg/L of cyanide or it may be a count (e.g. 100 E. coli per litre).

2.3 Indicators of Water Quality: An Overview.

Indicators of Water quality are parameters whose levels in water indicate water quality. They include physicochemical parameters such as total dissolved solids (TDS), taste, colour, odour, temperature, hardness, pH, conductivity, alkalinity, turbidity and some nutrient contaminants such as chlorides, sulphates, phosphates,

nitrites, nitrates as well as heavy metals. Okoye (2005) listed the following characteristics of water quality: pH, salinity, alkalinity, hardness, organic matter, and some anions including nitrate, phosphate, silicate and sulphate; and outlined the guidelines and techniques for their analyses in accordance with the American Public Health Association/American Water Works Association/Water Pollution Control Federation (APHA-AWWA-WPCF). The methods include:

► Determination of pH using pH meter, salinity and conductivity using conductometer.

► Determination of alkalinity by titrating the water 0.02M HCl using bromocresol green, methyl red indicator since alkalinity is due to the presence of bicarbonate and carbonate ions.

► Determination of hardness (as calcium and magnesium) using EDTA titration.

► Determination of organic matter by digesting the water sample overnight with 1/60M chromic acid and back titrating with 0.1M Fe(II) solution using diphenyl amine indicator.

► Using colorimetric reagents to determine nitrates, phosphates and silicates. The methods listed are as follows:

Phenoldisulphonic method for nitrate.

Molybdenum blue method for phosphates

Molybdosilicate method for silicate and

Turbidimetry using $Ba(NO_3)_2$ as precipitant for sulphate.

It is further stated that the colorimetric and turbidimetric methods require calibration graphs plotted with standard solutions after the appropriate chemical treatment. [21]

Agbazue and Akpanisi (2012) tabulated physicochemical parameters and indicated the suitable methods of analysis for each of them as follows: [2]

Table 2.4a. Some water quality parameters and their various methods of analysis.

S/N	PARAMETERS	METHODOLOGY
A.	**Physicochemical analysis**	
1.	pH	Potentiometric Method
2.	Total Dissolved and Suspended Solids (TDS & TSS)	Gravimetric Method
3.	Hardness	Titrimetric Method
4.	Alkalinity	Titrimetric Method
5.	Acidity	Titrimetric Method
6.	Dissolved Oxygen	Titrimetric Method
7.	Biological Oxygen Demand(BOD)	Titrimetric Method
8.	Sulphate	Turbidimetric Method
9.	Chloride	Argentometric Method
10.	Oil and Grease	Extraction
11.	Detergent	Methylene-blue
12.	Sulphide	Colorimetric Method
13.	Phosphate	Colorimetric Method
14.	Chlorine	Colorimetric Method
15.	Nitrogen (NH_3 & NO_3)	Colorimetric Method
16.	Cyanide	Colorimetric Method
17.	Phenol	Colorimetric Method
18.	Metals	Colorimetric Method
B.	**Microbiological Analysis**	
19.	Total coliforms	Lactose Fermentation Technique.

Amankona (2010) on groundwater quality indicators made the following submission of related literature:

2.3.1 Taste and Odour

Generally individuals have a more acute sense of smell than taste. Taste problems in water comes from total dissolved solids (TDS) and the presence of metals

such as iron, copper, manganese or zinc. Manganese chloride and magnesium bicarbonate are significant in terms of taste. Fluoride may also cause a significant change in taste.

Taste and odour problems of many different types can be encountered in drinking water. Troublesome compounds may result from biological growth or individual activities. Taste and odour may be produced in the water supply, in the water treatment plant from reactions with treatment chemicals, in the distribution system and or in the plumbing of consumers. Taste and odour can be caused by mineral contaminants in the water, such as salty taste of water when chlorides are 500 mg/L or above. Decaying vegetation is probably the most common cause for taste and odour in surface water supplies. In treated water supplies, chlorine can react with organics and cause taste and odour problems. [22] They may also originate from organics and in-organics present in municipal and industrial waste discharges and natural waters. [23] The measurement of taste and odour is somewhat subjective and may depend on the personal judgements of individuals. This is because the two sense modes differ in the nature and location of the receptor nerve sites: primarily on the tongue for taste and high in the nasal cavity for odour. [24]

2.3.2 Heavy metals

Heavy metals have been defined as one of the common transition metals, such as zinc, lead and copper. [25] They are natural components of the Earth's crust. [26] They cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air. Heavy metals (e.g. copper, selenium, zinc; lead) are essential to maintain the metabolism of the human body. According to Lane and Morel (2009), living organisms require varying amount of some metals such as zinc, molybdenum, manganese, iron, copper and cobalt. [27] However, at higher concentrations they can

lead to poisoning. Human activities are said to have drastically altered the geochemical cycles and biochemical balance of heavy metals. [26]

Heavy metals are dangerous because they tend to bioaccumulate. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. Prolong exposure of humans to heavy metals such as zinc, nickel, lead, copper and cadmium can lead to harmful health effects. [26]

Heavy metals can enter the water supply system through industrial and consumer waste, or even from acid rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater.

2.3.3 Analysis of metals

Total metals include all metals, inorganic or organically bounded, both dissolved and particulate. Analyses for metals involve digestion of the samples without preliminary filtration. Nitric acids adequately digest many metals. Nitrate is an acceptable matrix for flame and electro thermal atomic absorption. Some samples may require the addition of perchloric acids for complete digestion [26].

2.3.4 Iron

Chemical Symbol or Formula: Fe.

Units Used for Analytical Results: mg/L Fe.

Normal Method(s) of Analysis: Colorimetric (o-PhenanthroIine); Atomic Absorption Spectrometry. [22]

Iron is one of the most troublesome elements in water supplies. Making up at least 5 % of the earths crust, Iron is one of the earth’s most plentiful resources. Rainwater as

it infiltrates the soil and underlying geological formations dissolves iron causing it to seep into the aquifer that serves as source of ground water for bore holes. Although present in drinking water, iron is seldom found at concentrations greater than 10 milligrams per litre or 10 parts per million. However as little as 0.3mg/l can cause water to turn reddish brown in colour.

Iron is mainly present in water in two forms either the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colourless because the iron is completely dissolved. When exposed to air in the pressure tank or atmosphere the water turns cloudy and a reddish brown substance begins to form. This sediment is the oxidized or ferric form of the iron that will not dissolve in water. Iron is not hazardous to health but it is considered a secondary or aesthetic contaminant. Essential for good health, iron helps transport of oxygen in the blood. Concentrations of iron as low as 0.3 mg/L will leave reddish brown stains on fixtures, tableware and laundry that is very hard to remove. When these deposits break loose, from water piping, rusty water will flow through the faucet. [25]

Since iron combines with different naturally occurring organic materials, it may also exist as an organic complex. The combination of naturally occurring organic materials and iron can be found in shallow wells and surface water. This type of iron is usually yellow or brown but may be colourless. [25-30]

Recommended limits of iron in water as provided by the Environmental Protection Agency in 2001 is shown below:

Table 2.4b Iron: Recommended or Mandatory Limit Values [32]

EU Directive or National [Ministerial] Regulations		Units of Analysis	G Values	I/PV Value	Notes
Surface Water Regulations [1989]	A1 waters A2 waters A3 waters	mg/L Fe mg/L Fe mg/L Fe	n/a n/a n/a	0.2 2.0 2.0	[1,2] [1,2] [1,2]
Drinking Water Directive [98/83/EC]		mg/L Fe	n/a	200	[3]

Notes

[1] Parameter is described as "Dissolved iron."

[2] Departure may be granted by the Minister "in the case of surface water in shallow lakes or virtually stagnant surface water."

[3] Parameter is described as "Iron."

EPA (2001) also commented that iron is quite harmful to aquatic life, as evidenced by laboratory studies, but in nature the degree of toxicity may be lessened by the interaction of the iron with other constituents of water. Should the metal be converted to an insoluble form then the iron deposits will interfere with fish food and with spawning. Iron is said to be present in significant amounts in soils and rocks, principally in insoluble forms. However, many complex reactions which occur naturally in ground formations can give rise to more soluble forms of iron which will therefore be present in water passing through such formations. Appreciable amounts of iron may therefore be present in ground waters. Severe problems can be caused in drinking water supplies by the presence of iron although there is normally no harmful effect on persons consuming waters with significant amounts of iron. Rather, the problems are primarily aesthetic, as the soluble (reduced) ferrous (Fe^{2+}) iron is oxidised in air to the insoluble ferric (Fe^{3+}) form, resulting in colour or turbidity (or, in severe cases, precipitate formation). Laundry becomes stained if washed in water with excessive iron, and vegetables likewise become discoloured on cooking. Taste

problems may also occur. When waters rich in iron are used to make tea (in which tannins are present) there may be a reaction giving rise to off-colour which may in severe cases resemble that of ink. [31-36]

2.3.5 Copper

Chemical Symbol or Formula: Cu.

Units Used for Analytical Results: mg/L Cu.

Normal Method(s) of Analysis: Atomic Absorption Spectrometry. [36]

Copper is an essential substance to human life, but in high doses it can cause anaemia, liver and kidney damage and stomach and intestinal irritation. People with Wilson's disease are at greater risk for health effects from over exposure to copper. Copper normally occurs in drinking water from copper pipes, as well as from additives designed to control algal growth. Copper exhibits some harmful effects and because drinking water may be significant route of exposure to copper, it is important to know how much copper is in drinking water. A metallic taste is usually found in drinking water before copper levels are high enough to create adverse effect. Blue or blue green stains around sinks and plumbing fixtures are also noticed.

On the average, drinking water accounts for less than 5% of our daily copper intake. The United States Environmental Protection Agency (USEPA) has determined that copper levels in drinking water should not exceed 1300 μg/L. No adverse health effects would be expected if this level is not exceeded. Measures should be taken to reduce exposure to copper if this level is exceeded. Copper rarely occurs naturally in water. Most copper contamination in drinking water happens in the water delivery system as a result of corrosion of copper pipes or fittings. Copper piping and fittings are widely used in household plumbing.

The physical and chemical characteristics of water vary; the corrosive properties vary as well. Factors causing corrosion include acidity (low pH) high temperature, low total dissolved solids (TDS) content and high amount of dissolved oxygen or carbon dioxide. Generally naturally soft water is more corrosive than hard water because it is more acidic and has low TDS. Observations have shown increased copper levels in water softened with ion exchange water softener. If the water is not corrosive, hard water minerals are deposited on calcium carbonate lining inside pipes and fittings which protects it against copper contamination. However, it may take up to five years for an effective calcium carbonate lining to form and softening hard water with an ion exchange unit can either prevent or dissolve the calcium carbonate scale reducing or eliminating its protective effect.

The easiest and most effective method for reducing exposure to copper is to avoid drinking or cooking with water that has been in contact with house plumbing works for more than six hours. If an elevated level of copper in drinking water is observed it may be likely that lead levels are also elevated. This is especially true if the plumbing system contains lead solder joints. Since lead and copper enter drinking water under similar conditions, it is advisable to test for lead when testing for copper levels.

2.3.6 Lead

Chemical Symbol or Formula: Pb.

Units Used for Analytical Results: mg/L Pb.

Normal Method(s) of Analysis: Atomic Absorption Spectrometry. [36]

EPA (2001) states that lead is one of the most commonly determined heavy metals. This is because it accumulates in body tissue it follows that strict limits on its presence in raw and finished drinking waters must be imposed. Particular attention is

paid to this element as in many older houses extensive use is made of lead piping and there is a danger of lead being brought into solution ("plumbosolvency"). Levels may be quite marked in samples taken first thing in the morning when the initial yield will be of water which has been standing in such pipes for perhaps twelve hours. Hence the recommendation that drinking water pipes be flushed briefly in the morning before the water is consumed. The comments accompanying the standard in the Drinking Water Regulations reflect the fact that some waters which are in prolonged contact with old lead pipes are liable to dissolve possibly significant amounts of the metal. [36]

Amankona (2010) discusses that lead found in fresh water usually indicates contamination from metallurgical waste or from lead-containing industrial poisons. [34] Lead in drinking water is primarily from the corrosion of the lead used to put together the copper piping. Lead in the body can cause serious damage to the brain, kidneys, nervous system and red blood cells. Except in related cases lead is probably not a major problem in drinking water although they potentially exist in cases where old lead pipes is still used. Lead can be reduced considerably with a water softener activated carbon; filtration can also reduce lead to a certain extent. Reverse osmosis can remove 94 to 98% of the lead in drinking water at the point-of –use [34].

2.3.7 Effects of Lead on the environment

In humans, exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. High levels of exposure may result in toxic biochemical effects in humans which in turn cause problems in the synthesis of haemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system. Lead poisoning, which is so severe as to cause evident illness, is now very rare indeed. At intermediate

concentrations, however, there is persuasive evidence that lead can have small, subtle, sub-clinical effects particularly on neuropsychological developments in children. Some studies suggest that there may be a loss of up to 2 IQ points for a rise in blood lead levels from 10 to 20µg/dl in young children.

Average daily lead intake for adults in the United Kingdom (UK) is estimated at 1.6 µg from air, 20µg from drinking water and 28µg from food. Although most people receive the bulk of their lead intake from food, in specific populations other sources may be more important, such as water in areas with lead piping and plumb solvent in water, air near point of source emissions, soil, dust, paint flakes in old houses or contaminated land. Lead in the air contributes to lead levels in food through deposition of dust and rain containing the metal, on crops and the soil. For the majority of people in the UK however, dietary lead exposure is well below the provisional tolerable weekly intake recommended by the Unite Nations Food and Agriculture Organisation (UNFAO) and the World Health Organisation (WHO). Lead in the environment arises from both natural and anthropogenic sources. Exposure can occur through drinking water, food, air, soil and dust from old paint containing lead. In the general non-smoking adult population, the major exposure pathway is from food and water. Food, air, water and dust/soil are the major potential exposure pathways for infants and young children. For infants up to 4 or 5 months of age, air, milk formulae and water are the significant sources. Lead is among the most recycled non-ferrous metals and its secondary production has therefore grown steadily in spite of declining lead prices. Its physical and chemical properties are applied in the manufacturing, construction and chemical industries. It is easily shaped and is malleable and ductile. There are eight broad categories of use: batteries, petrol

additives (no longer allowed in the European Union), rolled and extruded products, alloys, pigments and compounds, cable sheathing, shot and ammunition. [35, 37-40]

In the EU as a whole, there is heightened concern about lead in drinking water, as is shown in the notes below pertaining to Drinking Water Directive Shown in Table 2.5. [36]

Table 2.5. Lead: Recommended or Mandatory Limit Values [32]

EU Directive or National [Ministerial] Regulations		Units of Analysis	G Value	I/PV Value	Notes
Surface Water Regulations [1989]	A1 waters A2 waters A3 waters	mg/L Fe mg/L Fe mg/L Fe	n/a n/a n/a	0.05 0.05 0.05	
Bathing Water Regulations [1989-1998]		mg/L Pb	-	-	[1]
Dangerous Substances Directive [76/464/EEC]			List II substance	List II substance	
Shellfish Directive [79/923/EEC]		Mg/L Pb	[2]	[3]	
Ground Water Directive [80/68/EEC]			List II substance	List II substance	
Drinking Water Directive [98/83/EC]		µg/L Pb	n/a	10	[4,5]

Explanatory Notes on Table 2.5

[1] Sampling to be carried out "where an investigation shows, or there are other grounds for believing, that there has been deterioration in the quality of waters"

[2] "The concentration of [this] substance in shellfish flesh must be so limited that it contributes, in accordance with Article 1 [of the Directive], to the high quality of shellfish products."

[3] "The concentration of [this] substance in the shellfish, water or in the shellfish flesh must not exceed a level which gives rise to harmful effects on the shellfish and their larvae. The synergic effects of [this and
other specified] metals must be taken into consideration."

[4] The value applies to a sample of water intended for human consumption obtained by an adequate sampling method at the tap and taken so as to be representative of a weekly average value ingested by consumers. Where appropriate the sampling and monitoring methods must be applied in a harmonised fashion to be drawn up in accordance with Article 7(4). Member States must take account of the occurrence of peak levels that may cause adverse effects on human health.

[5] For water referred to in Article 6(l) (a), (b) and (d), the value must be met, at the latest, 15 calendar years after the entry into force of this Directive. The parametric value for lead from five years after the entry into force of this Directive until 15 years after its entry into force is µg/l.

Member States must ensure that all appropriate measures are taken to reduce the concentration of lead in water intended for human consumption as much as possible during the period needed to achieve compliance with the parametric value.

When implementing the measures to achieve compliance with that value Member States must progressively give priority where lead concentrations in water intended for human consumption are highest.

DANGEROUS SUBSTANCES DIRECTIVE 76/464/EEC

LIST I & LIST II SUBSTANCES

LIST I OF FAMILIES AND GROUPS OF SUBSTANCES

List I contains certain individual substances which belong to the following families and groups of substances, selected mainly on the basis of their toxicity, persistence and bioaccumulation with the exception of those which are biologically harmless or which are rapidly converted into substances which are biologically harmless.

1. Organohalogen compounds and substances which may form such compounds in the aquatic environment
2. Organophosphorus compounds
3. Organotin compounds.
4. Substances in respect of which it has been proved that they possess carcinogenic properties in or via the aquatic environment
5. Mercury and its compounds
6. Cadmium and its compounds
7. Persistent mineral oils and hydrocarbons of petroleum origin

And for the purpose of implementing Articles 2, 8, 9 and 14 of this Directive:

8. Persistent synthetic substances which may float remain in suspension or sink and which may interfere with any use of the waters.

LIST II OF FAMILIES AND GROUPS OF SUBSTANCES

List II contains:

- Substances belonging to the families and groups of substances in List I for which the limit values referred to in Article 6 of the Directive have not been determined.
- Certain individual substances and categories of substances belonging to the families and groups of substances listed below and which have a deleterious effect on the aquatic environment, which can, however, be confined to a given area and which depend on the characteristics and location of the water into which they are discharged.

1. Families and groups of substances referred to in the second indent:

The following metalloids and their compounds:

1 Zinc 6 Selenium 11 Tin 16 Vanadium.

2 Copper 7 Arsenic 12 Barium 17 Cobalt.

3 Nickel 8 Antimony 13 Beryllium 18 Thallium.

4 Chromium 9 Molybdenum 14 Boron 19Tellurium

5 Lead 10 Titanium 15 Uranium 20 Silver.

2. Biocides and their derivatives not appearing in List I

3. Substances which have a deleterious effect on the taste and/or smell of the products for human consumption derived from the aquatic environment, and compounds liable to give rise to such substances in water.

4. Toxic or persistent organic compounds of silicon and substances which may give rise to such compounds in water, excluding those which are biologically harmless or are rapidly converted in water into harmless substances

5. Inorganic compounds of phosphorus and elemental phosphorus

6. Non-persistent mineral oils and hydrocarbons of petroleum origin

7. Cyanides, fluorides

8. Substances which have an adverse effect on the oxygen balance, particularly: ammonia, nitrites. Where certain substances in List II are carcinogenic they are included in category 4 of this list.

It has been emphasized that brief or prolonged exposure of the body to lead can lead to problems in the synthesis of haemoglobin, nervous system, reproductive system, joints, and kidney; and in children it can result to increased risk of learning disabilities in later years and neurolodegenarative diseases. [37, 41]

2.3.8 Zinc

Chemical Symbol or Formula: Zn.

Units Used for Analytical Results: mg/L Zn.

Normal Method(s) of Analysis: Atomic Absorption Spectrometry. [36]

Zinc has a natural geological occurrence and from wastes. [36] It occurs in small amounts in almost all igneous rocks. The principal zinc ores are sulphide such as sphalerite and wurzite. The natural zinc content of soils is estimated to be 1-300 mg/kg.

• Organoleptic properties.

Zinc imparts an undesirable astringent taste to water. UNEP and WHO, 1996 Tests were said to indicate that 5% of a population could distinguish between zinc-free water and water containing zinc at a level of 4 mg/L as zinc sulphate. [36]

In natural surface water the concentration of zinc is usually below 10 µg/L and in groundwater 10-40 µg/L in tap water the zinc concentration can be much higher as a result of the leaching of zinc from piping and fittings. The most corrosive waters are those of low pH. High carbon dioxide content and low mineral salts content. In a Finnish survey of 67% of the public water supply, the median zinc content in the water samples taken upstream and downstream of the waterworks was below 20 µg/L. Much higher concentrations were found in tap water; the highest being 1.1 mg/L. Even higher zinc concentrations up to 24 mg/L were reported in Finnish survey of water from 6000 wells. Zinc is essential to man but if ingested in gross amounts it has an emetic effect. However, the concern in water supply arises in regard to taste not toxicity, and quite high levels are permissible. In fishery water, in contrast, the toxic action is much more important and very much lower limits have been imposed. The toxicity of zinc to aquatic life is (as with copper) dependent on the hardness of the water: it decreases with rising hardness. [36] In an excess concentration of 5 mg/L, zinc may render water not portable. [38; 42]

2.3.9 Cadmium

Chemical Symbol or Formula: Cd.

Units Used for Analytical Results: µg/L Cd.

Normal Method(s) of Analysis: Atomic Absorption Spectrometry. [36]

Cadmium is produced as an inevitable by-product of zinc (or occasionally lead) refining, since these metals occur naturally within the raw ore. However, once collected the cadmium is relatively easy to recycle. Cadmium is a natural and usually a minor constituent of surface and ground water. It may exist in water as hydrated ions or as inorganic complexes such as carbonates, hydroxides, chlorides or sulphates or as organic complexes with humic acids.

Cadmium may enter aquatic systems through weathering and erosion of soils and bed rock, atmospheric decomposition of direct discharges from industrial operations, leakage from landfills and contaminated sites and the dispersive use of sludge and fertilizers in agriculture. Much of the cadmium entering fresh waters from industrial sources may be rapidly adsorbed by particulate matter and thus sediment may be a significant sink for cadmium emitted to the aquatic environment. [36]
Some data shows that recent sediments in lakes and streams range from 0.2 to 0.9 ppm in contrast to the levels of generally less than 0.1 ppm cited above for fresh water partitioning of cadmium between the adsorbed in sediment state and dissolved in water state is therefore an important factor in whether cadmium emitted to water is or is not available to enter the food chain and affect human health.

WHO in 1992 pointed that rivers containing excess cadmium can contaminate surrounding land, either through irrigation for agricultural purposes, dumping of dredged sediments or flooding. [36] It has also been demonstrated that rives can transport cadmium for considerable distance up to 50km from the source. Cadmium

derives its toxicological properties from its chemical similarity to zinc an essential micronutrient for plants, animals and humans. Cadmium is bio-persistent and, once absorbed by an organism, remains resident for many years (over decades for humans) although it is eventually excreted.

In humans, long-term exposure is associated with renal dysfunction. High exposure can lead to obstructive lung disease and has been linked to lung cancer, although data concerning the latter are difficult to interpret due to compounding factors. Cadmium may also produce bone defects (osteomalacia, osteoporosis) in humans and animals. In addition, the metal can be linked to increased blood pressure and effects on the myocardium in animals, although most human data do not support these findings.

The average daily intake for humans is estimated at 0.15μg from air and 1μg from water. Smoking a packet of 20 cigarettes can lead to the inhalation of around 2-4μg of cadmium, but levels may vary widely.

In the general, non-smoking population the major exposure pathway is through food, via the addition of cadmium to agricultural soil from various sources (atmospheric deposition and fertiliser application) and uptake by food and fodder crops. Additional exposure to humans arises through cadmium in ambient air and drinking water.

2.3.10 Effects of Cadmium on the environment

Cadmium is used in metal alloys and pigments for paints, cement, paper, rubber, and other materials. Low-level exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage to circulatory and nerve tissue. Cadmium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of Cadmium**.**

2.3.11 Sodium

Chemical Symbol or Formula: Na.

Units Used for Analytical Results: mg/L Na.

Normal Method(s) of Analysis: Flame Photometry; Atomic Absorption Spectrometry. [36]

Sodium levels in drinking water that are less than 20 mg/L are considered safe for most people. In the sea coast area however, elevated levels of sodium and chlorides occur naturally due to the proximity to sea water. Substantially higher levels of sodium and chloride may also be due to contamination by activities of man including the use of road de-icing salts, discharges from water softeners, human or animal waste disposal leachate from landfills and many other activities.

At present there are health standards for sodium and chloride in drinking water. A review by EPA in the mid-1980's showed that elevated levels of sodium in drinking water did not cause high blood pressure or heart disease, rather only that sodium should be avoided by those who already had such medical conditions.

It is important to note that sodium is an essential nutrient. The food and nutrition board of National Research Council recommends that healthy adults need to consume at least 500mg of sodium per day and that sodium intake be limited to no more than 2400 mg/day. The food and drug administration publication states that most American adults tend to eat between 4000 and 6000 mg of sodium per day. [36]

2.3.12 Potassium

Chemical Symbol or Formula: K.

Units Used for Analytical Results: mg/L K.

Normal Method(s) of Analysis: Flame Photometry, Atomic Absorption Spectrometry. [36]

Potassium is an essential constituent of many artificial fertiliser formulations, and hence its determination is often carried out on lake waters when an assessment is being made of nutrient input. However, potassium tends to be "fixed" in soils and is not that easily leached out. There are no implications of toxicity. Very often potassium is measured on samples solely to permit the calculation of an "ion balance" for the verification of the analysis. [36] It is an alkaline metal but is essential in a well defined balance diet and can be found in fruits such as bananas [36].

The potassium content of drinking water varies greatly depending on its source. It tends to be greater in mineral water than ordinary tap water. It however on the average, the daily water consumed by adults supplies less than 0.1 % of their potassium intake but tap water is also used to make beverages like tea, coffee, beer and wines. The average total potassium intake in beverages can supply about 13% of the total daily intake of adults. [36]

2.3.13 Total Dissolved Solids (TDS)

Chemical Symbol or Formula: Not applicable [Bulk parameter].

Units Used for Analytical Results: mg/L solids.

Normal Method (s) of Analysis: Gravimetric (dried at stated

temperature after filtration). The parameter is determined as for total solids except that the sample is filtered through a defined medium (membrane or glass fibre paper; cf. "Solids, Suspended") beforehand. The term *Total Filterable Solids* is also used. It is often convenient and acceptable to use the very rapid determination of conductivity (q.v.) to give an estimation of the total dissolved solids. [36]

TDS is the sum of all the materials dissolved in the water, it has many different mineral sources. Total dissolved solids (TDS) consist of mainly carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, calcium, magnesium, sodium,

potassium, iron, manganese and a few others. They do not include gases, colloids or sediments. The total dissolved solids can be estimated by measuring the specific conductance of the water. Dissolved solids in natural water range from less than 10 mg/L for rain water to more than 100,000 mg/L for brines. Below is an indication of TDS from various sources:

Distilled water = 0.

Deionised water = 8.

Rain and snow =10.

Brine well =125,000 and

Dead Sea = 250,000.

The TDS of a water sample is determined gravimetrically, a well mixed volume of sample is evaporated in a weighed dish and dried to constant weight in an oven at 103-105^{o}C. The increase in weight over that of the empty dish is the total solid. The value may not necessary represent the actual suspended and dissolved solids. This is due to interference from highly mineralized water with significant concentrations of calcium, manganese etc. which may be hygroscopic and requires excessive, proper desiccation and rapid weighing. A standard glass fibre filter is used to filter a well mixed sample and the filtrate is evaporated to dryness in a weighed dish to constant weight at 180^{o}C. APHA, 1992 recommends that Total Dissolved Solids can be determined by using an electric probe which also measures temperature and conductivity. [36]

2.4.2 Temperature

Chemical Symbol or Formula: Not applicable [Physical parameter]

Units Used for Analytical Results: Degrees Celsius [°C].

Normal Method(s) of Analysis: Thermometry or Thermistor [as in DO probe], with measurement in the field (usually in association with the DO measurement: q.v.). [36]

Water Temperature is the measure of how hot or cold water is. As far back as 1985, APHA recommended that temperature be measured with a thermometer in degree Celsius or Fahrenheit. The temperature of water to a large extent determines the extent of microbial activity. Water freezes at 0^{o}C and boils at 100^{o}C. [36]

The effect of temperature, and especially changes in temperature, on living organisms can be critical and the subject is a very wide and complex one. Where biochemical reactions are concerned, as in the uptake of oxygen by bacteria, a rise of 10°C in temperature leads to an approximate doubling of the rate of reaction. Conversely, such reactions are retarded by cooling, hence the recommendation often made that waters be cooled to 4°C in the interval between sampling and analysis.

Another most important factor is that some key constituents of a water either change their form (as in the ionisation of ammonia) or alter their concentration (as with dissolved oxygen) when temperature changes. In fact, the primary interest in the temperature of surface waters is due to the inverse relationship between it and oxygen solubility. [36]

Birhanu (2007) presents temperature as a bacteriological related parameter and maintains that in analysis of the physicochemical quality of water samples, temperature is considered as a critical parameter. It has an impact on many reactions, including the rate of disinfectant decay and by-product formation. As the water temperature increases the disinfectant demand and by product formation, nitrification,

microbial activity, algal growth, taste and odour episodes, lead and copper solubility increases. Moreover, sand calcium carbonate ($CaCO_3$) precipitation also increases. [36]

An aesthetic objective is set for maximum water temperature to aid in selection of the best water source or the best placement for a water intake. It is desirable that the temperature of drinking water should not exceed 15°C because the palatability of water is enhanced by its coolness. In addition to cool water tasting better than warm water, temperatures above 15 degrees Celsius can speed (as measured by heteroplate count increases significantly at water temperatures above 15ºC, in the absence of a disinfectant residual (WSTB, 2005). Therefore, water supplies generally tend to keep the temperature as low as possible in order to minimize the bacterial after growth. Keeping the temperature low reduces the risk for pathogenic proliferation and survival since the optimal temperature for most pathogens is close to the human body temperature. The chart below illustrates the effect of temperature change on coliforms:

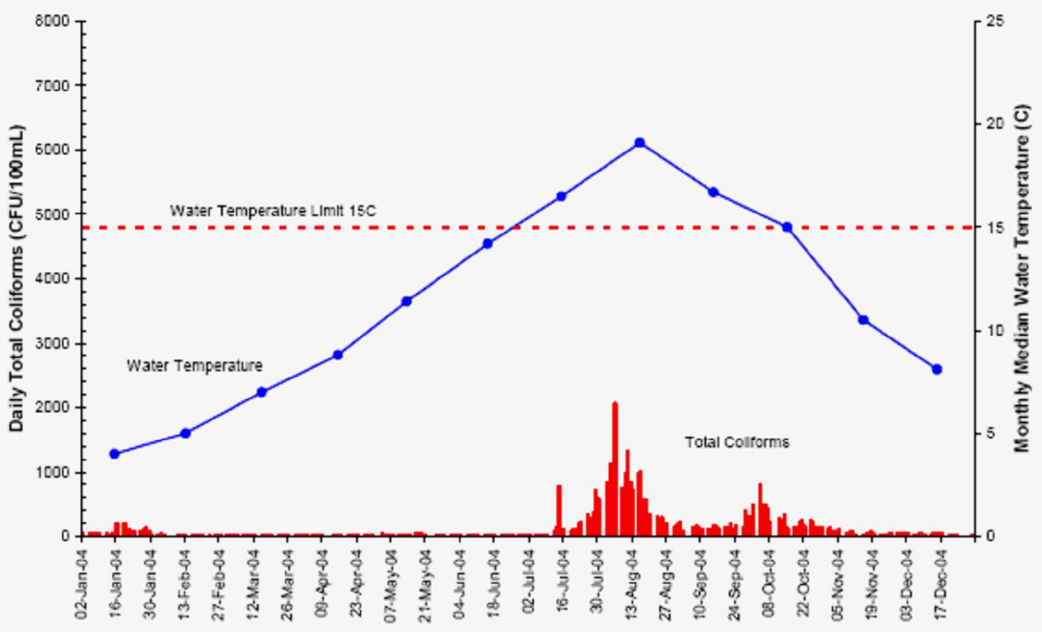

Fig. 2.2 Raw Water Entering Japan Gulch Plant Total Coliforms and Water Temperature in 2004. [33]

As Fig. 2.2 indicted above at the Japan Gulch Plant, the coldest daily water temperature recorded was 3.0°C in January while the warmest was 20.9°C in August 2004. The Guideline limit of 15°C was exceeded from July 9, 2004 to October 18, since the water services department could not control the temperature of the water the number of coliform increased at high temperatures during dry season seasons. [33]

To ensure accuracy in the measurement of temperature, a standard mercury thermometer with readings to the nearest 0.1^{o}c is normally used and the sample temperature is taken 'insitu'. [38]

2.4.3 Biochemical Oxygen Demand (BOD)

Chemical Symbol or Formula: Not applicable [Bulk parameter]

Units Used for Analytical Results: mg/L O_2.

Normal Method(s) of Analysis: Incubation technique with oxygen determinations by Winkler Method or by Oxygen Meter.

Occurrence/Origin: Natural or introduced organic matter in water.

Health/Sanitary Significance: No direct health implications, but an important indicator of overall water quality.

BOD is the amount of oxygen required by bacteria for breaking down decomposable organic matter present in water, waste water or effluent to simpler substances. [38] The greater the oxygen demand the greater the BOD. [2; 38] It is a measure of the productivity of a given body of water; that is the higher the BOD, the poorer the water quality and vice versa. [2] The level of dissolved oxygen (DO) of water may be depleted by some inorganic waste discharges. A waste containing sulphite, for example, can have serious effects. These will include the direct chemical uptake of oxygen during the BOD incubation period, the extent of which uptake will contribute to the apparent BOD value of the sample. It is arguable, however, that in such cases

while a percentage of the oxygen depletion may be caused by chemical rather than biochemical reaction, the results will still reflect the maximum possible oxygen depletion effects in the receiving water. [36]

BOD test consists of the determination of the amount of oxygen consumed after incubating the sample in the dark 20 ^{o}C for five days. [2; 38] the quantity of oxygen required for the oxidation (biochemical degradation) of organic material (carbonaceous demand) as well as that required to oxidize inorganic materials such as ferrous iron and sulphides is measured. [2] An ideal duration of this test is ninety days (a period assumed to be enough for the oxidation under the given condition). This period is rather too long for practical purpose; [2] hence the accepted standard incubation period of the test is five days at 20 ^{o} C. [2; 38] This period is said to give a reasonably reproducible result and can be used as the basis for calculations. [2] The oxygen consumption is determined from the difference between the dissolved oxygen (DO) levels before and after incubation period. [2, 38] The method consists of placing a sample in a full airtight bottle under specified conditions for a specified time. "DO" is then measured before and after incubation. A BOD of 500 mg/L would mean that 500 mg/L load of dissolved oxygen requires a period of five days to be absorbed. [2] BOD is written as BOD_5 and given by:

$$\mathbf{BOD_5} = \frac{\mathbf{DO_i - DO_f}}{\mathbf{P}}$$

Where DO_i = initial dissolved oxygen of diluted wastewater.

DO_f = final dissolved oxygen of diluted wastewater.

$$\mathbf{P = \text{dilution factor} = \frac{\text{volume of wastewater}}{\text{vol. of wastewater + dilution water}}}$$

A standard BOD bottle holds 300 mL, so "P" is just the volume of wastewater divided by 300mL. [2] Unpolluted water typically have BOD values of 2mg/L or less while

wastewater may have values up to 10mg/L or more, particularly near the point of waste discharge. [38]

2.4.4 Chemical Oxygen Demand (COD)

COD test procedure involves the use of additional reagents to catalyse the oxidation of organic matter and to suppress the effects of interfering substances such as chloride, and, as a result, in many cases the oxidation achieved is at or very near the maximum level. For biodegradable compounds the five-day BOD level corresponds to some 65 per cent oxidation of the total organic matter present so that, if for such compounds the chemical oxidation is fully efficient, the COD/BOD ratio should be 100:65 or 1.54:1. The COD test is applicable to heavily polluted waters and to wastewaters. This is because the sensitivity of the normal test procedure is not adequate for waters with an oxygen demand of only a few mg/L O_2. There is a "low level" test but this is best applied to waters with an oxygen demand in the vicinity of 25 mg/L O_2 which is rather larger than one would hope to find in clean waters. [36]

2.4.5 Hardness

Chemical Symbol or Formula: Not Applicable [Bulk parameter].

Units Used for Analytical Results: mg/L $CaCO_3$.

Normal Method(s) of Analysis: Titration with EDTA.

Occurrence/Origin: Rock formations - limestone etc

Hard water has high mineral content. [2] Amankona (2010) submits that the degree of hardness of water supply is determined by the content of calcium and magnesium salts. Calcium and magnesium combine with bicarbonates, chlorides, sulphates, and nitrates to form these salts. [2; 36] Again, the standard domestic measurement for hardness is gains per gallon (gpg) as $CaCO_3$. Water having hardness content less than 0.6 gpg is considered commercially soft. [36] The calcium and magnesium salts which

form the hardness are divided into two categories: Temporal hardness and permanent hardness. [2, 36, 37; 38] Hardness affects the amount of soap that is needed to produce foam or lather. Hard water requires more soap, [2; 36] because the calcium and magnesium ions form complexes with soap preventing the soap from sudsing. Hard water can also leave a film on the hair, fabrics, and glassware. Hardness of water is very important in industrial uses, because it forms scales in heat exchange equipment, boilers and pipes. [36] Hardness mitigates metal toxicity [36] because of the presence of Ca^{2+} and Mg^{2+}. [2, 36] Hardness helps to keep fish from absorbing metals such as lead, arsenic and cadmium into their bloodstream through their gills. The greater the hardness, the harder it is for toxic metals to be absorbed through the gills. [36]

2.4.5.1 Temporary hardness

Temporary hardness (or removable hardness) results from the presence of bicarbonates of calcium and or magnesium. [2] Calcium Carbonate ($CaCO_3$) often referred to as limestone in water supplies, [36] causes alkalinity in water. [36] Calcium Bicarbonate forms when water containing CO_2 is released and the calcium bicarbonate reverted to calcium carbonate forming scales. Temporary hardness consists mainly of bicarbonates and to a lesser extent the carbonates of calcium and magnesium. [37-38] Magnesium Carbonate ($MgCO_3$) known as magnetite has properties similar to calcium carbonate. [36]

2.4.5.2 Permanent Hardness

Permanent hardness often referred to as non-carbonate or irremovable hardness is due to the presence of chlorides and sulphates of calcium and magnesium which on increase of temperature become soluble. [2] Calcium sulphate ($CaSO_4$) known as gypsum used to make pop will precipitate and form scales in boilers when

concentrated, calcium chloride ($CaCl_2$) reacts in a boiler water to produce low pH as follows.

$$CaCl_2 + 2HOH \Rightarrow Ca(OH)_2 + 2HCl.$$

Magnesium Sulphate ($MgSO_4$) also known as Epsom may have laxative effect if of high quantity in the water. Sodium salts are found in household water supplies but they are considered harmless as long as they do not exist in large quantities. [36]

2.4.5.3 Measurement of Water Hardness:

Although hard water may also contain other substances such as aluminium and manganese, water hardness usually measures only the total concentration of calcium and magnesium ions present. [2] Scales for describing water hardness include the following:

- mg-eq/dm^3.
- Milligrams per litre (mg/L).
- Parts per million (ppm).
- Grams per gallon (gpg); 1 gpg = 171.1 mg/L.

The table below can be used to evaluate hardness of water supply: [2]

Table 2.6 Evaluation of hardness of water

Amount of Ca^{2+} and Mg^{2+} in $1dm^3$ 0f water, mg-eq	**Water hardness class**
0-1.5	Very soft
1.5-3	Soft
3-6	Medium soft
6-10	Hard
> 10	Very hard

2.4.6. pH

Chemical Symbol: Not applicable [Physical parameter].

Units Used for Analytical Results: pH units

Normal Method(s) of Analysis: Electrometric [pH electrode] **Occurrence/Origin:** Physical characteristic of all waters/solutions. [36]

The pH of a solution is the measure of how acidic or basic that solution is or the concentration of hydrogen ions in a solution. [35] It is the negative logarithm of the hydrogen ion concentration of a solution. The pH scale (derived from the ionisation constant of water) ranges from 0 (very acid) to 14 (very alkaline). [36] Natural waters often have a pH of 4-9 and most are slightly basic as a result of bicarbonate and carbonates of the alkali and alkaline earth metals. [35]

In waters with low dissolved solids, which consequently have a low buffering capacity (i.e. low internal resistance to pH change), changes in pH induced by external causes may be quite dramatic. Extremes of pH can affect the palatability of water but the corrosive effect on distribution systems is a more urgent problem.

The determination of pH involves the activity of hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode. The measurement of pH is influenced by temperature in two ways. Mechanical effects caused by changes in the properties of the electrode and chemical effects caused by equilibrium changes.

In the former, the nerstian slope increases with increasing temperature and takes a lot of time to attain thermal stability. This can cause a long term drift in the

pH. Due to the effect of chemical equilibrium on pH; standard pH buffers have a specific pH at specified temperatures. [35] pH values govern the behaviour of several other important parameters of water quality. Ammonia toxicity, chlorine disinfection efficiency, and metal solubility are all influenced by pH. [36]

Birhanu (2007) discussed pH as a bacteriological related parameter and that it is also one of the most important operational parameters for water treatment such as disinfection or coagulation-flocculation. pH adjustment is a common practice in water treatment. A nearly complete dissociation of HClO occurs from pH 6 to 8.5. This is because dissociation is poor at pH levels below 6. Thus pH is critical when disinfection of water is done using chlorine. As a consequence, an increasing pH of the potable water requires rising amounts of chlorine for the same disinfection efficacy [36]. The microbial activity of chlorine is greatly reduced at high pH, probably because at an alkaline pH, the predominant species of chlorine is OCl^-. Equilibrium concentrations of HOCl and OCl depend on the pH of the water. If the pH of the water is high, chlorine is less effective in killing pathogens. [36] According to Kent and collaborators (1998) pH values ranging from 3 to 10.5 could favour both indicator and pathogenic micro-organism growth. The overall pH pattern showed that the pH values were relatively high in dry season compared to rainy season. [33]

2.4.7 Conductivity

Chemical Symbol or Formula: Not Applicable [Physical parameter].

Units Used for Analytical Results: µS/cm.

Normal Method(s) of Analysis: Electrometric.

Occurrence/Origin: Reflects mineral salt content of water. [36] Conductivity is defined as the ability of a solution to carry electric current. This is

normally dependant on the presence of mobile ions their concentration, mobility, valency, relative concentration and temperature of measurement.

Compounds which dissociates easily in solution are good conductors whiles those which do not dissociate easily are poor conductors.

Inorganic, bases, and salts are good conductors whiles compounds are poor conductors. In a laboratory determination, conductivity is measured as resistance measured in ohms. The conductivity of fresh distilled water is in the range of 0.5-2.0 micro-ohms/cm. the conductivity of portable water is in the range of 50-10000μmhos/cm.

Laboratory conductivity measurements are used to:

- Establish degree of mineralization, to assess the effect of the total concentration of ions on chemical equilibria, physiological effects on living things and the rate of corrosion
- To assess the degree of mineralization of distilled water and deionised water.
- To check the result of a chemical analysis and estimate the sample size to be used for simple chemical determinations.
- Determine the amount of ionic reagents in the precipitation and neutralization reactions. The end point of such reactions is determined by plotting a graph of conductivity verses burette readings.

• When conductivity is multiplied by a factor, total dissolved solids of water can be determined. This factor may vary from 0.055 to 0.9 depending on the soluble component of the water and on the temperature of measurement. [35] EPA (2001) puts it that conductivity in itself is a property of little interest to a water analyst but it is an invaluable indicator of the range into which hardness and alkalinity values are likely to fall, and also of the order of the dissolved solids content of the water. While a

certain proportion of the dissolved solids (for example, those which are of vegetable origin) will not be ionised (and hence will not be reflected in the conductivity figures) for many surface waters the following approximation will apply:

Conductivity (μS/cm) x 2/3 = Total Dissolved Solids (mg/L).

In samples from a source which is regularly tested a rapid conductivity analysis may be an adequate replacement for other, longer determinations. Pointing further that it is important to note that there is an interrelationship between conductivity and temperature, the former increasing with temperature at a rate of some 2 per cent per degree C rise. There is a regrettable lack of uniformity in the terms in which conductivity is reported. Some UK methods manuals report the results at 20°C while the standard US reference manual uses 25°C. A difference of 10 percent can therefore arise depending on how the results are quoted. An error of this magnitude could not be tolerated, especially where conductivity readings are being used to estimate salinity.

2.4.8 Alkalinity

Chemical Symbol or Formula: Not Applicable [Bulk parameter]

Units Used for Analytical Results: mg/L $CaCO_3$.

Normal Method(s) of Analysis: Titration with Sulphuric Acid.

Alkalinity is defined as the ability of water to neutralize an acid, and is determined by titration against a known standard acid (usually 0.02N sulphuric acid). Alkalinity has traditionally been reported in terms of mg/L as calcium carbonate. This is somewhat a confusing nomenclature since the chemical species responsible for virtually all the alkalinity of natural waters is the bicarbonate ion. The optimal amount of alkalinity for a given water is a function of several factors including pH, hardness and the concentration of dissolved oxygen and carbon dioxide that may be present.

As a general rule 30 to 100 mg/L calcium carbonate is desirable although up to 500 mg/L may be acceptable. Alkalinity is apparently unrelated to public health but is very important in pH control. Alum, gaseous chlorine and other chemicals are occasionally used in water treatment to acts as acids and therefore tend to depress pH. Many waters are deficient in natural alkalinity and must be supplemented with lime (CaO) or some other chemicals to maintain the pH in the desirable range to usually 6.5 to 8.5. Alkalinity values can change significantly from groundwater between samples taken at the wellhead and samples taken from other spots. [35]

According to EPA (2001), the alkalinity of natural water is generally due to the presence of bicarbonates formed in reactions in the soils through which the water percolates. It is a measure of the capacity of the water to neutralise acids and it reflects its so-called *buffer capacity* (its inherent resistance to pH change). Poorly-buffered water will have a low or very low alkalinity and will be susceptible to pH reduction by, for example, "acid rain." At times, however, river alkalinity values of up to 400 mg/l $CaCO_3$ may be found; they are without significance in the context of the quality of the water. Alkalinity in natural waters may also be attributable to carbonates and hydroxides. Sometimes analysis is carried out to distinguish between the alkalinity elements and this is done by using different indicators in the titration procedure and by making appropriate calculations. The indicators most commonly employed are phenolphthalein (colour change around pH 8.3) and methyl orange (colour change around pH4.5), resulting in the additional terms *phenolphthalein alkalinity* and *methyl orange alkalinity*; the latter is synonymous with *total alkalinity*.

2.4.9 Colour

In the present context - and, indeed, in general usage - the term "colour" refers to the natural coloration occurring in waters and not to any induced colouring

resulting from wastes. [36] However, 'water colour' has been referred to as colour due to dissolved organic content. [38; 39]

Chemical Symbol or Formula: Not Applicable [Bulk parameter].

Units Used for Analytical Results: mg/L Pt/Co [mg/L Hazen].

Normal Method(s) of Analysis: Colorimetric.

Basically water is colourless so to a greater extent, colour in water is always due to the presence of foreign material. Suspended and decaying organic and inorganic materials usually extracted from decaying vegetation, add colour and odour to the water. Colour is common in surface water supplies. While it is virtually non-existent in spring and deep wells due to material screening, colour in water supplies may also be the result of natural metallic ions (iron and manganese) a yellow tint to the water indicates that humic acids are present, referred to as 'tannins' a reddish colour would indicate the presence of precipitated iron. Stains on bathroom fixtures and on laundry are often associated with colour also reddish –brown is ferric hydroxide (iron) will precipitate when the water is exposed to air. Dark brown to black stains are created by manganese. Excess copper can create blue stains.

The observed colour of water is the result of light back scattered upwards from the water after it has passed through various depths and undergone selective absorption.

Colour and turbidity determines the depth to which light penetrates in water systems [36; 38]. In water, light intensity or irradiance at a particular depth (Iz) is a function of the intensity at the surface (I o) to the exponent of the negative extinction coefficient at the depth distance z which is called the beer-lambert law: $Iz = Ioe^{-nz}$. [36] The visible colour in a water sample is the result of different wavelength not absorbed by water itself or the result of dissolved or particular substances present. [39] It is the

light that is refracted, reflected, emitted or re-emitted by substances in water because it has not been absorbed to produce heat or chemical reactions. Water colour is of two types: the 'true colour and the 'apparent colour' [38] True colour is due to minerals such as ferric hydroxide and dissolved organic substances such as humic or fulvic acids. Colour measured in water containing suspended matter is defined as apparent colour. [36] Again, the true colour is said to be attributed to substances in solution after removal of suspended materials by filtration or centrifugation. 'Apparent colour' is said to be caused by substances in suspension and can be determined on the original sample without filtration or centrifugation. [38]

The colour of water measured by colometric methods is based on the calibration or absorbance of the water sample at a variety of single wavelengths, usually against the Pt-Co Standard measurement. Comparisons can be made with sealed containers. Natural waters range from <5 mg/L Pt in very clear water to 1200 mg/L in dark peaty waters. [35]

2.6.10 Turbidity

Chemical Symbol or Formula: Not applicable [Bulk physical parameter].

Units Used for Analytical Results: Formazin Turbidity Units [FTU]; Jackson Turbidity Unit [JTU]; Nephelometric Turbidity Units [NTU]; Silica Units [SiO_2].

Normal Method(s) of Analysis: Turbidimeter or Nephelometer.

Turbidity is the term given to anything that is suspended in a water supply. It is the amount of particulate matter that is suspended in water. Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity. It is most common in surface waters and usually non-existent in ground water except in shallow wells and springs after heavy rains. Turbidity gives the water a cloudy appearance or shows as dirty sediments.

Undissolved materials such as sand, clay, silt or suspended irons contribute to turbidity.

Turbidity can cause the staining of sinks and fixtures as well as the discolouring of fabrics. Usually turbidity is measured in NTU (nephelometric turbidity units) typical drinking water have turbidity level of 0 to 1 NTU. Turbidity can also be measured in ppm (parts per million) and its size is measured in microns. Turbidity can be particles in the water consisting of finely divided solids larger than molecules, but visible to the naked eye, ranging from 0.001 to 0.150mm (1 to 150 microns).

Typically turbidity can be reduced to 75 microns with a cyclone separator then reduced down to 20 microns with standard back washable filter, however flow rates of 5 gpm/sq. ft are recommended maximum. Turbidity can be reduced to 10 microns with a multimedia filter while providing flow rate of 15 gpm/sq. ft cartridge filter of various sizes are also available down into the submicron range. [35-35]

Turbidity is caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic compounds and plankton and other microscopic organisms. Turbidity expresses the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line through the sample. Correlation of turbidity with weight concentration of suspended matter is difficult because the size, shape and refractive index of the particle also affect the light scattering properties of the suspension.

EPA (2001) asserts that turbidity in water arises from the presence of very finely divided solids (which are not filterable by routine methods). The existence of turbidity in water will affect its acceptability to consumers and it will also affect markedly its utility in certain industries. The particles forming the turbidity may also

interfere with the treatability of waters and in the case of the disinfection process the consequences could be grave. As turbidity can be caused by sewage matter in water there is a risk that pathogenic organisms could be shielded by the turbidity particles and hence escape the action of the disinfectant. [33]

2.5.0 Nutrient contaminants

2.5.1 Chlorides

Chemical Symbol or Formula: Cl^-

Units Used for Analytical Results: mg/L Cl.

Normal Method (s) of Analysis: Titration (Mohr Method: Silver Nitrate)[36]

Chlorides (Cl^-) is one of the major anions found in water and is generally combined with calcium, magnesium or sodium. Since almost all chloride salts are highly soluble in water, the chloride content ranges from 10 to 100 mg/L. Sea water contains over 30,000 mg/L as NaCl. Chloride is associated with the corrosion of piping systems. The corrosion rate and the iron dissolved into the water from piping increases as the NaCl content of the water is increased. The Suggested Maximum Contaminant Level (SMCL) for chloride is 250 mg/L which is due strictly to the objectionable salty taste produced in drinking water [33-35].

EPA (2001) states that Chloride does not pose a health hazard to humans and the principal consideration is in relation to palatability. At levels above 250 mg/L Cl water will begin to taste salty and will become increasingly objectionable as the concentration rises further. However, external circumstances govern acceptability and in some arid areas waters containing up to 2,000 mg/L Cl Turbidity is also considered as surrogate microbiological parameter because it is closely linked to the microbiological safety of drinking water. [36] Turbidity can indicate that water may be contaminated with pathogens presenting human health concerns. One study in the Eastern Cape Province, *South Africa* indicated that turbidity is typically high during a

storm as a consequence of rapid erosion of surface soils into rivers. Likewise, the rusted metal-piping system is probably contributing to the deterioration of the water quality by increasing turbidity at distribution. The high regrowth of heterotrophs and total coliforms occurring after chlorination indicates the inefficiency of the filtration and chlorination steps. Temperature also affects water treatment. If nutrients are available, the microbial activities are consumed. [36] Excessive concentrations (3.0 ppm) of can cause dental flourosis in children. [42]

2.5.2 Sulphate

Chemical Symbol or Formula: SO_4^{2-}

Units Used for Analytical Results: mg/L SO_4^{2-}

Normal Method(s) of Analysis: Turbidimetric (Barium Sulphate); Ion Chromatography.

Occurrence/Origin: Rocks, geological formations, discharges and so on.

Sulphates (SO_4) occur in almost all natural waters. Most sulphate compounds originate from the oxidation of sulphate ores, the presence of the shale and the existence of industrial waste. Sulphate is one of the major nutrients dissolved in rain. As water moves through the soil and rock formations that contain sulphate minerals, some of the sulphate dissolves in the water into the groundwater.

Minerals that contain sulphate include magnesium sulphate (Epsom salt) sodium sulphate and calcium sulphate (gypsum). A high concentration of sulphate in drinking water causes a laxative effect when combined with calcium and magnesium, the two most common components of water hardness. Bacteria which attack and reduce sulphates cause hydrogen sulphide gas to form. Sulphate has a suggested level of 250 mg/L in the secondary drinking water standards. [36]

Sulphate (SO_4) ion is precipitated in an acetic acid medium with barium chloride to form barium sulphate. Light absorbance of barium sulphate suspension by

a UV-visible spectrophotometer at 420 nm is used to determine the sulphate concentration. This is done by comparison with the calibration curve.

Sulphates exist in nearly all natural waters, the concentrations varying according to the nature of the terrain through which they flow. They are often derived from the sulphides of heavy metals (iron, nickel, copper and lead). Iron sulphides are present in sedimentary rocks from which they can be oxidised to sulphate in humid climates; the latter may then leach into watercourses so that ground waters are often excessively high in sulphates. As magnesium and sodium are present in many waters their combination with sulphate will have an enhanced laxative effect of greater or lesser magnitude depending on concentration. The utility of water for domestic purposes will therefore be severely limited by high sulphate concentrations, hence the limit of 250 mg/L SO_4. [36]

2.5.3 Sulphide

Chemical Symbol or Formula: S^{2-}

Units Used for Analytical Results: mg/L S.

Normal Method(s) of Analysis: Lead Acetate Paper (Qualitative); Specific Ion Electrode.

Occurrence/Origin: From anaerobic decomposition of organic matter in water or in waste, and from bacterial reduction of sulphate.

The principal interest in sulphide arises because of its toxicity, and also the odour problems associated with the presence of undissociated hydrogen sulphide (H_2S) which is produced by anaerobic reduction of sulphate. There is an equilibrium relationship between the dissociated and undissociated H_2S forms which is dependent on pH. If the latter is above 8 there will be no odour problems but as the pH drops to under 7 any H_2S present will give rise to offensive odours. This is because the chemical equilibria: $H_2S \rightarrow H^+ + HS^- \rightarrow H^+ + S^{2-}$ will shift to the left, favouring the

presence of undissociated hydrogen sulphide, which is a highly toxic substance. It is the H_2S species which particularly affects aquatic life and which has caused fatalities to persons working in sewers. [36]

2.5.4 Phosphate

Chemical Symbol or Formula: PO_4^{3-}.

Units Used for Analytical Results: mg/L P.

Normal Method (s) of Analysis: Manual or Automated Colorimetry.

Phosphorus is one of the key elements necessary for the growth of plants and animals. Phosphorus in elemental form is very toxic and is subjected to bioaccumulation. Phosphates PO_4^{-3} is formed from this settlement. Phosphates exist in three forms Orthophosphate, metaphosphates (polyphosphates) and organically bounded phosphate. Each compound contains phosphorus in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boilers and in detergents. In water, they change into ortho form.

Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contains phosphates. They exist in solution as particles, loose fragments or in the bodies of aquatic organisms. Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate stimulates the growth of plankton and aquatic plants which provides food for fishes. Phosphate also leeches into groundwater. It may not be toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphates [35-36].

A useful parameter is orthophosphates (strictly, total filterable and non-filterable orthophosphate) which is the phosphate responding to the analytical

procedure without any pre-treatment such as hydrolysis or oxidative digestion. Caution must be exercised in considering the results of phosphorus analysis as the element exists in bound and unbound forms which are very difficult to separate totally in analysis. There is always the likelihood, for example, of some of the bound polyphosphate forms being changed by hydrolysis to orthophosphate under the actual analytical conditions. However, the determination of orthophosphate as specified is of great use in highlighting the presence of one of the most important nutrients and the results are of special interest in waters receiving sewage discharges.

2.5.5 Nitrite

Chemical Symbol or Formula: NO_2^-

Units Used for Analytical Results: mg/L NO_2^-.

Normal Methods of Analysis: Manual or Automated Colorimetry.

Occurrence/Origin: Generally from untreated or partially treated wastes.

Health/Sanitary Significance: Methaemoglobinaemia-causing agent [cf. Nitrate].

Nitrites are not usually found in drinking water supplies at concentrations above 1 or 2 mg/L (ppm). Levels in unpolluted waters are normally low, below 0.03 mg/L. Values greater than this may indicate sewage pollution.[36] Nitrates are reduced to nitrites in the saliva of the mouth and upper gastro intestinal tract, this occur to much greater degree in infants than in adults because of the higher alkaline conditions in their gastrointestinal tract. The nitrite then oxidizes haemoglobin in the blood stream to methaemoglobin, thus limiting the ability of the blood to carry oxygen throughout the body leading to Anoxia and death can occur. The United States Environmental Protection Agency has established the MCL (Maximum contaminant level) for nitrites as 1 mg/ L. [36]

Nitrite ion in a suitable medium is diazotized with sulphanilamide resulting in diazo compound. This in turn is coupled with N (1-naphtyl) ethylene-diamine to form a highly coloured azo dye [35].

2.5.6 Nitrate

Chemical Symbol or Formula: NO_3^-

Units Used for Analytical Results: mg/L N or mg/L NO_3^-.

Normal Methods of Analysis: Manual/Automated Colorimetry; Specific Ion Electrode.

Occurrence/Origin: Oxidation of ammonia: Agricultural fertilisers run off.

Health/Sanitary Significance: Hazard to infants above 11 mg/L N [50 mg/L NO_3].

Nitrate (NO_3) comes into water supplies through the nitrogen cycle rather than via dissolved minerals. It is one of the major ions in natural water. Most nitrates that occur in drinking water are as a result of contamination of ground water by septic systems. Feed lots and agricultural fertilizers. Nitrates are reduced to nitrite in the body. When water containing about 50 ppm of nitrates is ingested in infants, or breastfeeding mothers, it leads to methaemoglobinaemia (blue baby conditions). [42]

Processes that remove nitrates include reverse osmosis (92-95%), anion exchange resin, and distillation. [36]

The table below shows a list of the potential groundwater contamination sources.

Table 2.7 Potential Sources of Groundwater Contamination [29]

Place of Origin	**Municipal Sources**	**Industrial Sources**	**Agricultural Sources**	**Individual sources**
At the surface of land	Air Pollution. Municipal Waste. Land spreading Salts for Streets de-icing. Streets Parking lots.	Air Pollution. Chemicals: Storage and spills. Fuels: Storage and spills. Mine tailing piles.	Air Pollution Chemical Spills and Fertilizers. Livestock Wastes Storage Facilities. Land Spreading Pesticides.	Air Pollution Home Cleaners. Detergents. Motor Oils and paints.
Below land surface	Landfills. Leaky Sewer Lines.	Pipelines. Underground Storage Tanks.	Poorly Constructed or abandoned Wells Underground Storage Tanks	Poorly Constructed or abandoned Wells Septic Systems.

Large quantities of organic compounds are manufactured and used by industries, agriculture and municipalities. These man-made organic compounds are of most concern. The organic compounds occur in nature and may come from natural sources as well as from human activities. In many locations groundwater has been contaminated by chemicals for many decades, though this form of pollution was not recognized as serious environmental problem until the 1980s. [29]

2.6 Sources of Groundwater Pollution:

2.6.1 Natural Sources of Groundwater Pollution:

According to Lentech (2014), natural groundwater contains some impurities, even if it is unaffected by human activities. [29] The types and concentrations of natural impurities depend on the nature of the geological material through which the groundwater moves and the quality of the recharge water. Groundwater moving through sedimentary rocks and soils may pick up a wide range of compounds such as magnesium, calcium, and chlorides. Some aquifers have high natural concentration of dissolved constituents such as arsenic, boron, and selenium. The effect of these natural sources of contamination on groundwater quality depends on the type of contaminant and its concentrations.

2.6.2 Agricultural Sources of Groundwater Pollution:

Pesticides, fertilizers, herbicides and animal waste are agricultural sources of groundwater contamination. The agricultural contamination sources are varied and numerous: spillage of fertilizers and pesticides during handling, runoff from the loading and washing of pesticide sprayers or other application equipment, using chemicals uphill from or within a few hundred metres of a well. Agricultural land that lacks sufficient drainage is considered by many farmers to be lost income land. So they may install drain tiles or drainage wells to make the land more productive. The drainage well then serves as a direct conduit to groundwater for agricultural wastes which are washed down with the runoff.

Storage of agricultural chemicals near conduits to groundwater, such as open and abandoned wells, sinks holes, or surface depressions where pond water is likely to

accumulate may also be a contamination source. Again, contamination may occur when chemicals are stored in uncovered areas, unprotected from wind and rain, or are stored in locations where the groundwater flows from the direction of the chemical storage to the well.

2.6.3 Industrial Sources of Groundwater Pollution:

Manufacturing and service industries have high demands for cooling water, processing water and water for cleaning purposes. Groundwater pollution occurs when used water is returned to the hydrological cycle.

Modern economic activity requires transportation and storage of material used in manufacturing, processing, and construction. Along the way, some of this material can be lost through spillage, leakage, or improper handling. The disposal of wastes associated with the above activities contributes to another source of groundwater contamination. Some businesses, usually without access to sewer systems, rely on shallow underground disposal. They use cesspools or dry holes, or send the wastewater into septic tanks. Any of these forms of disposal can lead to contamination of underground sources of water. Dry holes and cesspools introduce wastes directly into the ground. Septic systems cannot treat industrial wastes. Wastewater disposal practices of certain types of businesses, such as automobile service stations, dry cleaners, electrical component or machine manufacturers, photo processors, and metal platters or fabricators are of particular concern because the waste they generate is likely to contain toxic chemicals. Other industrial sources of contamination include cleaning off holding tanks or spraying equipment on the open ground, disposing of waste in septic systems or dry wells, and storing hazardous materials in uncovered areas or in areas that do not have pads with drains or catchment basins. Underground

and above ground storage tanks holding petroleum products, acids, solvents and chemicals can develop leaks from corrosion, defects, improper installation, or mechanical failure of the pipes and fittings. Mining of fuel and non-fuel minerals can create many opportunities for groundwater contamination. The problems stem from the mining process itself, disposal of wastes, and processing of the ores and the wastes it creates.

2.6.4 Residential Sources of Groundwater Pollution:

Residential wastewater systems can be a source of many categories of contaminants, including bacteria, viruses, nitrates from human waste, and organic compounds. Injection wells used for domestic wastewater disposal (septic systems, cesspools, drainage wells for storm water runoff, groundwater recharge wells) are of particular concern to groundwater quality if located close to drinking water wells. Improperly storing or disposing of household chemicals such as paints, synthetic detergents, solvents, oils, medicines, disinfectants, pool chemicals, pesticides, batteries, gasoline and diesel fuel can lead to groundwater contamination. When stored in garages or basements with floor drains, spills and flooding may introduce such contaminants into the groundwater. When thrown in the household trash, the products will eventually be carried into the groundwater because community landfills are not equipped to handle hazardous materials. Similarly, wastes dumped or buried in the ground can contaminate the soil and leach into the groundwater. [29]

A 2012-13 annual science review by the British Geological Survey reported that methane (an important greenhouse gas), is a common trace component of groundwater and revealed that certain aquifers in the USA in some of the areas where

shales are being commercially exploited for gas contain high concentrations of methane. [30]

Bio-films are another source of borehole water contamination. Birhanu, (2007) reported that bio-films are formed in distribution system pipelines when microbial cells attach to pipe surfaces and multiply to form a film or slime layer on the pipe. [33]

Within seconds of entering the water distribution system, large particles, including micro-organisms, absorb to the clean pipe surface [31]. Bacterial growth on bio-films is said to be affected by factors such as water temperature, type of disinfectant and residual concentration, assimilable organic carbon level, biodegradable organic carbon level, degree of pipe corrosion and treatment/distribution system characteristics. [32]

Table 2.8 Other sources of pollution and associated chemical pollutants/conditions:

Source	Common associated chemical pollutants
Cropland	Turbidity, phosphorus, nitrates, temperature, total solids
Forestry harvest	Turbidity, temperature, total solids
Grazing land	Faecal bacteria, turbidity, phosphorus, nitrates, temperature
Industrial discharge	Temperature, conductivity, total solids, toxics, pH
Mining	pH, alkalinity, total dissolved solids
Septic systems	Faecal bacteria (i.e., Escherichia coli, enterococcis), nitrates, phosphorus, dissolved oxygen/biochemical oxygen demand, conductivity, temperature
Sewage treatment plants	Dissolved oxygen and biochemical oxygen demand, turbidity, conductivity, phosphorus, nitrates, faecal bacteria, temperature, total solids, pH.
Construction	Turbidity, temperature, dissolved oxygen and biochemical oxygen demand, total solids, and toxics
Urban runoff	Turbidity, phosphorus, nitrates, temperature, conductivity, dissolved oxygen and biochemical oxygen demand

Birhanu (2007) also presented that in the city, septic tanks, open dumps, improper construction of latrines and surface impoundments are the most common sources for sewage contamination, so that regular examination of water quality for the presence of pathogenic organisms, chemicals and other physical contents must be conducted to provide information on the level of the safety of water. [33]

Again, several type of land application of waste or storm water may have contact with ground water that lead to ground water contamination. Many particles with domestic wastewater, livestock manure, septic tanks, cesspools, latrines and other on-site systems may also lead to contamination of ground water. Water percolating from these facilities contains viruses, bacteria and parasites and may contaminate ground water supplies. [33] The most recent compilation of waterborne disease outbreak data for the years 1999 and 2000 in USA, indicated that 26 of 37 infectious disease outbreaks were attributed 70.5 % to groundwater by well water sources. Because of the presence of pit latrines close to the water sources, lack or little environmental protection, and poor catchments management, there were increased contamination the sources of water. [33]

Table 2.9 Agricultural impacts on ground water quality.

Agricultural activity	Impacts on groundwater
Tillage/ploughing	Soil compaction can reduce infiltration to the groundwater system.
Fertilizing	Leaching of nitrate to groundwater; excessive levels are a threat to public health.
Manure spreading	Contamination of groundwater, especially by nitrogen
Pesticides	Some pesticides may leach into groundwater causing human health problems from contaminated wells (boreholes).
Feedlots/animal Corrals	Potential leaching of nitrogen, metals, etc. to groundwater
Irrigation	Enrichment of groundwater with salts, nutrients (especially nitrate)
Clear cutting	Disruption of hydrologic regime, often with increased surface runoff and decreased groundwater recharge; affects surface water by decreasing flow in dry periods and concentrating nutrients and contaminants in surface water.
Silviculture	Soil compaction limits infiltration.

Source: United Nations Food and Agriculture Organization (FAO) (1996) Paper 55.

Table 2.10 Connections between the energy extraction/production, power generation, refining, transportation /storage and water quality.

Energy process	Connection to water quality
Oil and gas production	Produced water can impact surface and groundwater
Oil and gas exploration	impact on shallow groundwater quality
Coal and uranium mining	Tailings and drainage can impact surface water and groundwater
Hydro-electric	Can impact water temperatures, quality, ecology
Traditional oil and gas refining	End-use can impact water quality
Bio-fuels and ethanol	Refinery wastewater treatment
Synfuels and hydrogen	Wastewater treatment
Thermoelectric (fossil, biomass, nuclear)	Thermal and air emissions impact surface waters and Ecology
Energy pipelines	Wastewater requires treatment
Coal slurry pipelines	Final water is poor quality, requires treatment
Barge transport of energy	Spills or accidents can impact water quality
Oil and gas storage caverns	Slurry disposal impacts water quality and ecology

Source: United States Department of Energy (US DOE). (2006) Report on the Interdependency of Energy and Water. (Online) Accessed April 6 2015 from http://www.sandia.gov/energy-water

2.7 Treatment of Borehole Water for Drinking/Domestic Uses.

The Treatment of raw water to produce water of potable quality involves primary treatment, secondary treatment and complete treatment. Water used for drinking must be free from contaminants and pathogenic bacteria and may require complete treatment depending on chemical elements that need to be removed. Water for other needs like general cleaning may perhaps need only primary treatment. Hence treatment processes are designed to achieve the quality of the water. The various processes may reduce suspended solids, biodegradable organics, pathogenic bacteria and nutrients such as nitrates and phosphates.

2.8 Empirical Studies

Several studies have investigated the quality of borehole water within and outside Nigeria. The parameters most often assessed include: Dissolved Oxygen, Biochemical Oxygen Demand, Temperature, pH, Turbidity, Phosphorus, Nitrates, Total Solids, Conductivity, Total Alkalinity and Pathogenic Bacteria. Ibeto (2010) cited Asubiojo et al., (1997) that were said to have found toxic metals such as cadmium in the range of 0.06 to 1.1 $\mu g/dm^3$ and lead in range of 0.61 to 1.4 $\mu g/dm^3$ in boreholes and dug wells in basement complex area of Ile-Ife, South-western Nigeria. The high level of lead and cadmium were said to be due to anthropogenic influence including solid-waste combustion, quarrying, gas station activities among others.

Oruonye and Medjor (2009) examined the physicochemical composition of the borehole water in the three resettlement areas of Lake Chad to determine its potability for human consumption using standard procedure. [44] The results showed that although some of the physical and chemical parameters were within the WHO permissible limits for drinking water. Some parameters such as, Fe, NO_2^-, Mg and pH

(1.854 ± 0.0701, 0.70 ± 0.4527, 14.47 ± 0.0816, and 9.13 ± 0.1159 respectively) were within the permitted limits, while others: NO_3^-, Cl^-, hardness, colour and turbidity (1.3667 ± 0.0566, 110.05 ± 0.2244, 867 ± 3.127, 124.64 ± 0.1399, 2.6667 ± 0.3801 and 2.8433 ± 0.0606 respectively) were outside. They stated that the high concentration of Fe, Mg and NO_2- in all the water samples is of great concern because of their health implications and therefore recommended improved water treatment facilities at the resettlement sites so as to safeguard the people's health. In discussing their findings, Oruonye and Medjor (2009) cited Illiya (2007) who carried out physical, chemical and bacteriological examinations in different sources of drinking water in the Lake Chad area and indicated conformity with the World Health Organization (WHO) standard guideline for drinking water except for iron, fluoride and calcium which were found to be outside the range in some instances. [45 & 46]

Bashir and Olalekan (2012) investigated the chemical concentration of borehole water in Yola-Jimeta Metropolis so as to assess their suitability for domestic use. Water samples were collected from twenty-two boreholes, one sample from each of the twenty-two administrative wards (Wards are the lowest political units in Nigeria) in the metropolis. Samples were analyzed in the laboratory using standard guideline procedures suggested by American Public Health Association (APHA). Eleven contamination indicators were tested and results obtained were compared with chemical guideline values for drinking water provided by World Health Organisation (2011) [46] and Standard Organisation of Nigeria (2007). [46] The study revealed chloride (Cl^-), iron (Fe^{2+}), nitrate (NO_3^-), pH, sodium (Na^+) and total hardness ($CaCO_3$) as the main sources of borehole water contamination in the study area. The result showed concentrations of the six chemical contamination indicators (namely; chloride, iron, nitrate, pH sodium and total hardness) in some wards deviated from the

chemical guideline values provided by either WHO or SON but concentration of bicarbonate, magnesium, phosphate, potassium and sulphate fell within the permissible limits. Bashir and Olalekan (2012) further stated the health implications to include hypertensions and heart and kidney diseases which are on the increase in the region. Poor sanitary condition and intensive use of inorganic fertilizer were implicated as sources of contaminants. The study suggested the setting up of water sanitary agencies that will monitor and regulate health based targets of water quality at ward levels. [47]

Omoboriowo et. al. (2012) carried out a detailed study of the physical and chemical quality analyses of several groundwater samples in an attempt to assess the potability of groundwater in Arochukwu area. A total of 10 numbers of boreholes were involved in the water sampling for quality analysis. The waters did not have objectionable colour, odour or taste and were not turbid. The pH had mean values of 6.72, showing acidic and aggressive groundwater in the area. The dominant cations were Ca^{2+} with mean values of 18.6. The Carbonate, Nitrate and Sulphate dominated the anion. CO_3^-, NO_3^- SO_4^{2-} and have mean values of 17.90, 0.049, 6.12, mg/L respectively. The groundwater in the area was found to be generally soft, and free from saltwater intrusion, with low iron constituents .The study therefore, suggested that the groundwater of the area was generally of acceptable quality for household, industrial and agricultural purpose. In discussing the geology and the hydrogeology of the Afikpo Basin (where their study area lies), the study mentioned Nsukka as one of its lithostratigraphic divisions [48 &49] and that the Nsukka Formation (Upper Coal Measure) lies conformably on the Ajali Sandstone occurring from the north of Awka to the Upper Ankpa sub-basin, with lithology of mainly shales, siltstones, sands and coals and lateritic cover. Age of the formation is from upper Maastrichtian to Danian,

and depositional environment is similar in many respects to the Mamu Formation (lower coal measures), consisting of transitional/shoreline, mudflats and swamps, deposited during a largely regressive phase of sea level changes. [50]

Omoboriowo et. al. (2012) observed that groundwater provide, more than half the drinking water consumed by Arochukwu Community at the time of the study and maintained that the advantages of groundwater over other sources are enormous. They cited that generally, it is free of pathogenic organisms and needs no purification for domestic or industrial uses, the temperature is nearly constant, turbidity and colour are generally absent, chemical composition is commonly constant. However, the quality of water usually available for exploitation is often limited by the geography and geology of the area under consideration [50 & 51]. There are discharge areas, where groundwater rises to the surface, and recharge areas, where rain and run-off percolate down to replenish supplies. The groundwater movement is affected by the type of rock comprising the aquifer; water moves quickly through loosely packed layers of rock, slowly through more impermeable ones [50 &52]. Shallow unconfined aquifers are more vulnerable to contamination than are deep ones protected by overlying layers of rock [50 & 53]. Everyday activities of people in an area can bring about possible pollution of groundwater, activities like changing of used engine oil which are left to be washed away by the next rain, others are herbicide, fertilizer, deliberate dumping of waste, leaks from underground tanks (mainly gasoline), septic tanks [50-55]. The study also suggested treatment of the water to adjust pH to between 7.0 and 8.5 by addition of lime. Evaluation of the results showed that the water was suitable for drinking and other domestic purposes as all the constituents fall below the WHO (1992) standard. Also, biological analysis showed that the water in the study area did not pose any threat to life. However, in a view cited by the study, Offodile [56] postulates that deep

wells are the best for area with acidic groundwater. Sources of contaminants in the area such as indiscriminate disposal of waste can be managed to curb the long-term effect that could emanate from such practices. [50]

Omoboriowo et. al [50] noted that water of very low pH may result from discharge of industrial wastes and drainage from mines, and that this can carry high concentrations of ferric and ferrous iron. Although, the measured values of pH, sulphate, nitrate, carbonate, calcium, hardness, conductivity, turbidity compared with WHO showed that they all fall within acceptable limits but the pH value is expected to be buffered. PVC pipes and other non-corrosive materials were recommended to be used for borehole construction in the area [57].

Harold and Xionjun (2014) carried out a literature assessment of the quality of groundwater in basement and alluvial aquifers of Malawi. The assessment summarized results for both bore-holes and shallow wells and pointed that Shallow wells can be open unprotected or closed protected wells. [58-62] It showed that high variations in range of values are expected if protected shallow wells are sampled together with unprotected open wells. It stated that most of the highest values for shallow wells are expected for open unprotected wells. It also cited observed higher values for faecal coliforms (FC) in unprotected open shallow wells both during dry and wet seasons [60-62] and stated that similar observations were made for other parameters such as sulphates (SO_4), turbidity, pH and electric conductivity (EC), pointing that some parameters improve during wet season while others worsen [59-61]. The assessment also provided data on physical characteristics of water quality, stating that average values of pH in most cases indicate near-neutral groundwater compositions with a range of 6 - 8. The permissible level of pH in groundwater for Malawi is in the range 6 – 9. [63] Total dissolved solids (TDS) were quoted as low, 24

mg/L with most of the higher values below the MPL value of 1000 mg/L. However values higher than 1000 mg/L were reported in some areas where higher electrical conductivities were also observed. Also cited are Chilton and Smith-Carington (1984) who observed values of total dissolved solids up to around 2500 mg/L in Livulezi (central) and Dowa West (south-central). On the other hand, Bath (1980) is said to have concluded that total dissolved solids up to 2900 mg/L can be expected in Nkhotakota and surrounding lake shore areas in colluviums and weathered basement. [58, 64 & 65]

On chemical quality, Harold and Xionjun (2014) sated that chloride (Cl) MPL for borehole and shallow well drinking water in Malawi reported was 750 mg/L. [63] However, chloride concentrations up to 4000 mg/L have been recorded in other areas (Shire Valley) and lower than 60 mg/L in Nkhotakota area. [65] British Geological Survey (2004) observed concentrations of chlorides up to 2100 mg/L in groundwater from alluvial deposits close to the edge of the Karoo sediments. [66] In South Rukuru catchment area, chloride concentrations of 4 – 2000 mg/L were reported [65]. Except for places like Chikhwawa [67; 68], Karonga, [69] Mzimba, [70] and Rumphi, [69] all the areas show values below the MPL of 750 mg/L. Nevertheless, the high values recorded in these areas were not rampant, an indication that the average majority of sampled groundwater had values less than 750 mg/L with very few exceptions. [58] calcium and magnesium values in some places had values outside the expected nationwide range and in some instances higher than the recommended MPL of 200 mg/L. The MPL for total iron (Fe) in groundwater for Malawian aquifers assessed is 3 mg/L [71]. The nationwide expected range is 1 – 5 mg/L in both weathered basement and alluvial aquifers. [72] According to UN (1989), the range for total iron in weathered basement rocks and alluvial sediments is 1 – 5 mg/L. [58; 73] The total hardness (TH) in

groundwater used for drinking reported was 800 mg/L $CaCO_3$. [71] Manganese (Mn) concentrations of 0.1 – 0.4 mg/L is said to have been reported in Central plains, [74-76] <0.001 mg/L in Mchinji, [77] <0.4 mg/L in Mzimba [70] and 0 – 0.29 mg/L in Nkhatabay [78] and the values are said to be below the MPL of 1.5 mg/L. Trace elements such as copper, lead, strontium, cadmium, boron, barium, beryllium, chromium, mercury are reported to have been analyzed in some areas including Nkhatabay and Lower Shire [67, 74-76; 78; 79]. However, no significant values were identified in these areas. [58] Phosphates of 0.16 – 1.16 were reported in Nkhatabay [78] while another study in Machinga indicated that phosphates do not pose a challenge. [80; 81] Ammonia (0.0 – 0.5 mg/L) and nitrite (0.0 – 0.06 mg/L) were studied in samples in Blantyre [82] and were found to be lower than the MPL set by WHO (2008) of 1.5 and 3 mg/L, respectively. [83] Based on spot checks carried out by the ministry as well as studies done by various researchers in Malawi arsenic was said not be an issue. [59, 60, 78; 82] All the arsenic values reported were below the MPL of 0.5 mg/L. [71]. As put by Harold and Xionjun (2014), generally, it has been observed that alluvial aquifers probably have high salinity values particularly in lower Shire valley, eastern Bwanje valley and around Lake Chilwa [84] while low salinity values for groundwater from weathered basement in the Bua catchment of western Malawi are on record [65] but elsewhere, in colluviums and basement aquifer, a very variable salinity has been observed in South Rukuru catchment area and in some instances high salinity values were recorded around Emcisweni in Mzimba District [65].

Harold and Xionjun (2014) also presented findings on faecal coliforms in groundwater. As put by the assessment, aquifer microbial contamination is from pit latrines, septic tanks, cesspool, leaky sewers and landfill leachate [85]. Major variations in faecal coliforms are observed between wet and dry seasons. Wet seasons are

expected to produce shallow well waters with high faecal coliforms, especially if open and unprotected. However boreholes exhibit lower and below MPL for faecal coliform. Faecal coliform values of 129 – 920 colony forming units (cfu)/100 mL were observed in shallow wells in Mzuzu. [86] The conclusion drawn from these data as pointed was that that the wells are contaminated since the values exceed the maximum recommended value of 50 cfu/100 ml [71]. On the overall quality of groundwater, the assessment stated that high contents of cations, anions and total dissolved solids (TDS) are limiting factors to the use of groundwater [66; 87] and concluded that studies in the literatures assessed do not conflict in the fact that groundwater quality in Malawi can be classified as good except for some sporadic zones where some elements exceed recommended drinking water guideline values. [58]

Elsewhere in South Africa, an assessment on the physicochemical quality of several borehole water sources, used by rural schools in Greater Giyani Municipality, using atomic absorption spectroscopy and ion chromatography to determine the chemical quality of the water sources revealed that the pH of the water samples varied between 5.29 and 8.3 and tended to be lower in rainy season and higher in dry season. The turbidity values varied between 6.17 and 44.7 NTU in some of the schools. High concentrations of magnesium and total hardness were obtained from all water sources. Calcium concentrations were high in some schools. Anions such as chloride and sulphate were within the recommended Department of Water Affairs and Forestry (DWAF) limits except for two sampling points. High concentrations of nitrates were obtained from all schools except in Nyanisi high school. There were no fluorides and phosphates from all schools. Heavy metals like arsenic, iron, cadmium and lead were within the recommended DWAF limits. The results obtained in the study indicated that the water from the studied boreholes was not suitable for human consumption

based on hardness and nitrate content and may pose a serious threat to the health of the consumers and therefore called for urgent intervention in order to reduce such chemicals and preserve the health of the school children. [88] In the study, physical parameters such as conductivity, turbidity, pH and temperature were measured in the field using cyberscan 500 conductivity meter, AQ2010 LABOTEC turbidity meter, H1 8014 HANNA instrument pH meter and Mercury thermometer, respectively. pH meter was calibrated in a buffer solution of pH of 7 and 10 before measurement. The probe was immersed in water sample and readings were taken. After taking the reading, the probe was rinsed with distilled water. The turbidity meter was calibrated using 1, 10, 100, and 1000 NTU standards provided by the manufacturer. After calibration, the readings were taken. For chemical Analysis, water samples were collected using polyethylene or Teflon vessels were used, and before use, the containers were washed and stored in 10% nitric acid for two days and rinsed with double distilled water. Samples were collected once in a month (during June, August, September and October). The water was left to run for 3 to 4 min to avoid collecting water with high accumulation of metals stemming from pipes, soldering and welds. Three samples were collected in each point. The containers were completely full to avoid oxidation. Depending on the pH, the samples were stabilized with nitric acid except for the samples used for the determination of nitrate. [88; 89] The study established the chemical quality of the water samples by conducting an anion analysis using a Metrohm 850 professional ion chromatograph. Heavy metals were determined by use of a Varian 220 atomic absorption spectrophotometer coupled to a GTA 110 electrothermal atomiser. The standards were prepared in accordance with [90; 91]. Atomic absorption spectroscopy and ion chromatography are used to measure the

concentrations of metals and non-metals, respectively [92]. Methods used for the measurement of anions include ion chromatography and titration method [93].

The study revealed that for all the schools, the pH values ranged from 5.29 to 8.23. These values were generally higher compared to values obtained from the western coast of Africa in Lagos, Nigeria, where Adebo and Adetoyinbo (2009) described pH values mostly around 7. [94] For the 1st sampling (June) and the 2nd sampling (August), the pH values of ground-water in all the schools were within the recommended [95] limits for human consumption of 6.0 to 9.0. During September and October, the pH values of the high school borehole water from most of the storage tanks, were less than 6, and hence were below the recommended [95] limit for human consumption.

In most cases, particularly in spring (September) and beginning of rainy season (October), the pH was less than the recommended [95] limits for human consumption, the pH range was from 5.29 to 5.94. Contrary to a study conducted in the Province of North West South Africa, where the pH was generally higher varying from 6.5 to 9.1 [96]. Similarly, it is reported that a study in Pakistan found that the pH was much higher compared to those found in the study [88]. The pH values reported in the study tended to be higher in dry season compared to spring and beginning rainy season and were much lower compared to those described in Nigeria where the pH varied from 6.3 to 7.1 during the dry season and 6.2 to 8.00 during the wet season [97].

For all the boreholes, the temperature values ranged between 18 to 29°C during dry season and increased from 25°C to a maximum of 34°C during rainy season. High temperatures were achieved during September and October months. It was noted that Warm water holds less oxygen than cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life [98]. Some

compounds are also more toxic to aquatic life at higher temperatures. [88] The temperatures observed in the study were slightly lower compared to those described in Nigeria [99] where temperature range of 26.5 to 33.0°C were described. [88] The electrical conductivities for all the boreholes were within the recommended [95] of 0 to 70 mS/m. That indicated that the water was not salty and as such was said to be drinkable and capable of slaking thirst. The reason given was that conductivity is an indicator of total dissolved salts (TDS), and also tells whether the water is drinkable and capable of slaking thirst or not. [100]

The turbidity values for the high school borehole water from some storage tanks were within the recommended [95] limits for human consumption of 0 to 1 NTU throughout the sampling period. During September, the turbidity of the primary school borehole water from some storage tanks, were above the recommended [95] limits for human consumption. The high turbidity values are said to constitute a health risk for the children consuming the water. High turbidity also reported to indicate higher amount of total suspended solids which might include micro-organisms such as bacteria or parasites as well as an increase in the concentration of minerals [99; 101]. Heavy metals assessed included iron, lead, cadmium and arsenic. The iron concentrations during August and October in Nyanisi high school borehole water from storage tank were (0.38 and 0.22 mg/L, respectively) both above the recommended [95] limit of 0.1 to 0.3 mg/L for human consumption. The concentration of lead and cadmium from all the boreholes were said to be within the recommended concentrations of 0 to 10 mg/L and 0 to 5 mg/L, respectively. The concentrations of arsenic from all the schools were within the recommended limits of 0 to 10 mg/L. The arsenic values obtained were less than 0.1 mg/L. Unlike in many African countries where arsenic contamination of groundwater is rare, many Asian countries face the

problem of arsenic in ground water like Bangladesh, Malaysia and Pakistan, and in some cases have serious health and social implications [102-104]. Heavy metal cations including those of magnesium and calcium were found to be present. The concentrations of magnesium from all the schools boreholes were outside the limits of 0 to 30 mg/L recommended for human use. [95] In another study in the North-West of South Africa cited, 45% of the boreholes did not comply with the magnesium limit [96]. It was estimated that the most common source of calcium and magnesium in groundwater was through the erosion of rocks, such as limestone and dolomite, and minerals, such as calcite and magnesite. [105] Magnesium said to give undesirable taste to drinking water and may have a laxative effect, particularly with magnesium sulphate concentrations above 700 mg/L; although the human body tends to adapt to this laxative effect with time [106].

The concentrations of calcium were outside the recommended [95] limits of 0 to 32 mg/L for human consumption. An intake of high concentrations of calcium is said to adversely affect the absorption of other essential minerals in the body and over a long period of time intake of higher amounts of calcium raises the risk of kidney stones in some people [107]. In the study by Mpenyana-Monyatsi and Momba (2012) cited, 43% of borehole water tested did not comply with the calcium limit in the North West Province of South Africa. [96; 88] The concentrations of calcium in the borehole water from the storage tanks were within the recommended [95] limits for human consumption but the total hardness concentrations for all the school boreholes were outside the South African recommended [95] limits of 50 to 100 mg $CaCO_3$/L. This according to the study indicates that hardness seems to be a major problem with ground water. Similar results were found in Cameroon where it was found that groundwater contents of Ca^{2+}, Mg^{2+} and HCO^{3-} and total hardness (TH) all exceeded

World Health Organization (WHO) standards. [108] Again, similarly results were found in Gujarat, India. [24, 109] The results of assessment of anions including chloride, nitrate, sulphate, fluoride and phosphate were presented. The concentrations of chloride from all schools were within the recommended [95] limits of 0 to 100 mg/L, except for Khomisani primary school bore-hole water from storage tanks 1 and 2 which were higher than the recommended limits. However, the nitrate concentrations from all the schools borehole water reported as above the recommended [95] limits of 0 to 6 mg/L for human consumption, except for Nyanisi high school borehole water from storage tank which were within the recommended limits. [88]

The sulphate concentrations from the water from all the schools boreholes were within the recommended [95] limits of 0 to 200 mg/L for human consumption, except for Nyanisi high school borehole water from storage tank in which the concentrations were higher than the recommended [95] limits. There were no fluorides and phosphates from all the schools borehole water. Analysis were done twice but the concentrations were below the detection limits of the instrument used (ion chromatography). [88]

According to South African Water Quality Guidelines [95] set in 1996, the results obtained in the study exceeded the limits for nitrates and hardness in all the schools borehole water. The limits for chloride exceeded the guidelines. [88; 95] High concentrations of such elements make water unsuitable for domestic purposes (that is, drinking, cooking and cleaning). Consumption of drinking water high in nitrates causes methemoglobinemia in infants [13, 104]. High concentration of chloride causes salty taste in water while high concentrations of sulphate may result in diarrhoea. Samie et. al. (2012) concluded that following the results obtained, the borehole water samples studied had poor physicochemical quality but the origin of contamination

could not be identified. The researchers thus emphasized the need for further investigation to establish the actual source of chemical contamination and recommended a short term solution to initiate the use of methodologies that can further remove these salts from the water such as ultra filtration or reverse osmosis before distribution through the taps. [88]

Njar et. al (2012) assessed heavy metals status of boreholes in Calabar South Local Government Area of Cross River State, Nigeria. In the study, four functional boreholes in the area were sampled. As reported, result showed that the concentrations of iron (Fe), zinc (Zn) and Manganese (Mn) were within WHO maximum permissible limit with mean values of 0.065 ml-1g, 0.015 mg/L and 0.002 mg/L respectively. The proportion of copper (Cu), chromium (Cr) and lead (Pb) in the sampled boreholes reported was zero, indicating the absence of these metals in the sampled boreholes. The absolutely low levels of heavy metal contents across the sampled boreholes showed they were not polluted and as such suitable for human consumption. The low content also revealed that boreholes in the area were located far away from dumpsites; soak away pits, automobile shops and other forms of heavy metal contaminants [110].

However, in discussing the physicochemical parameters of the water samples from the four boreholes, Njar, et. al stated that the borehole water samples were acidic with mean pH value of 5.56 and attributed the acidic nature of borehole water to the presence of tiny shale intercalations in the aquiferous coastal plain sand [111]. The pH values are below the minimum desirable limits of 6.5. [112] The values of total suspended solids

(TSS) and turbidity recorded were zero; reported to mean that the water samples were harmless and ideal for human consumption; and that it indicates the absence of organic and inorganic solids [111]. The conductivity of the borehole samples varied with

a mean value of 357 µS/cm within WHO desirable limit of 500µ/Scm for drinking water. [112] However, total hardness of the water samples ranged from 16.00 to 32.00 mg/L with a mean value of 32.00 mg/L, and is below WHO 500 mg/L acceptable limit, meaning the water is soft and foamy as reported [110]. In discussing the results obtained from assessment of heavy metals, Njar, e. al. (2012) pointed that the concentration of iron (Fe) in the borehole water ranged between 0.016 to 0.088 mg/L with a mean value of 0.065 mg/L.

Fe content in the sampled boreholes is within WHO maximum permissible limit of 0.3 mg/L. The value of manganese (Mn) ranged from 0.002 to 0.003 mg/L with a mean value of 0.002 mg/L within the maximum desirable limit of 0.5 mg/L [112]. The report discussed that due to the low concentration of Mn in the water from the sampled boreholes, algal growth would not be promoted in reservoirs or collection tanks. [113] Zinc is considered non-toxic, but excess amount can cause system dysfunctions that result in impairment of growth and reproduction. The clinical signs of zinc have been reported to include vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, kidney failure and anaemia [114; 115]. Zinc (Zn) content in the borehole water samples ranged from 0.012 to 0.018 mg/L with a mean value of 0.015 mg/L is within WHO maximum allowable of 5.0 mg/L for drinking water (Table 2.1). This indicates that the sampled water contained the right proportion of Zn which is an essential plant and human nutrient element. The low concentration further implies the boreholes do not have caustic taste, hence ideal for consumption and other domestic uses. Lead is the most toxic of the heavy metals. Its inorganic forms are absorbed through ingestion by food, water and inhalation [116]. In humans exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. High levels of exposure may result in toxic biochemical effects

in humans which in turn cause problems in the synthesis of haemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system [115; 117]. The proportion of lead (Pb) in the sampled boreholes was zero, indicating the absence of lead contamination. Copper is an essential substance to human life, but in high doses it can cause anaemia, liver and kidney damage, and stomach and intestinal irritation.

Copper occurs in drinking water from copper pipes, as well as from additives designed to control algal growth. Just like Pb, Cu and Cr were absent in the sampled boreholes. Chromium is used in metal alloys and pigments for paints, cement, paper, rubber, and other materials. Low-level exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage too circulatory and nerve tissue. Chromium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of chromium [117]. The proportion of copper (Cu), chromium (Cr) and lead (Pb) was zero, indicating the absence of these metals in the sampled boreholes. Njar et. al (2012) concluded that the absolutely low levels of heavy metal contents across the sampled boreholes show they are not polluted and as such suitable for human consumption. The low content also reveals that boreholes in the area are located far away from dumpsites, automobile shops and other forms of heavy metal contamination and that the result therefore implies that the quality status of boreholes in the area is not in any way polluted, as the examined parameters are within WHO maximum permissible limits for drinking water. [110]

In Gombe Metropolis, North-eastern Nigeria, Ahmed, Haruna and Abubaka (2013), studied groundwater from wash-boreholes to ascertain its quality status and suitability for drinking and domestic uses. The physicochemical and bacteriological analyses

conducted were in accordance with the standard procedures. The mean values for temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), sulphate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-), hardness, copper, manganese, total were within the permissible limits recommended by the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO) standards with the exception of nitrate (NO_3^-).

In the investigation, three wards namely Tudun Wada, Pantanmi and Jeka da Fari in Gombe Metropolis were chosen. In each of the wards, 3 wash-boreholes were randomly selected. 4 water samples (replicates) were collected from each wash borehole using sterile 1000 mL polythene containers. Before collection, the mouth and the outer parts of the borehole taps were sterilized with the flame of a cigarette lighter, and allowed to cool by running the water for about 1 minute as reported. Thereafter, the sample bottles were said to have been rinsed with the sample water before filling them. The bottles were held at the bottom while filling, to avoid contamination of water from the hands or fingers [114]. All the sample containers were kept in ice boxes and brought to the laboratory for analysis.

Temperature, pH and Conductivity, were directly measured on site using a portable multipurpose pH, Temperature and conductivity field meter. Total Dissolved Solids (TDS) calculated from the conductivity values obtained. Turbidity determined with a HACH 2100 P Turbidity meter. Nitrate, nitrite, sulphate, phosphate and flouride contents were colorimetrically analysed using DR890 Colorimeter. Trace elements – Copper, Iron and Manganese were determined using Atomic absorption Spectrophotometer (AAS, Unicom 969) after extraction with Aqua-regia.

The mean temperature values recorded in water samples were 26.38OC, 29.93OC and 29.73^{O}C for wards A, B, and C respectively. The levels of pH recorded were

5.64±0.78, 6.74±0.51 and 6.60±0.17 for ward A, B and C, respectively. The mean values of Electrical Conductivity were 272.0 µS/cm, 116.7 µS/cm and 553.3 µS/cm for wards A, B and C, respectively. Laboratory analysis revealed that the mean turbidity values of the wash-borehole water were 7.76 NTU, 9.02 NTU and 14.15 NTU for ward A, B and C, respectively. The results of the analysis revealed that wash-borehole water samples obtained from the three wards A, B and C had their mean concentration of Total Dissolved Solids (TDS) as 136.0 mg/L, 58.42 mg/L and 276.67 mg/L, respectively. Ward A had a mean nitrate concentration of 33.80 mg/L, while wards B and C had mean concentrations of 21.80 mg/L and 23.34 mg/L, respectively. The NO_3- levels in the waters exceeded the tolerable limit set by WHO (10mg/L) [115], which suggested that there was an indication of NO_3- pollution in the water sources. The high concentration of NO_3- in the wash-borehole water was attributed to the intrusion and contamination of nitrogenous wastes coined from dumped wastes and human waste from proximate dump sites and pit latrines. The mean SO_4^{2-} concentrations in water samples were 5.67 mg/L for ward A, 2.01 mg/L for ward B and 21.82 mg/L for ward C. The sulphate values in water samples collected from all the three wards were quite below 100 mg/L recommended limits set by both national and international drinking water regulatory authorities. Ward A had a mean phosphate value of 1.12 mg/L, while wards B and C had their mean phosphate values as 0.07 mg/L and 10.82 mg/L, respectively. No fluoride was detected in water samples obtained from ward A. However, in ward B and C mean fluoride concentrations of 0.80 mg/L and 0.40 mg/L were recorded, respectively.

The hardness of drinking water is determined largely by its content of calcium and magnesium. It is expressed as the equivalent amount of calcium carbonate that could be formed from the calcium and magnesium in solution.

The mean values for hardness were 2.42 mg/L, 0.95 mg/L and 2.33 mg/L for wards A, B and C, respectively. Thus, the wash-borehole waters showed their suitability for drinking, as their values were far below the recommended limits given by NSDWQ and WHO as 150 mg/L and 200 mg/L, respectively. The level of Iron in wash-borehole water in ward A (0.14 mg/L) was within the NSDWQ and WHO agreed limits of 0.3 mg/L. However, the levels in wards B (0.93 mg/L) and C (0.79 mg/L) were above the recommended limits approved by WHO and NSDWQ. The levels of copper (Cu) were not detected in the water samples collected from wards A and B. Even in ward C, the amount detected (0.05 mg/L) was very low and far below the recommended limits of 1.0 mg/L set by both WHO and NSDWQ. The manganese concentrations, 0.20 mg/L, 0.06 mg/L and 0.09 mg/L for wards A, B and C, respectively, fall within the desired limit of 0.2 mg/L recommended by the NSDWQ. The study concluded that the water obtained from the wash-boreholes if use for drinking purpose could lead to outbreak of some health problems especially gastroenteritis disease since the water from all the three wards contained high levels of turbidity and nitrite (NO_2^-) above the limits recommended by the Nigerian regulatory authority for drinking water and also, contained level of nitrate (NO_3^-) beyond the WHO limit. [116]

In Ghana, it is reported that there have been major expansions on the Kumasi water supply system all in the bid to meet the demand of its ever-growing population. However, many places in the metropolis are believed to be experiencing interrupted water supply and Kwame Nkrumah University of Science and Technology (KNUST) even though it is a priority area, continues to experience water shortages. In a bid to cover these shortages, colleges, departments, hostels etc. have drilled boreholes to

make up for the shortages. As a result, many boreholes are dotted over the university campus serving the needs of individual departments and hostels. [18]

Boakye, O. R. (2013) assessed the groundwater potential of KNUST and estimated the daily water demand for the university to be 3000m^3. The potential of all the boreholes drilled on campus was assessed to be 2220m^3 when pumping for 18 hours a day. The water quality from the boreholes has been analysed and the results showed no major health concerns in terms of iron, lead, manganese, arsenic and fluoride. The presence of coliform was however found and the pH value was slightly acidic and is said to be a health risk to consumers. Therefore the water from the boreholes requires a limited amount of treatment in respect of disinfection and pH correction. [18]

Akinbile and Yusoff (2011) assessed the groundwater quality near a municipal landfill in Akure, Nigeria and found that all but one of the boreholes was strongly polluted. Physicochemical parameters studied included turbidity, temperature, pH, Dissolved oxygen (DO), total dissolved solids (TDS), Total Hardness, Total Iron, Nitrate, Nitrite, Chloride, Calcium and heavy metals such as Copper, Zinc and Lead using standard laboratory procedures. Most of the parameters indicated traceable pollution but were said to be within the World Health Organization (WHO) limit for consumption.

The pH ranged from 5.7 to 6.8 indicating toxic pollution, turbidity values were between 1.6 and 6.6 NTU and temperature ranged from 26.5 to 27.50C. Concentrations of iron, nitrate, nitrite and calcium ranged from 0.9 to 1.4 mg/ L, 30 to 61 mg/L, 0.7 to 0.9 mg/L and 17 to 122 mg/L respectively. For heavy metals, zinc ranged between 0.3 and 2.3 mg/L and lead ranged from 1.1 to 1.2 mg/L. The study suggests that the water be treated before being used for domestic purpose. This is

because though it ranged from 17 to 122 mg/L, below the WHO and NSDWQ levels, the presence of chlorides connotes pollution. [117 & 118]

The results obtained by Akinbile and Yusoff confirmed leachate infiltration into the wells [119 & 120] as evidenced by the presence of colour [117]. Similar views regarding temperature values obtained as ranging from 26.5 and 27.5^{0}C (outside the range of the WHO standard of 5^{0}C for domestic water) and that this indicates the presence of foreign bodies were reported in another study [121]. The high values recorded for both colour and temperature in the water samples analyzed were suspected to be due to pollution from a nearby abattoir. The turbidity readings of the samples were found to be above the WHO and NSDWQ standards with samples W1, W2 and W3 having average turbidity values of 6.6 NTU, 3.5 NTU and 1.6 NTU respectively. Similar high turbidity values had also been reported by another study [122]. Heavy usage of Dissolved Oxygen, DO, by the pollutants were said to have been noticed. Again similar results were had been reported [123] underlining the presence of pollutants in appreciable quantities. DO is an important factor used for water control quality and similar values were had been reported [118 & 121]. The nitrate values in the study ranged from 30 to 61 mg/L, showing appreciable presence of pollutants in all the water samples. Nitrite also ranged from 0.7 to 0.9 mg/L and all these agree with observations made by a previous study [118] Heavy metals tested were not detected with the exception of iron, lead, zinc and chromium metals which indicated suspected presence of toxic wastes from disposed battery cells, used aerosol cans and other materials with certain degree of toxicity. Iron and Lead ranged from 0.9 to 1.2 mg/L and 1.11 to 1.2 mg/L which indicated the presence of toxic wastes in the landfill. Zinc ranged from 3.3 to 5.4 mg/L which also indicated pollution. Again similar results were reported [118, 122,124 & 125]. Cyanide, mercury and silver were not detected.

However, the presence of chromium (0.25 Mg/L) in the sample 100 metres from the landfill suggested pollution from a nearby abattoir and not from the landfill site as reported. Similar view as this was shared [117 & 118].

Nwachukwu et. al. (2014) conducted a human health risk assessment in relation to heavy metals in water sources in rural regions of south east Nigeria and reported that the Total Hazard Index (THI) of the water bodies assessed were of high risk one river.[125] In the study, the concentration of arsenic (As) in most of the water samples were higher than the WHO maximum set limit of 0.050 mg/L for domestic water. The hazard risk reported by the study for arsenic, cadmium (Cd), chromium (Cr) and lead (Pb) were found to be greater than one (> 1) and thus said to constitute moderate risk. The metals were determined using flame atomic absorption spectrophotometer (Model UNICAM 929) with air/acetylene flame except for mercury where cold vapour was used and the determinations were carried out according to the standard methods for water quality prescribed by APHA 1998. [125]

CHAPTER THREE

3.0 EXPERIMENTAL

3.1 Description of Study Area:

The Study Area, Enugu North is one of the three Senatorial Districts in Enugu State, Nigeria. It comprises of seven Local Government Areas (LGAs) including Igbo Etiti, Igboeze North, Igboeze South, Isi-uzo, Nsukka, Udenu and Uzo-Uwani. As of 2007, Enugu North Zone had an estimated population of 1,377,001. [126]

A ten-day reconnaissance survey of the twelve towns and communities within the study area was conducted to identify sites for sample collection and marked with Geographical Positioning System (GPS Garmin 724). The 12 sample locations and their designation are shown in Table 3.1. Fig. 3.1 is the map of Enugu State showing Enugu north Senatorial District (study area) highlighted in green colour.

During the survey, the following demographic information was collected:

3.1.1 Demographics of Enugu North Senatorial District

Table 3.1a Study area

Uzo Uwani LGA (bordering Kogi State and Anambra State).

•Headquarters:	the town of Umulona.
•Coordinates:	6°45′N 7°12′E / 6.750°N 7.200°E
•Total Area	855 km^2 (330 sq mi)
•Total Population	124,480 [126]

Igbo Etiti LGA

•Headquarters:	the town of Ogbede.
•Coordinates:	6°40′N 7°22′E/6.667°N 7.367°E
• Total Area	325 km^2 (125 sq mi)
• Total Population	209,248 [126]

Udenu LGA

•Headquarters:	the town of Obollo-Afor.

•Coordinates: 6°55′N 7°31′E / 6.917°N 7.517°E

• Total Area: 248 km 2 (96 sq mi)

• Total Population: 178,466 [126]

Igbo Eze North LGA (It borders Kogi State and Benue State)

•Headquarters: the town of Enugu-Ezike.

•Coordinates: 6°59′N 7°27′E / 6.983°N 7.450°E

• Total Area: 293 km^2 (113 sq mi)

• Total Population: 259,431 [126]

Igbo Eze South LGA

• Headquarters: the town of Ibagwa-Aka.

• Coordinates: 6°55′N 7°24′E / 6.917°N 7.400°E

• Total Area: 158 km 2 (61 sq mi)

• Total Population: 147,328 [126]

•Major economic activities: Agriculture and trade.

•Climate:

•Rainy season: March/April - October/November.

•Annual rainfall: varies from 1,400 mm to 2,000 mm

•Annual relative humidity during rainy season [at an average annual temperature above 20 °C (68.0 °F.)]: 75%

•Humidity in the dry season: 90%

Nsukka LGA

Coordinates: 6°51′24″N 7°23′45″E / 6.85667°N 7.39583°E

• Total Area: 45.38 km^2 (17.52 sq mi)

Elevation: 1,810 ft (550 m)

• Total Population: 309,633 [126]

Other Neighbouring towns: Adani, Edem Ani, Ede- Oballa, Enugu Ezike, Ibagwa Ani, Nimbo, Mkpologwu, Orba, Opi, Obimo, Obollo-Afor, and Uzo Uwani.

Isi Uzo LGA

Coordinates: 6°47′N 7°43′E / 6.783°N 7.717°E

• Total Area: 877 Km^2 (339 sq mi)

• Total Population 148,415 [126]

Headquarters: are in the town of Ikem.

The central town in this zone is Nsukka where the University of Nigeria is sited

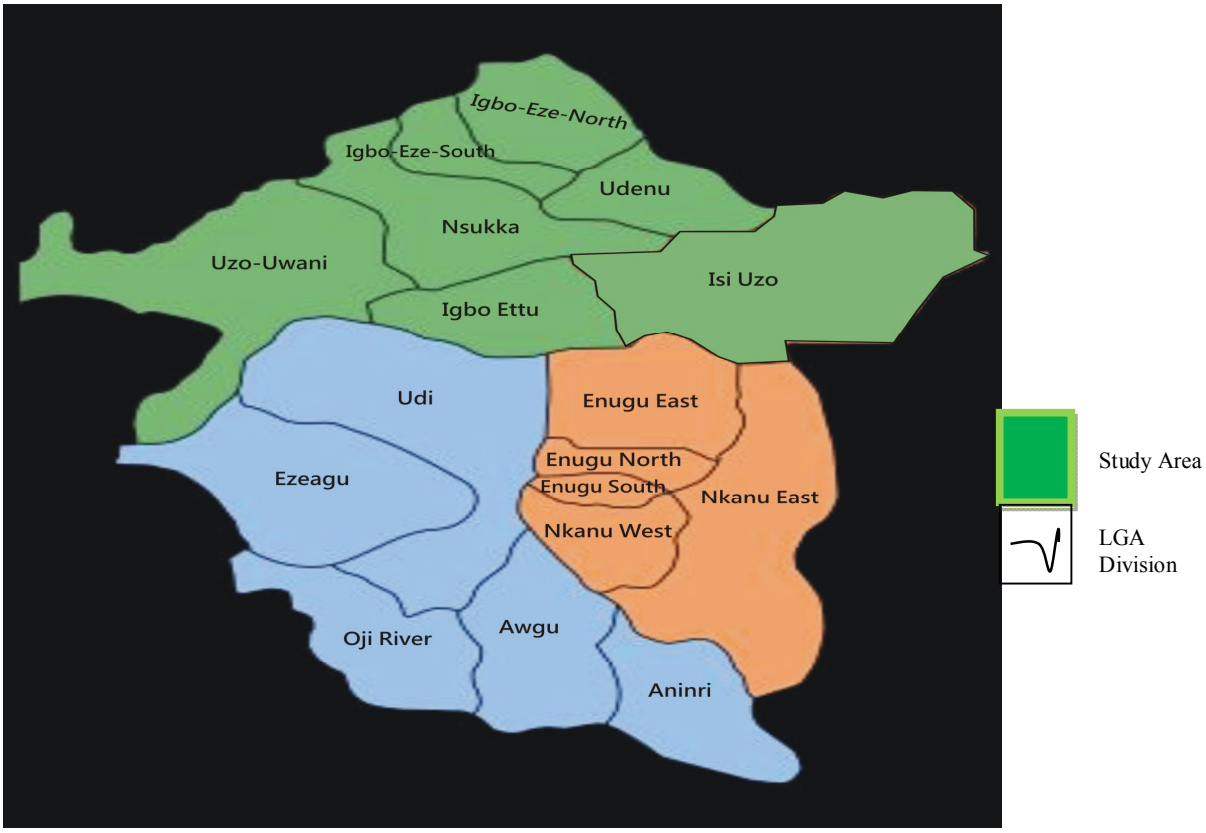

Fig. 3.1: Map of Enugu State, showing Study Area (Enugu North Senatorial District).

3.2 MATERIALS AND METHODS

3.2.0 Sampling and Sample Collection

3.2.1 Sampling

Sampling was done to extensively cover the area of study. The sampling operation/technique was done so as to:

► collect only representative samples for laboratory analysis; that is samples in which the concentration of analytes (determinants) are identical to the borehole water in question at the time of sampling.

► ensure that the samples collected for analysis do not become contaminated between sampling and analysis. This is by considering and preventing potential sources of hazards during sample collection and transportation.

Borehole water was collected from twelve sample points covering the seven LGAs in the study area. The sampled boreholes were determined by spatial and depth distribution so as to allow reasonable distribution across and within the target area of study. The sample points and their locations are as shown in Table 3.1b:

Table 3.1b: Sample Points and Locations

Sample Designation	LGAs	Town/GPS Coordinates	Sample Points/surrounding features
BH1	Igbo-Eze North	Enugu-Ezike (N: 6 ^{0} 41'24" E: 7 ^{0} 06' 53")	Umuitodo Community Borehole (farmland, residential houses, automobile road).
BH2	Nsukka	Nsukka(N: 6 ^{0} 51'24" E: 7 ^{0} 23' 01")	University of Nigeria Nsukka/Odili Hostel Borehole (farmland at pumping site)
BH3	Udenu	Obolo (N: 6 ^{0} 34'08" E: 6 ^{0} 27' 54")	Commercial Borehole at Mr Jude Ogbu's residence (residential houses, market, busy vehicular activities/roads)
BH	Igbo-Eze South	Ovoko (N: 06 ^{0} 41'33" E: 007 ^{0} 11' 04")	Commercial Borehole opposite First Bank Plc. (residential houses, farmlands busy vehicular activities/roads)
BH5	Igbo-Etiti	Ogbede (N: 5 ^{0} 23'46" E: 6 ^{0} 30' 12")	Ukehe Community Borehole. (market, surrounding farmlands, residential houses, market, busy vehicular activities/roads)
BH6	Nsukka	Opi (N: 06 ^{0} 43'36" E: 007 ^{0} 13' 08")	Commercial Borehole at Opi Junction (Petrol station, cement block factory, farmlands, automobile and metal bending workshops; church).
BH7	Isi-Uzo	Eha Amufu (N: 06 ^{0} 42'35" E: 007 ^{0} 13' 05")	Hand Driven Borehole at Federal College of Education, Eha-Amufu (refuse dump site; nearby farmlands).
BH8	Nsukka	Eha-Alumona (N: 06 ^{0} 43'35" E: 007 ^{0} 13' 07")	Public borehole (surrounding farmlands).
BH9	Uzo-Uwani	Adani (N: 06 ^{0} 43'30" E: 007 ^{0} 13' 00")	Residential borehole(residential houses distant farmlands)
BH10	Nsukka	Ede-Obala (N: 6 ^{0} 43'35" E: 007 ^{0} 13' 09")	Borehole at a church premises (Aluminium warehouse, automobile repair shops, district hospital, block-moulding industries, hotel, metal-welding workshop, etc)
BH11	Nsukka	Ibagwa-Agu (N: 06 ^{0} 41'34" E: 007 ^{0} 11' 06")	Borehole close to farmland and residence.
BH12	Nsukka	Okpuje (N: 06 ^{0} 41'30" E: 007 ^{0} 11' 02")	Commercial borehole (busy, building site, metal welding workshops, farmland).

BH = Borehole Location.

Borehole water samples for the study were collected at monthly intervals from December 2014 to June, 2015 for the twelve sampling points. The selected borehole water sources were those used for drinking and other domestic purposes such as cleaning and cooking.

I: General Preparation of Sampling Containers

The following method was used in preparing all sample containers and glassware for monitoring conductivity, total solids, turbidity, pH, and alkalinity. Latex gloves were worn.

1. Each sample container was washed with phosphate-free detergent.
2. They were rinsed three times with tap water.
3. They were also rinsed three times with deionized water and dried. These were kept in a clean environment with temperature maintained approximately 4 ^{0}C.

II: Acid Wash Procedure for Preparing Sampling Containers

This method was used in preparing all sample containers and glassware for monitoring nitrate and phosphate. Latex gloves were worn. Each sample bottle was:

1. Washed with a brush and phosphate-free detergent.
2. Rinsed three times with cold tap water.
3. Rinsed with 10 percent or 1:1 hydrochloric acid.
4. Rinsed three times with deionized water and dried.

These were kept in a clean environment with temperature maintained approximately 4 ^{0}C.

Polyethylene containers were used for samples in which anions were being determined while glass containers were used for samples in which heavy metals were determined to prevent leaching of the heavy metals from the samples.

The samples were preserved as stated in section 3.3.

3.3 Sample Collection, Preparation and Storage:

Groundwater samples from twelve boreholes were collected in the clean sterilized two litre polyethylene containers with tightly fitting covers; wrapped in black polyethylene plastic bags and put in an improvised ice-box. The twelve samples were collected from twelve different sample points in the seven Local Government Areas in Enugu North Senatorial District for the analysis and were immediately transported to the laboratory for analysis. At the collection points, the sample containers were meticulously rinsed with the borehole water before filling them with the sample.

Before each sampling (collection of the water samples), the taps were purged, that is, stagnant water from the bores or pipes was removed. This was done by allowing the water to flow for a while and observing electrical conductivity and temperature of the discharge water to stabilise. Thus the water was left to run for 5 to 10 minutes before collection. The collected water samples were stoppered, labelled and thereafter refrigerated at 4°C in the laboratory prior to analysis. The samples for heavy metals were preserved by adding 5 mL concentrated HNO_3 to prevent metals from adhering to the walls of the containers. The filtration of samples was done using 0.45 mm millipore membrane paper placed in an all glass millipore filtering system. The membrane filters were washed with 1% HNO_3 followed by rinsing in high purity water prior to filtration. [127] After sampling, field (physical) parameters such as pH,

Electrical Conductivity (EC), Total Dissolved Solids (TDS); Temperature were measured directly in a flow cell (Fig. 3.2) connected to a multi-parameter meter to avoid contact between the ground water and the atmosphere and then in situ using a new Hanna multi-meter with replaceable electrodes. The equipments were accurately calibrated against known standard according to standard operating procedure and following manufacturers' instructions. The known standards were newly purchased from reputable laboratory supply companies (BDH, England).

Fig.3.2 Flow cell used to monitor the field parameters.

3.4 Procedure:

Physical Parameters determined included electrical conductivity (EC), temperature, total suspended solid (TSS), total solid (TS), total dissolved solid (TDS) and turbidity while chemical parameters which included, biochemical oxygen demand (BOD), chemical oxygen demand (COD), metals cadmium (Cd), copper (Cu), lead (Pb), iron

(Fe), zinc, (Zn), potassium, sodium), nitrates, pH, phosphate, sulphate, total acidity, total alkalinity and total hardness.

All parameters were determined using standard methods as indicated below. The physicochemical parameters were categorised and determined as follows:

3.4.1 Parameters Indicating General Degree of Pollution:

3.4.1.1 BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD was determined using standard method [128 &129] as follows:

Materials Required:

Apparatus:

a) Incubation bottles 300 mL with glass stoppers.

b) Incubator - electrically grounded water bath (maintained at 20 ± 1˚c).

c) 500 mL conical flask.

d) 250 mL graduated cylinders.

e) Wash bottles.

f) Pipettes.

Reagents

i) Water obtained by distillation from an all-glass water distillation unit.

ii) Calcium chloride solution containing 27.5g anhydrous $CaCl_2$ per litre.

iii) Ferric chloride solution containing 0.25g $FeCl_3.6H_2O$/L.

iv) Magnesium sulphate solution containing 22.5g $MgSO_4.7H_2O$/L.

v) Phosphate buffer solution – pH 7.2 prepared by dissolving 8.50g of KH_2PO_4, 21.75g of K_2HPO_4, 33.40g $Na_2HPO_4.7H_2O$ and 1.70g NH_4Cl in 500 mL H_2O and diluted to 1 L.

vi) Sodium hydroxide solution containing 50 g NaOH /L.

vii) Freshly prepared sodium sulphite solution containing 1.575g $Na_2S_2O_3$ /L.

viii) Dilution water prepared 5 days before initiating BOD test by aerating distilled water, 3.4.1.1(a) above (organic free water), with clean compressed air for an hour and stabilized by incubation at 20 ˚C for 4 hours. The oxygen-saturated water was added was transferred to suitable bottles and 1 mL each of phosphate buffer, $MgSO_4$, $FeCl_3$ and $CaCl_3$ solutions /L were added.

ix) Alkaline iodide-sodium azide solution prepared by dissolving 500 mg of NaOH and 135 g NaI in H_2O, diluted to 950 mL and cooled. While stirring, a solution of 10g of NaN_3 in 40 mL was slowly added. This was tested to ensure it did not give colour with starch indicator and then stored in dark bottle with rubber stopper.

x) Manganese Sulphate solution prepared by dissolving 364 g of $MnSO_4.H_2O$ in water, filtered and diluted to 1 L.

xi) Potassium biiodate standard solution (0.025 N) prepared by dissolving 0.8125 g $KH(IO_3)_2$ in water in 1 L volumetric flask and then diluted to volume.

xii) Potassium fluoride prepared by carefully dissolving 40 g of $KF.2H_2O$ in 100 mL of H_2O.

xiii) Sodium thiosulphate standard solution (0.1 N) prepared by dissolving 25 g of $Na_2S_2O_3.5H_2O$ in H_2O, 1 g NaOH added and then diluted to 1 L.. This was standardised against $KH(IO_3)_2$ and 250 mL of this 0.1 N solution was diluted to 1 mL (to give 0.2 mg O).

xiv) Starch indicator prepared by dispersing 6g of potato in a mortar with few mL of water and then poured into 1 L boiling water, boiled for a few

minutes and let to settle overnight. The clear solution was decanted and preserved with 1.3 g salicylic acid.

Determination:

Four 300 mL glass stoppered BOD bottles were labelled as required (two for the sample and two for blank) 10 mL of the sample was added to each of the two 300 mL glass BOD bottles and then filled using the dilution water.

Dilution water alone was then added to the remaining two BOD bottles and immediately covered with glass stopper.

One blank solution bottle and one sample solution bottle were then placed in the BOD incubator at 20 ˚C for five days. The other two bottles (one blank and one sample) were analysed immediately. Air bubbling and trapping of air was avoided.

2.0 mL each of Manganese sulphate solution and alkali-iodide azide reagent were added to the 300 mL BOD bottle using a calibrated pipette inserted just below the surface of the liquid to avoid introducing oxygen into the sample. This was allowed to settle the floc and after immediately replacing the stopper (avoiding introducing bubbles), it was shaken by inverting several times to mix. 2.0 mL of sulphuric acid was then added using a pipette just above the surface of the sample, stoppered and inverted several times to mix. 203 mL of the solution was immediately titrated 0.025 N $Na_2S_2O_3$ to pale straw yellow. 1 mL starch indicator was then added and titration continued until the blue colour disappeared. The titration was repeated for concordant values of the volume of $Na_2S_2O_3$ added. This was recorded and represents the Dissolve Oxygen (D.O) in mg/L.

ppm D.O = (mL 0.025 N $Na_2S_2O_3$ x 0.2/200) x 1000

After five days, the bottles in the BOD incubator were removed and the sample and the blank were analysed for $D.O_5$ following the procedure above.

Calculation

Specimen Calculation was done using the formula below:

$$\textbf{Biochemical Oxygen Demand } (BOD_5) = \frac{(D.O_1 - D.O_5 - B.C) \times \text{vol. of diluted sample}}{\text{Volume of sample}}$$

Where: $D.O_1$ = initial D.O of the diluted sample.

$D.O_5$ = D.O at the end of five days for the diluted sample.

B.C = Blank Correction = difference of mg/L D.O in blank

(i.e. $D.O_{blank1} - D.O_{blank5}$).

3.4.1.2. Chemical Oxygen Demand (COD)

COD was determined using standard method [128 &129] as follows:

Materials Required:

Apparatus

Pipette and pipette bulb.

COD vials with stand.

COD digester

Reflux apparatus – Erlenmeyer flask (250 mL conical flask).

Wash bottles

Burette with stand.

Reagents

Distilled water was used throughout for preparation if the solutions and for blank determinations.

Potassium dichromate standard solutions:

(i) 0.25 N prepared by dissolving 12.259 g $K_2Cr_2O_7$ (primary standard grade which was previously dried at 103 ˚C for 2 hours) in distilled water and then diluted to 1 L.

(ii) 0.025 N prepared by diluting 100 mL of the 0.25 N to 1 L with distilled water.

Sulfuric acid reagent (catalyst solution) prepared by carefully adding 4.1 kg bottle H_2SO_4 to 23.5g Ag_2SO_4 and kept for 48 hours for complete dissolution of the silver sulphate crystals.

Ferroin (Phenanthroline ferrous sulphate) indicator solution prepared by dissolving 1.48g 1, 10 – (ortho) phenanthroline. H_2O and 0.70 g $FeSO_4.7H_2O$ in 100 mL H_2O.

Standard Ferrous Ammonium Sulphate Solution (FAS) – $Fe(NH_4)_2SO_4)_2$ - Prepared and standardized.

Preparation:

(i) 0.25 N FAS prepared by dissolve 98g $FeSO_4.6H_2O$; 20 mL of H_2O was added then cooled and diluted to 1 L. This was standardized against.

(ii) 0.025 N FAS prepared by diluting 100 mL 0.25 N FAS to 1 L with distilled water. This was standardized against 0.025 N $K_2Cr_2O_7$.

Sample Preservation

Samples collection was done using glass bottles. Prior to laboratory analysis, the samples were preserved with 2 mL H_2SO_4 /L at 4 ˚C.

Determination:

Standardization of FAS:

10.0 mL of 0.025 N $K_2Cr_2O_7$ was added to 15 mL H_2O then 20 mL of H_2SO_4 added, cooled and titrated with 0.025 N $Fe(NH_4)_2SO_4)_2$ using 1 drop ferroin indicator (the

solution became blue-green in colour). End point of the titration was the sharp change of colour from blue-green to reddish brown and normality was calculated as:

Normality = (mL $K_2Cr_2O_7$ X normality)/ mL $Fe(NH_4)_2SO_4)_2$.

The test was conducted by adding 2.5 mL each of the sample to two COD vials with stopper and 2.5 mL of distilled water to another COD vial for blank determination. 1.5 mL of potassium dichromate reagent (digestion solution) was added to each of the samples and the blank; then 3.5 mL of sulphuric acid reagent also added. With the tubes tightly capped, the COD digester was switched on, set at 2 hours and temperature of 150 ˚C. The three vials were placed in the block digester and heated for 2 hours. These were removed after the digester turned automatically off then cooled to room temperature. Each vial content was then titrated against 0.025 N $Fe(NH_4)_2SO_4)_2$ using ferroin indicator. The volumes of $Fe(NH_4)_2SO_4)_2$ that titrated the sample and the blank were recorded.

Specimen calculation:

The COD was calculated as follows:

$$\text{mg COD /L} = \frac{(V_{FAS\text{-}blank} - V_{FAS\text{-}sample}) \times N_{FAS} \times 8 \times 1000}{\text{Volume of sample (in L)}}$$

3.4.1.3 Temperature

Temperature was measured using electrometric method [129- 133]

Apparatus

Hanna HI 9811-5 multi-meter.

Determination

Temperature measurement was immediately taken in the field at collection points. The multi-meter probe was rinsed several times with a portion (1L) of the water sample. The probe was then completely dipped into a beaker containing 10 mL of the

sample and held for about one minute to obtain stable readings. Temperature reading was recorded to the nearest 0.1 °C.

3.4.2 Parameters Due to Agricultural/Fertilizer Inputs:

3.4.2.1. Nitrate NO_3^-

The determination of nitrates was done using Cadmium reduction Method[129 &130]

Materials Required:

Apparatus

(i) Reduction column

(ii) Filter photometer with maximum transmittance at 540 nm.

(iii) Drying oven-Capable of maintaining a constant temperature in the range of 103-105°C.

(iv) Analytical balance-Capable of weighing to 0.001 g (1 mg).

(v) Glass wool.

(vi) Syringe filters—0.45 μm pore diameter rinsed with a dilute sulphuric acid solution before use.

Reagents

(i) Nitrate and nitrite-free (deionised) water.

(ii) Hydrochloric acid, 6N $HCl_{(aq)}$.

(iii) 2% Copper sulfate (CuSO4) solution prepared by dissolving 20 g CuSO4·5H2O in 1 L water.

(iv) Cadmium granules: 25g of new 20 – 100 mesh Cd granules was washed with 6N $HCl_{(aq)}$ followed by rinsing with water. 100 mL of 2% $CuSO_4$ solution was added to the silver coloured Cd and the mixture swirled until the blue colour faded. This took about 5 minutes. This process was repeated after decanting the liquid until a brown colloidal precipitate began

to form then flushed with water to remove the Cu precipitate; a black coloured Cd was obtained.

(v) 85% Phosphoric acid (H_3PO_4).

(vi) Colour reagent prepared by:

Adding 100 mL 85% phosphoric acid (H_3PO_4) and 10 g sulfanilimide to about 800 mL reagent water and mixed to completely dissolve the sulfanilimide; Then 1 g N-(1-naphthyl)-ethylenediamine dihydrochloride was added and mixed to dissolve and diluted to 1 L with reagent water. This solution was stored refrigerated in an amber glass container.

(vii) Ammonium chloride (NH_4Cl)

(viii) Ammonium chloride-EDTA solutions prepared by dissolving 13 g NH_4Cl and 1.7 g disodium ethylenediamine tetraacetate in 900 mL water. The pH was adjusted to 8.5 with concentrated NH_4OH and then diluted to 1 L. This formed the stock NH_4Cl-EDTA solution. Dilute solution of ammonium chloride-EDTA was obtained by diluting 300 mL of stock NH_4Cl-EDTA solution to 500 mL in reagent water.

(ix) Potassium nitrate (KNO_3).

(x) Sodium nitrite ($NaNO_2$).

(xi) Blank sand obtained by baking 500 g of clean sand at 400 ˚C for eight hours then cooled and stored in a glass container with a sealing lid.

(xii) Oxidized nitrogen standards included:

I. Nitrate stock solution—1000 mg/L NO_3-N prepared by drying several grams of potassium nitrate (KNO_3) in an oven at 105 ˚C for 24 hours, cooled in a dessicator and then 0.7218 g of the KNO_3 was dissolved in

reagent water and diluted to 100 mL in a volumetric flask. This was preserved with 0.2 mL chloroform ($CHCl_3$).

II. Nitrate working standard—10 mg/L NO_3-N. This was prepared by diluting 10 mL of nitrate stock solution to 1 L in reagent water in a volumetric flask.

III. Nitrite (NO_2) stock solution—1000 mg/L NO_2-N prepared by dissolving 0.4928 g $NaNO_2$ from a fresh unopened bottle of sodium nitrite ($NaNO_2$) in reagent water and diluting to 100 mL in a volumetric flask and preserved with 0.2 mL $CHCl_3$.

IV. Nitrite working standard—10 mg/L NO2-N. Dilute 10 mL of nitrite stock solution to 1 L in reagent water in a volumetric flask.

Determination

Preparation of reduction column

► A glass wool plug was inserted in the end of the chromatographic column then the tube filled with reagent water to prevent entrapment of air bubbles during filling.

► The copper-cadmium granules were poured into the column until a column height of 18.5 cm was created. The sides of the column were gently tapped to release trapped air bubbles.

►The column was washed with about 200 mL of dilute ammonium chloride-EDTA solution. Before the column was used for analysis, it was activated by passing 100 mL of a solution consisting of 25 mL of 1.0 mg/L nitrate (NO_3^-) standard and 75 mL dilute ammonium chloride EDTA solution at a flow rate of 7-10 mL/min. through it.

Sample Preparation

The sample was thoroughly mixed using a 0.45 μm membrane filter,

25 mL of the sample was filtered into a volumetric flask. Record the amount collected.

► The volumetric flask was sealed with a stopper, secured with a small portion of PTFE thread sealing tape, and placed in the shaker.

► The samples were shaken for 4 hours and allowed to settle out and a 0.45 μm membrane filter was used to filter up to 25 mL of the extracted sample into a volumetric flask. The amount of filtered extract collected was recorded.

Reduction of nitrate to nitrite

► The pH of the filtrates was checked and adjusted to between 5 and 9 with concentrated HCl or concentrated NH_4OH.

► 75 mL of dilute ammonium chloride-EDTA solution was added to 25 mL of sample extract.

► The sample was passed through the reduction column at a rate of 7-10 mL/min. The first 25 mL of eluent was discarded; then the rest collected in the sample flask. The reduced sample was not allowed to sit for more than 15 minutes before analysis.

Analysis

► 2 mL of colour reagent was added to 50.0 mL of sample then allowed for ten minutes for the colour to develop; and then the absorbance of the sample at 540 nm measured.

► A calibration curve was generated. Every tenth sample was measured as a calibration verification standard. Sample absorbance was compared to the calibration curve and the sample concentration determined by calculation.

Calculation:

All values were reported in mg/L to three significant figures.

Calculation was done using the equation:

$$C_s = \frac{(C_{extract})\ (V_{sample})\ (R_{vol})\ (F_{dil})}{1000\ mL/L}$$

Where: Cs = Oxidized nitrogen in the sample (mg/L)

$C_{extract}$ = Concentration of oxidized nitrogen in extract, mg/L

Vol_{sample} = Volume of sample, mL (100 mL)

F_{dil} = Dilution factor of extract.

R_{vol} = ratio of initial sample volume to volume of filtrate collected (100/25)

3.4.2.2. Phosphate, PO_4^{3-}

The determination of phosphates was done using colorimetric method (Ascorbic Acid Method) [129, 131 & 132.]

Apparatus

a. Colorimetric equipment

Filter photometer, equipped with a red colour filter and a light path ≥ 0.5 cm.

b. Acid-washed glassware cleaned with hot dilute HCl (aq) and rinsed thoroughly with distilled water.

Reagents

a. Sulfuric acid, H_2SO_4, 5*N* prepared by diluting 70 mL concentrated H_2SO_4 to 500 mL with distilled water.

b. Potassium antimonyl tartrate solution prepared by dissolving 1.3715 g $K(SbO)C_4H_4O_6.1/2H2O$ in 400 mL distilled water in a 500-mL volumetric flask, diluting to volume and stored in a glass-stoppered bottle.

c. Ammonium molybdate solution prepared by dissolving 20 g $(NH_4)_6Mo_7O_{24}.4H_2O$ in 500 mL distilled water and stored in a glass-stoppered bottle.

d. Ascorbic acid, 0.1M prepared by dissolving 1.76 g ascorbic acid in 100 mL distilled water. This was not kept in use for more than six days. It was stored at 4°C.

e. Combined reagent: The above reagents were mixed in the following proportions for 100 mL of the combined reagent: 50 mL 5*N* H_2SO_4, 5 mL potassium antimonyl tartrate solution, 15 mL ammonium molybdate solution, and 30 mL ascorbic acid solution. Mixing was done after addition of each reagent and; after they reach room temperature and in the order given.

f. Stock phosphate solution prepared by dissolving in distilled water 219.5 mg anhydrous KH_2PO_4 and diluting to 1000 mL; 1.00 mL = 50.0 µg PO_4^{3-}-P.

g. Standard phosphate solution prepared by diluting 50.0 mL stock phosphate solution to 1000 mL with distilled water; 1.00 mL = 2.50 µg P.

Procedure

a. Treatment of sample:

50.0 mL sample was pipetted into a clean, dry 125-mL erlenmeyer flask and 0.05 mL (1 drop) phenolphthalein indicator added. 5*N* H_2SO_4 solution was also added drop-wise to just discharge red colour in cases where it developed. 8.0 mL combined reagent was then added and thoroughly mixed. Absorbance of each sample at 880 nm, was measured after at least 10 minutes but no more than 30 minutes using reagent blank as the reference solution.

b. Preparation of calibration curve: Individual calibration curves were prepared from a series of standards within the phosphate ranges indicated in the table below: [129]

Approximate P Range mg/L	**Light path (cm)**
0.30–2.0	0.5
0.15–1.30	1.0
0.01–0.25	5.0

Distilled water blank was used with the combined reagent to make photometric readings for the calibration curve. Absorbance was plotted vs. phosphate

concentration to give a straight line passing through the origin. At least one phosphate standard was tested with each set of the samples.

Calculation:

$$\text{mg P/L} = \frac{\text{mg P (in approximately 58 mL final volume)} \times 1000}{\text{mL sample}}$$

3.4.3 Parameters Due to Variation in Soil Types and Geological Differences:

3.4.3.1 pH

The pH of the water samples was measured using potentiometric method. [128]

Apparatus and Reagent:

Hannah multimeter.

Standard buffer solution.

Determination:

The instrument's electrode was thoroughly wet, prepared in according to manufacturer's instruction and standardized with standard buffer solution with pH near that of sample and then with two others to check linearity of the electrodes response. Samples were analysed within the same hour of collection and the electrode was washed several times with portions of the sample. Readings were taken after equilibrium was established as indicated by the absence of drift.

3.4.3.2 Turbidity

Turbidity was determined using standard method (Nephelometric Method) [129] measured in nephelometric turbidity units (NTU).

Apparatus

Hanna Turbidity meter, sample cell, standard flask, funnel, wash bottle, high density polyethylene (HDPE) plastics containers and tissue papers.

Reagents

Hydrazine sulphate

Hexamethylenetetramine

Distilled water

Determination

The analysis was performed as soon as samples were collected- within the same day and/or held at 4 ^{0}C in the dark within 24 hours where necessary.

The reagents were first prepared and the multi-meter calibrated before testing of the samples.

Preparations

Calibration standards obtained from instrument manufacturer (Hanna) were prepared according to manufacturer's instructions a day before analysis as follows:

Hydrazine sulphate:

1.0 g of hydrazine sulphate was accurately weighed and dissolved in 50 mL turbidity free distilled water. This was transferred to a 100 mL standard flask and made up to mark with turbidity-free distilled water.

Hexamethylenetetramine:

10.0 g of Hexamethylenetetramine was accurately weighed and dissolved in 50 mL turbidity free distilled water. This was transferred to a 100 mL standard flask and made up to mark with turbidity-free distilled water.

Standard 4000 NTU Solution:

5 mL of hydrazine sulphate solution was mixed with 5 mL hexamethylenetetramine solution in a 100 mL standard measuring flask and allowed to stand for 24 hours after which it was made up to 100 mL mark using turbidity-free distilled water.

Sample Test

After calibrating the instrument according to manufacturer's instruction, the water sample was poured into the sample cell up to the horizontal mark, then the cell was gently wiped with soft tissue paper and placed in the turbidity meter such that the vertical mark in the sample cell coincided with the mark in the turbidity meter. The sample cell was covered and the readings observed until a stable reading was obtained and recorded.

3.4.3.3. Sulphate (SO_4^{2-})

Sulphate was determined using Turbidimetric Method [128 – 129]

The method is based on the precipitation of sulphate ion as barium sulphate ($BaSO_4$) in the presence of hydrochloric acid, sodium chloride and glycerol. Light absorbance of the $BaSO_4$ is measured by a photometer and the SO_4^{2}–concentration is determined by comparison of the reading with a standard curve

Apparatus

a. Magnetic stirrer kept at a constant stirring speed for each run of samples and standards and adjusted to prevent splashing.

b. Photometer: a Nephelometer was used.

c. Stopwatch.

d. Measuring spoon, capacity 0.2 to 0.3 mL.

Reagents

a. Buffer solution prepared by dissolving 30 g magnesium chloride, $MgCl_2.6H_2O$, 5g sodium acetate, $CH_3COONa.3H_2O$, 1.0g potassium nitrate, KNO_3, and 20 mL acetic acid, CH_3COOH (99%), in 500 mL distilled water and made up to 1000 mL.

b. Barium chloride, $BaCl_2$, crystals, 20 mesh.

c. Standard sulphate solution prepared by diluting 10.4 mL standard 0.0200N H_2SO_4 to 100 mL with distilled water (1.00 mL = 100 μg SO_4).

Procedure

a. Formation of barium sulphate turbidity:

100 mL sample was measured into a 250-mL erlenmeyer flask and 20 mL buffer solution added then mixed in stirring apparatus. While stirring, a spoonful of $BaCl_2$ crystals was added and timing began immediately. Stirring continued for 60 ± 2 s at constant speed.

b. Measurement of barium sulphate turbidity:

After stirring period ended, the solution was pour into absorption cell of the photometer and turbidity measured at 5 ± 0.5 min.

c. Preparation of calibration curve:

SO_4^{2-} concentration in sample was estimated by comparing turbidity reading with the calibration curve prepared by carrying SO_4^{2-} standards through the entire procedure. The standards were spaced at 5-mg/L increments in the 0- to 40-mg/L SO_4^{2-} range. Reliability of calibration curve was checked by running a standard with every three or four samples.

d. Correction for sample colour and turbidity:

This was done by running blanks to which $BaCl_2$ was not added.

Calculation

$$\text{mg } SO_4^{2-}/\text{L} = \frac{\text{mg } SO_4^{2-} \times 1000}{\text{mL sample}}$$

SO_4^{2-} concentration was determined directly from the calibration curve after subtracting sample absorbance before adding $BaCl_2$.

3.4.3.4. Total Hardness (as $CaCO_3$)

Total Hardness was determined using EDTA (Ethylenediaminetetraacetic acid) Titrimetric Method [128 - 129]

The analysis started within two hours of sample collection. Where this was not possible, samples were stored at 4 ^{0}C and analysed within five hours of collection.

Apparatus

Burette with stand, porcelain tile, pipettes, conical flask (Erlenmeyer flask), 250 mL graduated cylinders, standard flasks, wash bottle and beaker.

Reagents

a. *Buffer solution:* This was commercially obtained and incorporated both buffer and a complexing agent (this maintained a pH of 10.0 ± 0.1 during titration and gave a clear, sharp end point when the sample was titrated).

b. *Indicator*: *Calmagite:* 1-(1-hydroxy-4-methyl-2-phenylazo)-2-naphthol-4-sulfonic acid was used since it is stable in aqueous solution and produces the same colour change as Eriochrome Black T, with a sharper end point. It was prepared by dissolving 0.10 g Calmagite in 100 mL distilled water. 1 mL was used per 50 mL solution to be titrated.

c. *Standard EDTA titrant,* 0.01*M* prepared by weighing 3.723 g analytical reagent-grade disodium ethylenediaminetetraacetate dihydrate (EDTA), dissolved in distilled water, and diluted to 1000 mL in a standard flask and stored in polyethylene containers to avoid extraction of hardness-producing cations from soft-glass containers. This was standardized against standard calcium solution.

d. *Standard calcium solution* prepared by weighing 1.000 g anhydrous $CaCO_3$ powder (primary standard) into a 500-mL erlenmeyer flask and 1: 1 HCl added, a little at a time, until all $CaCO_3$ dissolved. 200 mL distilled water was added and boiled for a

few minutes to expel CO_2. This was cooled, and a few drops of methyl red indicator added, and adjusted to the intermediate orange colour by addition of 3*N* NH_4OH or 1 + 1 HCl, as was required. This was transferred quantitatively and diluted to 1000 mL with distilled water; 1 mL = 1.00 mg CaCO3.

e*. Sodium hydroxide,* NaOH, 0.1*N*.

Procedure

The titration was completed within 5 minutes measured from time of buffer addition. 25.0 mL sample was diluted to about 50 mL with distilled water in a porcelain casserole and 1 mL buffer solution added to give a pH of 10.0 to 10.1.

Then 2 drops indicator solution was added. Standard EDTA titrant was added slowly and continuously stirred, until the last reddish tinge disappeared. At the end point, the solution was blue in daylight.

Calculation

$$\text{Hardness (EDTA) as mg } CaCO_3/L = \frac{A \times B \times 1000}{\text{mL sample}}$$

Where:

A = mL titration for sample and

B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant.

3.4.3.5. Total Acidity

Acidity of the water samples was determined using standard method (Titrimetric method) [128-129]

Apparatus

a. Wash bottles and beakers

b. Titration vessel

c. Magnetic stirrer.

d. Pipettes; pipette bulb.

e. Volumetric Flasks.

f. Burettes, borosilicate glass, 50-, 25-, 10-mL with stand.

g. Polyolefin bottle, 1-L.

Reagents

a. Carbon dioxide-free water*:* All stock, standard solutions and dilution water for the standardization procedure were prepared with deionised water that was freshly boiled for 15 min and cooled to room temperature. The final pH of the water was 6.0.

b. 0.05*N* Potassium hydrogen phthalate solution prepared *by* crushing 20 g primary standard $KHC_8H_4O_4$ to about 100 mesh and dried at 120°C for 2 h then cooled in a desiccator. 10.5 g of this was weighed, transferred to a 1-L volumetric flask, and then diluted to 1000 mL.

c. 0.1*N* Standard sodium hydroxide titrant standardized by titrating 40.00 mL $KHC_8H_4O_4$ solution using a 25-mL burette.

$$\text{Normality} = \frac{A \times B}{204.2 \times C}$$

Where:

A = g $KHC_8H_4O_4$ weighed into 1-L flask,

B = mL $KHC_8H_4O_4$ solution taken for titration, and

C = mL NaOH solution used.

d. 0.02*N* Standard sodium hydroxide titrant, prepared by diluting 200 mL 0.1*N* NaOH to 1000 mL. This was stored in a polyolefin bottle and protected from atmospheric CO2 by a tight cap. This was standardized against $KHC_8H_4O_4$ using

15.00 mL $KHC_8H_4O_4$ solution and a 50-mL burette. Normality was determined as shown above. (1 mL = 1.00 mg $CaCO_3$.)

e. Hydrogen peroxide, H_2O_2, 30%.

f. Bromphenol blue indicator solution, pH 3.7 indicator prepared by dissolving 100 mg bromphenol blue, sodium salt, in 100 mL water.

g. Metacresol purple indicator solution, pH 8.3 indicator prepared by dissolving 100 mg metacresol purple in 100 mL water.

h. Phenolphthalein indicator solution, alcoholic, pH 8.3 indicator.

i. Sodium thiosulphate, 0.1M, prepared by dissolving 25 g $Na_2S_2O_3.5H_2O$ and dilute to 1000 mL with distilled water.

Procedure

Preliminary titration was done to determine optimum sample size and/or normality of titrant. 20 mL of the titrant was selected as sample size. The sample was adjusted to room temperature and discharge into an Erlenmeyer flask, using a pipette. 0.2 mL (5 drops) indicator solution was added and titrated over a white surface to a persistent colour change characteristic of the equivalence point. Colour at end point was checked by adding the same concentration of indicator used with sample to a buffer solution at the designated pH. The titration was repeated for concordance values.

Calculation

$$\text{Acidity, as mg } CaCO_3/L = \frac{[(A \times B) - (C \times D)] \times 50\,000}{\text{mL sample}}$$

where:

A = mL NaOH titrant used,

B = normality of NaOH,

C = mL H_2SO_4 used, and

D = normality of H_2SO_4.

3.4.3.6. Total Alkalinity

Alkalinity of the water samples was determined using standard method (Titrimetric method) [128-129]

Apparatus

a. Conical flasks (Erlenmeyer flask), wash bottles and beakers

b. Titration vessel

c. Magnetic stirrer.

d. Pipettes; pipette bulb.

e. Volumetric Flasks.

f. Burettes, borosilicate glass, 50-, 25-, 10-mL with stand.

g. Polyolefin bottle, 1-L.

h. Electrically operated titrator with a glass electrode (0.05 pH unit) standardized and calibrated according to the manufacturer's instructions.

Reagents

a. *Sodium carbonate solution,* approximately 0.05N prepared by drying 5g primary standard Na_2CO_3 at 250°C for 4 h and cooled in a desiccator then 2.52 g weighed and transferred to a 1-L volumetric flask, the flask was filled to the mark with distilled water, and then the reagent was dissolved and mixed.

b. *Standard sulphuric acid,* 0.1N standardized against 40.00 mL 0.05*N*

Na_2CO_3 solution, with about 60 mL water, in a beaker by titrating potentiometrically to pH of 5. The electrodes were rinsed into the same beaker, boiled gently for 5 minutes under a watch glass cover and cooled to room temperature. The cover glass

was also rinsed into beaker, and then titration done to the pH inflection point. Normality was calculated using:

$$\text{Normality, } N = \frac{A \times B}{53.00 \times C}$$

where:

A = g Na_2CO_3 weighed into 1-L flask,

B = mL Na_2CO_3 solution taken for titration, and

C = mL acid used.

c. *Bromcresol green indicator solution,* pH 4.5 indicator prepared by dissolving 100 mg bromcresol green, sodium salt, in 100 mL distilled water.

d. *Mixed bromcresol green-methyl red indicator solution* prepared by dissolving 100 mg bromcresol green and 20 mg methyl red in 100 mL 95% ethyl alcohol.

e. *Metacresol purple indicator solution,* pH 8.3 indicator prepared by dissolving 100 mg metacresol purple in 100 mL water.

f. *Phenolphthalein solution, alcoholic,* pH 8.3 indicator.

g. *Sodium thiosulfate,* 0.1*N*, prepared by dissolving 25 g $Na_2S_2O_3 \cdot 5H2O$ and diluted to 1000 mL with distilled water.

Procedure

Titration was done to the end-point pH without record of intermediate pH values and without delay. As the end point was approached smaller additions of acid were made to ensure reaching pH equilibrium before addition of more titrant.

Calculations

$$\text{Alkalinity, mg } CaCO_3/L = \frac{A \times N \times 50\,000}{\text{mL sample}}$$

Where: A = mL standard acid used and N = normality of standard acid.

3.4.3.7. Electrical Conductivity

Conductivity was determine in accordance with IS 3025 (Part 14) test procedure. [129]

Materials

HANNA (Model HI 9811-5) multi-meter, magnetic stirrer with stirring bead, standard flask, measuring jar, 250 mL beaker, funnel, tissue paper, potassium chloride and distilled water.

Sampling Handling and Preservation:

Samples bottles were washed using phosphate-free detergent and thoroughly rinsed with both distilled water and tap water. Conductivity was measured within ten hours of sample collection or filtered through 0.4 µ filter paper (which was washed with high quality distilled water) and stored at 4 ^{o} C (freezing of sample was strictly avoided).

Procedure

First potassium chloride solution was prepared and the instrument calibrated according to the manufacturer's instructions.

0.1N $KCl_{(aq)}$ was prepared as follows:

The electronic balance was switched on and set at zero after placing the weighing pan. 50 mL of distilled water was measured and transferred to a beaker then 0.7456g of KCl was added to it and thoroughly mixed to dissolve using glass rod. The content was transferred into a 100 mL standard flask and made up to mark by adding distilled water and then shaken. The solution was used for calibration.

Calibration of the instrument:

The magnetic stirrer was switched on and a beaker containing $KCl_{(aq)}$ was placed on it; then the magnetic bead placed in the beaker. The conductivity of 0.1 N $KCl_{(aq)}$ was adjusted to 14.12 millisiemens/cm at 30 ^{o}C.

Sample Analysis:

The electrode was thoroughly washed with deionised water and carefully wiped with tissue paper. 200 mL of water sample was measured and transferred to a beaker and then placed on the magnetic stirrer. The electrode was then dipped into the sample in the beaker and a stable reading taken.

3.4.3.8. Total Suspended Solid (TSS)

TSS was determined by gravimetric method. [128-129]

Apparatus

Drying oven (104 ± 1 ^{o} C), porcelain crucible, and analytical balance (capable of weighing up to 0.1 mg).

Procedure

The clean porcelain crucible was dried in the drying oven at 100^{o}C

To obtain a known constant weight, W_1. A 10 mL volume of water sample was introduced into the crucible and this was heated in an oven at 100^{o}C until the sample vaporized. It was then cooled in a desiccator and reweighed to obtain W_2. The Total Suspended Solid was calculated using the formula:

$$\mathbf{TSS = W_2 - W \times \frac{100}{mL\ sample}}$$

3.4.3.9. Total Dissolved Solids (TDS)

This was determined by direct reading using HANNA (Model HI 9811-5) multi-meter pre-calibrated according to manufacturer's instruction 10 mL of water sample was introduced into a 100 mL glass beaker. The probe was dipped into the beaker and the TDS mode activated by gently pressing on the meter's soft touch button. The value displayed at the LCD panel of the meter was allowed to stabilize and recorded.

3.4.3.10. Total Solid (TS)

TS was obtained by calculating the arithmetic sum of the TSS and TDS.

3.4.4 Metals/Heavy Metals (Possible Inputs from Water Sources Especially Waste Water Percolation):

3.4.1. Determination of Potassium and Sodium

Test Method: Flame photometric Method (APHA 3500-K Band APHA 3500-Na B standard methods respectively) [129].

Instrument: Flame photometer (Sherwood Flame Photometer Model 360, Sherwood Scientific Ltd, Cambridge).

Potassium

Reagents:

1000 mg/L Potassium Stock Solution:

This was prepared by dissolving 1.9070g dry 'Analar-grade' potassium chloride in 250 mL of doubly deionised water and then diluted to 1 litre in a volumetric flask using deionised water.

100 mg/L Standard Potassium Solution:

This was prepared by measuring 10 mL of the stock potassium solution into 100 mL volumetric flask and made to mark with deionised water.

Deionised water was used for the blank determinations.

100 mg/L Control Standard Potassium Solution:

This was also prepared by measuring 5 mL of the 100 mg/L standard potassium solution into 100 mL volumetric flask and made up to make with deionised water.

Procedure:

The flame photometer was switched on and the filter selector set to potassium position. The instrument was fed with deionised water and allowed to warm up for 30 minutes. During the aspiration of deionised water, the 'blank control' was adjusted to read 0.0. 100 mg/L standard potassium solution was then aspirated to adjust the coarse and fine controls for standardization. The standard was removed and the blank aspirated after ten minutes for a period of twenty minutes and adjusted to zero. After aspirating the standard potassium solution and the control potassium solution, the samples were aspirated accordingly.

Sodium

Reagents:

1000 mg/L Stock Sodium Solution:

This was prepared by dissolving 2.5420g of 'Analar-grade' sodium chloride in 200 mL of doubly deionised water then diluting to 1 litre in a volumetric flask.

100 mg/L Standard Sodium Solution:

This was prepared by measuring 10 mL of the stock sodium solution into 100 mL volumetric flask and made to mark with deionised water.

Deionised water only was used for the blank determinations.

100 mg/L Control Standard Sodium Solution:

This was also prepared by measuring 5 mL of the 100 mg/L standard sodium solution into 100 mL volumetric flask and made up to make with deionised water.

Procedure:

The flame photometer was switched on and the filter selector set to sodium position. The instrument was fed with deionised water and allowed to warm up for 30 minutes. During the aspiration of deionised water, the 'blank control' was adjusted to read 0.0. 100 mg/L standard sodium solution was then aspirated to adjust the coarse and fine controls for standardization. The standard was removed and the blank aspirated after ten minutes for a period of twenty minutes and adjusted to zero. The standard sodium solution and the control sodium solution were aspirated; then the samples were aspirated accordingly.

Only deionised water was used throughout the experiment in the determination of sodium.

3.4.4.2. Determination of Heavy Metals:

The following five heavy metals were determined in accordance with standard procedure [128 -129]: Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb) and Zinc (Zn).

Instrument:

Perkin Elmer PinAAcle 900T Atomic Absorption Spectrophotometer (PerkinElmer Inc. USA).

Method: Graphite Furnace Atomic Absorption Spectroscopy (GFAAS) technique was chosen using a 'technique decision matrix' based on method and instrument sensitivity; and detection limits. Graphite furnace shows greater sensitivity than Flame Atomic Absorption Spectroscopy (FAAS) and the atomisation process is more efficient. The atomic absorption spectroscopy detection limits for both techniques are given below as follows: [134]

Metal	FAAS	GFAAS
Cadmium	0.8	0.002
Copper	1.5	0.014
Iron	5	0.06
Lead	15	0.05
Zinc	1.5	0.02

125 mL Nalgene (high density polyethylene bottles-HDPE) plastic bottles were used as sample bottles because plastic bottles made from low density polyethylene (LDPE) tend to leak, those made from previously used HDPE bottles were found to leach trace quantities of Zn over time. [135]

Preparation of Metal Standard Solutions:

1000 mg/L Stock Solutions:

Stock solutions of the metals were separately prepared in accordance with AOAC Method 974.27 summarised [128] by the table below:

Metal	Weight(g)	Compound	Dissolving medium (1 L total)
Cadmium	1.142	CdO	5 mL HNO_3 (redistilled)
Copper	1.000	Cu (electrolytic)	5 mL HNO_3 (redistilled)
Iron	1.000	Fe	5 mL HNO_3 (redistilled)
Lead	1.599	$Pb(NO_3)_2$	H_2O + 10 mL HNO_3 (redistilled)
Zinc	1.000	Zn	10 mL HNO_3.

Working standard solutions were prepared by serial dilution of the 1000 mg/L stock solutions.

The instrument was calibrated according to the manufacturer's instruction. The procedure was carried out for each element at specific wavelengths and instrumental conditions as given by the table below:

Element	Wavelength (nm)	Slit width (nm)	Lamp Type	Lamp Current
Cd	228.8	0.7	Hollow Cathode Lamp (HCL)	4
Cu	324.7	0.7	HCL	4
Fe	248.3	0.7	HCL	15
Pb	283.3	0.7	HCL	10
Zn	213.9	0.7	HCL	15

Recovery Analysis was performed in the months of December (2014), April, May and June (2015) using four randomly selected samples. This was to determine instruments working conditions and method accuracy.

Concentration of Metals added to the Spiked Water Samples for the Recovery Analysis

Cd	0.524 ppm
Cu	0.514 ppm
Fe	0.513 ppm
Pb	0.502 ppm
Zn	0.529 ppm
K	1.000 ppm
Na	2.000 ppm

3.5 Data Analysis

Data was recorded, organised and summarised in simple descriptive statistics methods using SPSS-PC Statistical Package for Social Scientists (SPSS 20 for windows version). Results were analysed using this statistical software analyses and presented in descriptive statistics such as Analysis of Variance (ANOVA) in office excel, two-factor analysis to determine significance at p(0.05), Dunnett's t-test (Post Hoc test) of

multiple comparison (see Appendices 3A – 5C) and Pearson correlation measures (at 0.05 and 0.01 significant levels) (attached as Appendix 6).

Water Quality Index:

The overall physicochemical water quality of each borehole was computed using the Water Quality Index (WQI).

$$\mathbf{WQI} = \frac{\sum \mathbf{WQ}}{\sum \mathbf{W}}$$

W is the unit weight, calculated by taking the reciprocal value for the standard permissible value, **S** for the parameter considered. That is,

$$\mathbf{W_n = k/S_n}$$

Where **k** is the proportionality constant and the quality rating ($\mathbf{Q_n}$) was deduced using:

$$\mathbf{Q_n = 100(V_o - V_n)/ (S_n - V_n).}$$

The water quality index was thus determined by aggregating the products of the parameter qualities and the unit weights and then divided by the aggregate of the unit weights.

The water quality ratings assigned to water quality index values are given below:

Water Quality Index	Water Quality Rating
0 – 25	Excellent
26 – 50	Good
50 – 75	Poor
76 – 100	Very Poor
› 100	Unfit for Drinking

Details of the WQI computed for dry season and rainy season results can be seen in Appendices 1.1A – 1.2L.

The rainy season WQI and the dry season WQI were then compared by being subjected to Independent Samples Test using Levene's T3 test for equality of variances (see Appendix 7).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Table 4.1 shows the concentration (mean ± standard deviation and ranges) of 22 physicochemical parameters in 12 boreholes water samples during rainy season and dry season.

4.2 Discussion

4.2.1 Parameters indicating General Degree of Pollution: Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and Temperature.

4.2.1.1: BOD_5

In the dry season, the lowest BOD_5 value of 3.140 mg/L was recorded in the water samples from BH10 and the highest value of 6.370 mg/L was recorded in BH3. The mean BOD_5 value for all the 12 boreholes water during dry season period was 5.155±0.822. During rainy season, BOD_5 ranged from 2.880 mg/L in BH7 to 6.100 mg/L in BH5. The mean BOD_5 value for all the 12 boreholes water during rainy season period was 4.288±0.703 as shown in Table 4.1. The higher BOD_5 mean value of 5.155±0.822 during dry season could be due to percolation of biodegradable organic matter and leaching of inorganic iron and/or manganese into groundwater aquifers. Recent findings from an assessment of selected groundwater samples from Amike-Aba, Abakaliki, South East Nigeria recorded a BOD_5 range of 10.87 – 12.98 mg/L. [136] From the BOD_5 results in this study, it can be concluded that the ground water in the area studied is generally polluted due to high biochemical oxygen demand during dry season and rainy season periods and may be unfit for drinking since the range of BOD_5 values is above the maximum permissible level of 3.00 mg/L

recommended by National Agency for Food and drugs Administration and Control (NAFDAC) [18] and World Health Organisation (WHO) [82].

4.2.1.2: COD

As shown in Table 4.1, the mean COD content was higher during dry season (7.541±1.085 mg/L) than at rainy season (5.207±0.879 mg/L) with values ranging from 5.840 mg/L (lowest in BH8) to 10.51 mg/L (highest in BH7) at dry season and 3.490 mg/L (lowest in BH7) to 7.450 mg/L (highest in BH5) at rainy season. The higher mean COD content at dry season may be due to prolong accumulation of seeped organic leachates into the aquifers. The COD ranges in this study shows similarity with COD range of 55.00 - 89.25 mg/L obtained in the assessment of water quality of boreholes around selected landfills in Kano Metropolis [137] in that they are both below the recommended value of 294.0 mg/L set by the NAFDAC[18] and WHO. [82] Hence pollution of the borehole water samples studied may not be due to the found low content of oxidizable organic matter.

Table 4.1: Results (Mean ± SD) and Range of the Concentrations for rainy season and dry season.

Parameter	Season	Sample Designation									
		BH1		BH2		BH3		BH4		BH5	
		(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range
pH	**Dry season**	5.01±0.058	5.000 – 5.100	5.01±0.058	5.000 – 5.100	4.90±0.000	4.90-4.90	5.32±0.058	5.30 – 5.40	5.27±0.058	5.20 – 5.30
	Rainy season	4.63±0.153	4.50-4.80	5.01±0.115	5.00-5.20	5.17±0.058	5.10-5.20	4.13±0.231	4.00-4.40	4.97±0.058	4.90-5.00
E.C. (µS/cm)	**Dry season**	23.33±5.774	20.000-30.000	20.00±0.000	20.00-20.00	40.00±0.000	40.00-40.00	60.00±0.000	60.00-60.00	16.67±5.774	10.000-20.000
	Rainy season	63.33±5.774	60.000-70.000	23.33±15.28	10.00-40.00	123.3±11.55	110.0-130.0	236.7±5.774	230.0-240.0	20.00±10.00	10.00-30.00
Temp.(°C)	**Dry season**	30.8±0.100	30.7-30.9	31.8±0.231	31.5-31.9	31.3±0.115	31.20-31.40	30.5±0.000	30.5-30.5	30.1±0.058	30.1-30.2
	Rainy season	29.1±0.058	29.0-29.1	30.1±0.058	30.1-30.2	31.8±0.115	31.7-31.9	30.1±0.058	30.10-30.2	29.9±0.346	30.80-31.00
TDS (mg/L)	**Dry season**	10.00±0.000	10.00-10.00	0.000±0.000	0.000-0.000	10.00±0.000	10.00-10.00	20.0±0.000	20.0-20.00	0.000±0.000	0.000-0.000
	Rainy season	93.33±11.55	80.00-100.0	3.333±5.774	0.000-10.00	143.3±28.87	110.0-160.0	53.33±11.55	40.00-60.00	6.667±5.774	0.000-10.00
TSS (mg/L)	**Dry season**	250.0±0.000	250.0-250.0	120.0±0.000	120.0-120.0	190.0±0.000	190.0-190.0	150.0±0.000	150.0	70.00±0.000	70.00-70.00
	Rainy season	256.7±5.774	250.0-260.0	130.0±10.00	120.0-140.0	200.0±0.000	200.0-200.0	173.3±5.774	170.0-180.0	103.3±5.774	100.0-110.0
TS(mg/L)	**Dry season**	260.0±0.000	2600.0-260.0	120.0±0.000	120.0-120.0	200.0±0.000	200.0-200.0	170.0±0.000	170.0-170.0	70.00±0.000	70.00
	Rainy season	350.0±17.32	330.0-360.0	133.3±5.744	130.0-140.0	343.3±28.87	310.0-360.0	226.7±15.28	210.0-240.0	110.0±10.00	110.0-120.0
T/Ac(mg/L)	**Dry season**	0.357±0.006	0.350-0.360	0.153±0.012	0.140-0.160	0.237±0.006	0.230-0.240	0.067±0.006	0.060-0.070	0.203±0.006	0.200-0.210
	Rainy season	8.447±0.045	8.400-8.490	0.167±0.006	0.160-0.167	0.497±0.006	0.490-0.500	0.103±0.006	0.100-0.110	0.217±0.006	0.210-0.220
T.Al(mg/L)	**Dry season**	28.03±0.058	28.00-28.10	40.00±0.000	40.00-40.00	36.08±0.052	36.05-36.14	52.10±0.000	52.10-52.10	47.03±0.058	47.00-47.10

	Rainy season	26.03±0.058	26.00-26.10	29.03±0.058	29.00-29.10	30.07±0.115	30.00-30.20	52.03±0.058	52.00-52.10	47.00±0.000	47.00-47.00
NO_3^- (mg/L)	**Dry season**	1.733±0.021	1.710-1.750	1.767±0.112	1.760-1.780	1.730±0.010	1.720-1.740	1.777±0.006	1.770-1.780	1.887±0.006	1.880-1.890
	Rainy season	12.17±1.041	11.00-12.00	1.700±0.000	1.700-1.700	2.267±0.404	1.800-2.500	7.333±4.619	2.000-10.00	1.897±0.006	1.890-1.900
PO_4^{3-} (mg/L)	**Dry season**	0.150±0.010	0.140-0.160	0.257±0.015	.240-.270	0.850±0.017	0.840-0.870	0.130±0.010	0.120-0.140	0.620±0.010	0.610-0.630
	Rainy season	6.000±3.464	4.000-10.00	0.343±0.040	0.300-0.380	2.267±0.252	2.000-2.500	4.367±1.097	3.100-5.000	0.647±0.006	0.640-0.650
SO_4^{2-} (mg/L)	**Dry season**	21.18±0.038	21.14-21.21	20.14±0.064	20.10-20.21	22.13±0.058	22.10-22.20	20.11±0.017	20.10-20.13	22.16±0.058	22.10-22.20
	Rainy season	26.23±1.686	24.30-27.40	20.53±0.153	20.40-20.70	24.33±21.13	0.000-38.00	26.27±5.160	20.40-30.10	37.20±2.307	34.60-39.00
BOD	**Dry season**	5.070±0.373	4.640-5.310	5.720±0.217	5.470-5.860	5.953±0.550	5.330-6.370	5.607±0.165	5.440-5.770	5.973±0.2122	5.800-6.210
	Rainy season	4.177±0.225	4.000-4.300	5.157±0.462	4.720-5.640	4.197±0.259	4.000-4.200	4.647±0.035	4.610-4.680	5.760±0.322	5.460-6.100
COD	**Dry season**	6.883±0.482	6.330-7.210	7.190±0.226	7.000-7.440	9.587±0.924	8.520-10.13	7.380±0.214	7.210-7.620	7.393±0.508	6.810-7.740
	Rainy season	5.007±0.140	4.870-5.150	6.550±0.235	6.320-6.790	4.937±0.280	4.760-5.260	5.447±0.404	5.100-5.890	7.047±0.542	6.430-7.450
Turb.(NTU)	**Dry season**	8.700±0.000	8.700-8.700	4.270±0.000	4.270-4.270	5.050±0.000	5.050-5.050	4.500±0.000	4.500-4.500	3.450±0.000	3.450-3.450
	Rainy season	8.867±0.058	8.800-8.900	4.297±0.006	4.290-4.300	5.867±0.058	5.800-5.900	4.867±0.115	4.800-5.000	3.833±0.058	3.800-3.900
T/Hard(mg/L)	**Dry season**	126.0±0.058	126.0-126.1	130.1±0.139	130.0-130.2	140.0±0.069	140.0-140.1	120.1±0.242	120.0-120.4	125.0±0.064	125..0-125.1
	Rainy season	110.0±10.00	110.0-120.0	120.0±0.000	120.0-120.0	126.7±5.774	120.0-130.0	110.0±0.000	110.0-110.0	120.0±0.000	120.0-120.0
Cd (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000
	Rainy season	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000
Cu (mg/L)	**Dry season**	22.27±0.146	22.13-22.42	0.012±0.021	0.000-0.040	22.51±0.857	21.52-23.01	1.670±0.193	1.500-1.880	0.008±0.003	0.008-0.010

	Rainy season	24.20±0.167	24.01-24.30	0.034±0.006	0.030-0.040	27.56±1.156	26.23-28.30	2.673±2.208	1.300-5.440	0.045±0.014	0.030-0.060
Fe (mg/L)	**Dry season**	0.068±0.002	0.068-0.070	0.079±0.105	0.020-0.200	0.280±0.097	0.210-0.390	0.762±0.002	0.760-0.762	0.002±0.003	0.000-0.010
	Rainy season	0.077±0.005	0.070-0.080	0.023±0.004	0.020-0.030	1.324±0.005	1.320-1.330	1.087±0.040	1.040-1.110	0.000±0.000	0.000-0.000
Pb (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000
	Rainy season	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.001±0.002	0.000-0.001	0.001±0.002	0.000-0.001	0.001±0.002	0.000-0.001
Zn (mg/L)	**Dry season**	2.640±0.191	2.420-2.750	0.021±0.001	0.020-0.021	0.861±0.042	0.820-0.900	0.010±0.001	0.010-0.010	0.021±0.001	0.020-0.021
	Rainy season	2.857±0.040	2.810-2.880	0.028±0.004	0.020-0.030	2.120±0.215	1.910-2.340	0.081±0.103	0.020-0.200	0.025±0.001	0.025-0.030
Na (mg/L)	**Dry season**	10.02±0.010	10.01-10.03	3.310±2.867	0.000-4.970	12.32±0.012	12.31-12.33	2.037±0.006	2.030-2.040	6.013±0.006	6.010-6.020
	Rainy season	12.20±0.176	12.00-12.34	3.420±2.965	0.000-5.150	13.34±0.112	13.24-13.46	2.137±0.015	2.120-2.150	6.077±0.031	6.050-6.110
K (mg/L)	**Dry season**	6.006±0.006	6.000-6.100	1.907±0.006	1.900-1.910	7.080±0.010	7.070-7.090	8.370±0.010	8.360-8.380	0.630±0.000	0.630-0.630
	Rainy season	10.12±0.015	10.11-10.14	2.087±0.015	2.070-2.100	11.14±0.096	11.03-11.21	11.03±0.058	11.00-11.10	1.327± 0.012	1.320-1.340

Parameter	Season	Sample Designation									
		BH6		BH7		BH8		BH9		BH10	
		(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range	(^{x}Mean±SD)	^{x}Range
pH	**Dry season**	5.37±0.058	5.30-5.40	6.90±0.000	6.90-6.90	6.65±0.000	6.65-6.65	7.20±0.000	7.20-7.20	7.10±0.000	7.10-7.10
	Rainy season	4.83±0.058	4.80-4.90	4.83±0.058	4.80-4.90	6.03±0.058	6.00-6.10	7.10±0.100	7.00-7.20	5.57±0.379	5.30-6.00
Temp. (°C)	**Dry season**	30.7±0.058	30.7-30.8	29.9±0.173	29.8-30.1	29.9±0.289	29.7-30.2	29.0±0.058	29.0-29.1	30.1±0.000	30.1-30.1
	Rainy season	30.9±0.115	30.80-31.00	31.07±0.115	31.00-31.20	29.93±0.115	29.80-30.00	29.0±0.058	29.00-29.10	30.03±0.058	30.00-30.10
E.C. (µS/cm)	**Dry season**	66.67±5.774	60.00-70.00	130.0±0.000	130.0-130.0	220.0±0.000	220.0-220.0	410.0±0.000	410.0-410.0	180.0±0.000	180.0-180.0
	Rainy season	236.7±5.774	230.0-240.0	340.0±34.64	300.0-360.0	220.0±17.32	200.0-230.0	220.0±17.32	210.0-240.0	206.7±5.774	200.0-210.0
TDS (mg/L)	**Dry season**	20.00±0.000	20.00-20.00	60.00±0.00	60.00-60.00	110.0±0.000	110.0-110.0	210.0±0.000	210.0-210.0	90.00±0.000	90.00-90.00
	Rainy season	220.0±34.64	200.0-260.0	250.0±50.00	200.0-300.0	123.3±11.55	110.0-120.0	216.7±11.55	210.0-230.0	100.0±10.00	90.00-110.0
TSS (mg/L)	**Dry season**	130.0±0.000	130.0-130.0	190.0±0.000	190.0-190.0	250.0±0.000	250.0-250.0	160.0±0.000	160.0-160.0	70.00±0.000	70.00-70.00
	Rainy season	140.0±0.000	140.0-140.0	253.0±5.774	250.0-260.0	260.0±0.000	260.0-260.0	166.7±5.774	160.0-170.0	153.3±5.774	150.0-160.0
TS(mg/L)	**Dry season**	150.0±0.000	150.0-150.0	250.0±0.000	250.0-250.0	360.0±0.000	360.0-360.0	370.0±0.000	370.0-370.0	160.0±0.000	160.0-160.0
	Rainy season	360.0±34.64	340.0-400.0	503.3±55.08	450.0-560.0	383.3±11.55	370.0-390.0	383.3±15.26	370.0-400.0	266.7±11.55	240.0-260.0
T/Ac(mg/L)	**Dry season**	0.327±0.012	0.320-0.340	0.243±0.006	0.240-0.250	0.367±0.012	0.360-0.380	1.233±0.006	1.230-1.240	0.203±0.006	0.200-0.210
	Rainy season	0.403±0.006	0.400-0.410	10.43±0.058	10.40-10.50	0.317±0.029	0.300-0.350	1.213±0.112	1.200-1.220	0.247±0.006	0.240-0.250
T.Al(mg/L)	**Dry**	34.03±0.058	34.00-	35.03±0.058	35.00-	28.14±0.069	28.10-	28.11±0.023	28.10-	37.04±0.064	37.00-

	season		34.10		35.10		28.22		28.14		37.11
	Rainy season	28.67±1.155	28.00-30.00	15.43±0.058	15.40-15.50	27.33±0.577	27.00-28.00	28.00±0.000	28.00-28.00	20.03±0.058	20.00-20.10
NO_3^- (mg/L)	**Dry season**	1.853±0.112	1.840-1.860	1.727±0.006	1.720-1.730	1.737±0.006	1.730-1.740	1.253±0.112	1.240-1.260	1.887±0.006	1.880-1.890
	Rainy season	6.333±0.289	6.000-6.500	14.07±0.982	13.50-15.20	2.000±0.100	1.900-2.100	1.300±0.173	1.200-1.500	7.667±2.517	5.000-10.00
PO_4^{3-} (mg/L)	**Dry season**	0.230±0.026	0.200-0.250	0.247±0.006	0.240-0.250	0.367±0.006	0.360-0.370	0.143±0.006	0.140-0.150	0.420±0.010	0.410-0.430
	Rainy season	7.530±1.343	6.000-8.500	9.933±0.115	9.800-10.00	10.33±0.306	10.00-10.60	0.153±0.015	0.140-0.170	3.883±2.644	0.850-5.700
SO_4^{2-} (mg/L)	**Dry season**	24.18±0.136	24.10-24.34	22.21±0.078	22.15-22.30	21.23±0.070	21.18-21.31	23.20±0.100	23.10-23.30	22.20±0.200	22.00-22.40
	Rainy season	82.63±21.78	58.20-100.0	21.43±0.115	21.30-21.50	21.53±0.252	21.30-21.80	33.50±2.773	30.30-35.20	25.73±0.635	25.00-26.10
BOD	**Dry season**	4.893±0.206	4.760-5.130	5.513±0.975	4.430-6.320	4.487±0.215	4.320-4.730	4.303±0.031	4.270-4.330	3.190±0.046	3.140-3.230
	Rainy season	4.037±0.210	3.800-4.200	2.950±0.062	2.880-3.000	4.023±0.078	3.960-4.110	3.970±0.177	3.780-4.130	4.400±0.174	4.200-4.520
COD	**Dry season**	8.670±1.339	7.710-10.20	9.230±2.140	6.760-10.51	6.180±0.308	5.840-6.440	6.430±0.118	6.330-6.560	6.617±0.342	6.230-6.880
	Rainy season	4.947±0.292	4.610-5.130	3.650±0.260	3.490-3.950	4.903±0.087	4.830-5.000	4.847±0.304	4.520-5.120	5.327±0.067	5.270-5.400
Turb.(NTU)	**Dry season**	4.750±0.000	4.750-4.750	8.900±0.000	8.900-8.900	8.900±0.000	8.900-8.900	8.950±0.000	8.950	4.700±0.000	4.700-4.700
	Rainy season	4.823±0.025	4.800-4.850	10.58±0.068	10.50-10.63	10.91±0.012	10.90-10.92	10.03±0.058	10.00-10.10	4.983±0.029	4.950-5.000
T/Hard(mg/L)	**Dry season**	100.0±0.058	100.0-100.1	140.1±0.015	140.1-140.1	100.1±0.058	100.0-100.1	100.2±0.059	100.2-100.3	105.1±0.053	105.1-105.2
	Rainy season	100.0±0.000	100.0-100.0	113.3±11.54	100.0-120.0	100.0±0.000	100.0-100.0	120.2±0.252	120.0-120.5	103.3±5.774	100.0 110.0
Cd (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000
	Rainy season	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000

Cu (mg/L)	**Dry season**	19.28±0.835	18.76-20.24	16.64±0.280	16.47-16.96	10.76±0.010	10.75-10.77	0.327±0.006	0.320-0.330	0.120±0.156	0.030-0.300
	Rainy season	21.58±1.343	20.11-22.74	24.69±5.632	18.21-28.37	18.30±8.784	11.40-28.19	0.460±0.161	0.330-0.640	0.032±0.002	0.030-0.032
Fe (mg/L)	**Dry season**	0.456±0.117	0.320-0.530	10.58±0.451	10.13-11.03	0.074±0.098	0.020-0.190	0.096±0.007	0.090-0.100	0.092±0.001	0.090-0.092
	Rainy season	1.651±1.071	0.240-2.340	12.29±0.064	12.22-12.33	0.152±0.113	0.020-0.220	0.124±0.010	0.110-0.130	0.095±0.010	0.080-0.100
Pb (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000
	Rainy season	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000
Zn (mg/L)	**Dry season**	2.392±0.294	2.110-2.700	2.143±0.038	2.120-2.190	1.684±0.251	1,410-1.910	0.031±0.002	0.030-0.031	0.156±0.041	0.110-0.190
	Rainy season	3.387±0.230	3.150-3.610	0.044±0.012	0.030-0.050	2.439±0.111	2.310-2.510	0.045±0.015	0.030-0.060	0.172±0.016	0.150-0.180
Na (mg/L)	**Dry season**	3.123±0.006	3.120-3.130	22.43±0.012	22.42-22.44	13.90±0.053	13.86-13.96	17.28±0.010	17.27-17.29	17.01±0.010	17.00-17.02
	Rainy season	4.153±0.040	4.110-4.190	21.24±0.038	21.21-21.28	14.17±0.072	14.12-14.25	15.19±0.042	15.14-15.22	17.12±0.031	17.09-17.15
K (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	7.740±0.020	7.720-7.760	9.280±0.010	9.270-9.280	12.01±0.015	12.00-12.03	9.270±0.015	9.260-9.290
	Rainy season	12.02±0.026	12.00-12.05	15.10±0.006	15.10-15.11	13.22±0.010	13.21-13.23	11.01±0.006	11.00-11.01	10.04±0.010	10.03-10.05

Parameter	Season	Sample Designation								
		BH11		BH12		([y]Mean±SD)	[y]Range		Recommended Maximum Permissible Level	
		([x]Mean±SD)	[x]Range	([x]Mean±SD)	[x]Range					
pH	**Dry season**	7.20±0.00	7.20-7.20	7.50±0.00	7.50-7.50	6.13±1.03	4.900-7.500		[†*#]8.500	
	Rainy season	6.07±0.21	5.90-6.30	6.43±0.06	6.49-6.50	5.40±0.85	4.00-7.20			
Temp. (°C)	**Dry season**	31.1±0.1	31.1-31.2	30.0±0.1	30.0-30.1	30.4±0.746	29.0-31.9		25.0(ambient)	
	Rainy season	31.40±0.346	31.00-31.60	30.40±0.200	30.20-30.60	30.32±0.848	29.00-31.90			
E.C. (µS/cm)	**Dry season**	200.0±0.000	200.0-200.0	240.0±0.000	240.0-240.0	133.9±120.3	10.000-410.0		#1000	
	Rainy season	276.7±32.15	240.0-300.0	308.3±7.638	300.0-315.0	189.6±107.7	10.00-360.0			
TDS (mg/L)	**Dry season**	100.0±0.000	100.0-100.0	120.0±0.000	120.0-120.0	62.50±64.97	0.000-210.0		[†#]500.0	
	Rainy season	183.3±5.774	180.0-190.0	135.0±8.660	130.0-145.0	127.4±81.13	0.000-260.0			
TSS (mg/L)	**Dry season**	120.0±0.000	120.0-120.0	270.0±0.000	270.0-270.0	164.2±67.62	70.00-270.0		NS	
	Rainy season	130.0±0.000	130.0-130.0	273.3±5.774	270.0-280.0	186.7±60.03	100.0-280.0			
TS(mg/L)	**Dry season**	220.0±0.000	220.0-220.0	390±0.000	390.0-390.0	226.7±103.1	70.00-390.0		[†]500.0	
	Rainy season	313.3±5.774	310.0-320.0	408.3±7.638	400.0-415.0	311.8±120.7	110.0-560.0			
T/Ac(mg/L)	**Dry season**	0.167±0.012	0.160-0.180	0.603±0.006	0.600-0.610	0.347±0.311	0.060-1.240		[a] 0.300	
	Rainy season	10.17±0.058	10.10-10.20	0.663±0.012	0.650-0.670	2.739±4.222	0.100-10.50			
T.Al (mg/L)	**Dry**	37.04±0.064	37.00-	38.81±0.162	38.62-	36.48±7.398	28.00-		80.00	

	season		37.11		38.90		22.10			
	Rainy season	20.17±8.808	10.00-25.50	25.00±5.000	20.00-30.00	29.07±10.56	10.00-52.10			
NO_3^- (mg/L)	**Dry season**	1.733±0.031	1.700-1.760	8.710±0.010	8.700-8.720	2.316±2.020	1.240-8.720		†# 50.00	
	Rainy season	13.43±1.530	12.50-15.20	70.00±43.30	45.00-120.0	11.68±18.97	1.200-120.0			
PO_4^{3-} (mg/L)	**Dry season**	0.310±0.010	0.300-0.320	0.320±0.010	0.310-0.330	0.337±0.212	0.120-0.870		† 10.00	
	Rainy season	9.500±0.794	8.600-10.00	2.300±0.200	2.100-2.500	4.772±3.818	0.300-10.60			
SO_4^{2-} (mg/L)	**Dry season**	20.14±0.061	20.10-20.21	22.40±0.055	22.35-22.46	21.78±1.267	20.10-24.34		†*# 200.0	
	Rainy season	29.17±0.115	29.10-29.30	29.667±0.757	28.80-30.20	31.27±16.95	0.000-100.0			
BOD	**Dry season**	5.593±0.038	5.550-5.620	5.560±0.157	5.450-5.730	5.155±0.822	3.140-6.370		†* 3.000	
	Rainy season	4.413±0.042	4.380-4.460	3.730±0.057	3.680-3.790	4.288±0.703	2.880-6.100			
COD	**Dry season**	7.673±0.365	7.280-8.000	7.257±0.302	7.000-7.590	7.541±1.085	5.840-10.51		†* 294.0	
	Rainy season	5.260±0.076	5.180-5.330	4.567±0.049	4.510-4.600	5.207±0.879	3.490-7.450			
Turb.(NTU)	**Dry season**	4.740±0.000	4.740-4.740	50.00±0.000	50.00-50.00	9.743±12.86	3.450-50.00		†# 5.000	
	Rainy season	4.867±0.058	4.800-4.900	55.67±0.577	55.00-56.00	10.80±14.37	3.800-56.00			
T/Hard(mg/L)	**Dry season**	130.2±0.058	130.1-130.2	110.1±0.058	110.1-110.2	111.7±8.839	100.0-140.1		# 150.0	
	Rainy season	113.3±11.55	100.0-120.0	103.3±5.774	100.0-110.0	118.9±15.27	100.0-130.0			
Cd (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000		†# 0.003	
	Rainy season	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000			

Cu (mg/L)	**Dry season**	12.47±762	11.59-12.91	0.041±0.001	0.040-0.041	8.961±9.371	0.000-23.01		[#]1.000	
	Rainy season	13.00±0.755	12.20-13.70	0.080±0.036	0.050-0.120	11.08±11.52	0.030-28.37			
Fe (mg/L)	**Dry season**	0.828±0.663	0.060-1.210	1.608±0.591	0.930-2.030	1.244±2.978	0.000-11.03		[#]0.300	
	Rainy season	0.048±0.005	0.040-0.050	0.066±0.010	0.060-0.070	1.499±3.448	0.000-12.29			
Pb (mg/L)	**Dry season**	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000		[†#]0.010	
	Rainy season	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000	0.000±0.000	0.000-0.000			
Zn (mg/L)	**Dry season**	3.000±0.000	3.000-3.000	2.858±0.005	2.850-2.860	1.317±1.251	0.010-3.000		[†*#]3.000	
	Rainy season	2.931±0.099	2.850-3.040	2.858±0.005	2.850-2.860	1.437±1.422	0.020-3.610			
Na (mg/L)	**Dry season**	13.96±0.010	13.95-13.97	18.62±0.196	18.41-18.80	11.81±6.608	0.000-22.44		[#]200.00	
	Rainy season	14.10±0.078	14.04-14.19	19.04±0.067	19.00-19.12	11.97±6.193	0.000-21.28			
K (mg/L)	**Dry season**	6.533±0.015	6.520-6.550	8.063±0.006	8.060-8.070	6.408±3.711	0.000-12.03		[a] 10.00	
	Rainy season	11.19±0.025	11.16-11.21	14.00±0.010	13.99-14.01	10.17±4.240	1.320-15.11			

Legend: Turb. = Turbidity. NS =Not Stated. Temp.= Temperature. TDS = Total Dissolved Solids. TSS= Total Suspended Solids. TS= Total Solids. BOD= Biochemical Oxygen Demand. COD= Chemical Oxygen Demand. E.C. = Electrical Conductivity. T/Ac. = Total Acidity. T/Al. = Total Alkalinity. T/Hard. = Total Hardness. BH= Borehole

[x] is mean concentration and range of values for a given sample;

[y] is mean concentration and range of values for all the 12 samples.

† Values are given by World Health Organisation.

*****Values are given by National Agency for Food and drugs Administration and Control.

[#] Values are given by Nigerian Standard for Drinking Water Quality (NSDWQ).

[a] Value is given by the European Union (EU).

4.2.1. 3. Temperature

The highest temperature value of 31.9 ^{0}C observed, was the same for both dry season (in BH2) and rainy season (BH3) seasons. Lowest temperature recorded was 29.0 ^{0}C during dry season (BH9) and rainy season (BH1 and BH9). The mean temperatures were 30.4±0.7 and 30.3±0.8 during dry season and rainy season respectively indicating moderate temperature stability in the ground water aquifers and a slight decrease at rainy season due to seasonal changes. The slightly elevated values of temperature during dry season could be due to thermal storage of solar energy. A similar study reported a temperature of 25.4 ^{0}C in Ikare borehole in Kogi, Nigeria lower than the mean temperature values observed in this study. [138] Temperature values obtained in this study were also above ambient level (25^{0}C) of the Nigerian Standard for Drinking Water Quality (NSDWQ) recommended by the Standard Organisation of Nigeria (SON) [11] indicating thermal pollution. The observed high level temperatures may be due to groundwater flow, heat transfer in porous groundwater media owing to geothermal gradient, thermal activity or geochemical sources such as acidic water in a highly alkaline soil causing exothermic reactions. The temperature variation in some of the boreholes could be as a result of differences in borehole depths, topography or nearness of boreholes to the thermal injection source such as power plants.

4.2.2 Parameters due to Agricultural and Fertilizer inputs Nitrate (NO_3^-) and Phosphate (PO_4^{3-}):

4.2.2.1 NO_3^-

Nitrate concentration in the borehole water samples was in the range from 1.240 - 8.720 mg/L and 1.200 - 120.0 mg/L at dry season and rainy season respectively. The mean concentration for the dry season period was 2.316±2.020 mg/L and 11.68±18.97 mg/L in rainy season (Table 4.1). The higher content of NO_3^- during rainy season

period could be due to anthropogenic factors such as the application of nitrogen-rich fertilizers to plants and agricultural processes leading to the leaching of nitrate through porous soil into ground water. Waste materials such as human and animal sewage disposal as well as proximity to cultivated fields may be possible sources of nitrate in some of the borehole water containing high concentration of nitrate. The mean content of nitrate in the samples studied during rainy season was higher than the mean content of nitrate reported in shallow (4.36±0.63) and deep (5.77±8.63) groundwater but less than surface water (22.48±24.08) in Yola area of north-eastern Nigeria. [139] Although nitrate content in the samples during dry season were below standard recommended maximum permissible level of 50.0 mg/L[11, 82], during rainy season, some samples revealed higher nitrate content (120.0 mg/L and mean value of 70.00±43.30 mg/L in BH12 rainy season result) than the permissible level set by WHO and the SON.

4.2.2.2. PO_4^{3-}

Phosphate ranged from 0.120 - 0.870 mg/L during dry season and 0.300 - 10.60 mg/L at rainy season. The mean PO_4^{3-} content in all the water samples for the dry season study was 0.337±0.212 mg/L and 4.772±3.818 mg/L in rainy season. The increased level of PO_4^{3-} concentration in the rainy season result could be due to the use of phosphorus-rich fertilizers during the rainy farming season and /or use of phosphate detergents for laundry which eventually enters the groundwater system as runoffs. In 2012, a mean value of 0.430 ± 0.660 mg/L phosphate content was reported in boreholes of different depths in Uyo Municipality. [140] This is slightly higher than the mean value of phosphate content in the dry season result of this study but less than the rainy season phosphate mean concentration of 4.772 ±3.818 mg/L. Although the mean concentrations of phosphates in this study are below the standard value of 10.00 mg/L

set by WHO [82] for portable water, some of the boreholes PO_4^{3-} contents during rainy season are slightly above this value as shown in Table 4.1. For instance BH8 had a mean PO_4^{3-} content of 10.33 ± 0.306 mg/L suggesting that the borehole water may be unsafe for drinking during rainy season and may cause digestive problems at such concentration levels. The mean concentration of PO_4^{3-} in the water samples during rainy season (4.772±3.818 mg/L) is found to be above the value of 3.50 mg/L cited [140] as recommended maximum permissible level of phosphate in drinking water by the NSDWQ. This indicates probable unsafe water quality during rainy season.

4.2.3 Parameters due to Soil Type and Geological Differences:

pH, Electrical Conductivity, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Solids (TS), Turbidity, Sulphate (SO_4^{2-}), Total Acidity, Total Alkalinity and Total Hardness:

4.2.3.1 pH:

Most of the water samples indicated acidic pH values. In dry season, the pH range recorded was 4.9 - 7.5 in all the 12 boreholes water samples with a mean value of 6.13±1.0. During rainy season, pH ranged from 4.00- 7.20 with a mean value of 5.403±0.854 indicating a seasonal decrease in pH which may be due to increased infiltration of aquifers with water containing chemical fertilizers, herbicides, pesticides, landfill leachate municipal and industrial wastes.. A physicochemical and microbial analysis of potable water sources in Enugu Metropolis in early 2015 revealed similar acidic pH values of 2.1, 4.3, 2.0, 4.2, 4.8 and 5.0 in five boreholes. [141] Okoye and Adiele (2014) also reported an acidic pH range of 4.56 – 6.36 in borehole water in Imo state, Southeast Nigeria. [142] The mean values obtained in this study during dry season and rainy season fall outside the highest desirable level of 7.00-8.50, maximum permissible level of 6.5-9.2 set by WHO guidelines for drinking

water quality [82, 111] and maximum tolerance level of 6.50 – 8.50 recommended by NAFDAC[11] and the NSDWQ [18] by SON, hence indicating unsafe, corrosive, acidic drinking water capable of leaching metal ions such as Cu, Pb and Zn from plumbing fixtures, piping of the distribution systems and aquifers. The general low pH values observed in this study may be associated with the soils and geological conditions of the borehole locations.

4.2.3.2 Electrical Conductivity:

Electrical Conductivity ranged from 10.000- 410.0 μS/cm in water samples studied during dry season and 10.00- 360.0 μS/cm during rainy season study. The mean values for dry season and rainy season studies were 133.9±120.3 μS/cm and 189.6±107.7 μS/cm respectively, indicating a seasonal change in electrical conductivity (an increase in rainy season conductivity mean value) which may be due to a rise in the content of ionisable materials transported into the groundwater. Generally, all the water samples showed electrical conductivity values below the standard maximum permissible level of 1000 μS/cm [11] recommended for potable water. Primarily, the geology of the area may account for this common trend in conductivity of the groundwater. Similar studies revealed lower conductivity mean values in shallow and deep groundwater in Yola, [139] in borehole water samples randomly selected from communities in Obio Akpor, River State, [143] but showed higher mean values of 436.0 μS/cm in borehole water samples from Wukari town, [144] 1600 μS/cm, 782.50 μS/cm, 562.50 μS/cm and 495 μS/cm in water samples from four selected boreholes located close to municipal landfill site in Kano Metropolis, Nigeria. [137]

4.2.3.3 TDS, TSS and TS

As shown in Table 4.1, TDS ranged from 0.000- 210.0 mg/L with a mean value of 62.50±64.97 mg/L in dry season. The rainy season TDS results range was 0.000-260.0 mg/L with a mean value of 127.4±81.13 mg/L indicating an increase in total dissolved solid in the rainy season water samples which may be due to increase in the concentration of soluble species from the environment entering the water. This could include soluble inorganic solutes from fertilizers residue run-off during rainy season growing season of crops, urban run-off, and sewage or from industrial effluents washed by rainwater and leached into groundwater. In 2011, Ani et. al characterized industrial effluents in Enugu, Nigeria and recorded high concentrations level of total dissolved solids in effluents from beverage and fibre-cement plants. [145] Okoye et. al had in 2010 reported TDS in the range between 0.14- 266.67 mg/L in different sources of water from Anambra, Abia, Enugu and Imo. [146] The values of TDS obtained in this study were all below the recommended value of 500 mg/L for TDS in potable water set by standard bodies. [11, 82; 111]

The range of values for total suspended solid (TSS) during dry season was 70.00-270.0 mg/L with a mean concentration of 164.2±67.62 mg/L. During rainy season, TSS range was 100.0- 280.0 mg/L with a mean concentration of 186.7±60.03 mg/L.

Total Solids (TS) during dry season ranged from 70.00 - 390.0 mg/L and had a mean concentration of 226.7±103.1 mg/L but had a concentration range of 110.0 - 560.0 mg/L and mean of 311.8±120.7 mg/L during rainy season indicating a seasonal increase in TS content. However, the mean value obtained for the TS in this study were below the standard value of 500 mg/L [82, 111] recommended by W.H.O. but above the NAFDAC set value of 100 mg/L [18] recommended for drinking water quality.

4.2.3.4 Turbidity:

Turbidity at dry season ranged between 3.450- 50.00 NTU with a mean value of 9.743±12.86. At rainy season the range was 3.800- 56.00 NTU and mean of 10.80±14.37 NTU, indicating a very slight (perhaps due to relative decrease in ground water flow rate) increase in turbidity. The increase in TSS and turbidity may be due to increase in silt and clay carried into groundwater by rainfall runoff on the landscape. The mean turbidity content during both seasons was found to be higher than the values recorded in some other studies [147, 148.] The mean turbidity values were higher than the highest desirable level of 5 NTU recommended by standard bodies. [11, 82; 111]

4.2.3.5 Sulphate (SO_4^{2-}):

SO_4^{2-} range between 20.10- 24.34 mg/L at dry season and 0.000- 100.0 mg/L in rainy season. The mean SO_4^{2-} contents were 21.78±1.267 mg/L and 31.27±16.95 mg/L during dry season and rainy season respectively showing an increase in sulphate concentration. The concentration of sulphate during both seasons was below the recommended value of 200 mg/L [11, 18, 82; 111] set by standard regulatory bodies. Studies in other parts of South-east Nigeria and Enugu in the past agree with the finding that sulphate content in the borehole water content is below the recommended value. [146, 149; 150]

4.2.3.6 Total Acidity:

The range of concentration of total acidity was between 0.060- 1.240 mg/L at dry season and 0.100- 10.50 mg/L at rainy season. There was seasonal variation in total acid contents in the borehole water as the mean acidity concentration increased from 0.347±0.311 mg/L at dry season to 2.739±4.222 mg/L at rainy season. This increase in acidity loading could be due to flushing and percolation of water containing dissolved acidic radicals into the groundwater. The range of total acidity in borehole

water in Enugu state, Nigeria as observed by a previous study [141] showed similarities in acid content with the range of total acidity concentrations observed in the dry season result of this study. The mean total acid content of the water samples in this study during dry season and rainy season were within standard guideline values for total acidity in drinking water. [151]

4.2.3.7. Total Alkalinity:

The respective ranges of total alkalinity during dry season and rainy season are 28.00-22.10mg/L and 10.00 - 52.10 mg/L. As acidity increased, there was a corresponding drop in the mean total alkalinity contents from 36.48±7.398 mg/L during dry season to 29.07±10.56 mg/L at rainy season. This noticeable seasonal variation in alkalinity may be due to chemical processes in the groundwater and sodic soils (alkaline soils-rich in salts or carbonates of sodium or some other alkali metal) resulting from farming activities. The range of values as well as mean total alkalinity content obtained in the water samples of this study were within the standard recommended guidelines values. [18, 82, 111; 151] Similar findings were made in the study of total alkalinity in borehole water samples in Enugu and parts of South-east [142] as well as some other parts of Nigeria [149] during dry season and rainy season [152]

4.2.3.8. Total Hardness:

Total hardness remained fairly the same at both seasons. It dry season range recorded was 110.1- 110.2 mg/L with a mean of 110.1±0.058 mg/L and rainy season results ranged between 100.0- 110.0 mg/L with a mean value of 118.9±15.27 mg/L. The similarity in total hardness in all the samples could be due to the general hydrogeology, geochemistry and soil conditions of the area. The range and means of total hardness concentrations in all the water samples obtained during dry season and

rainy season were below the recommended guideline value of 150 mg/L as contained in the NSDWQ. [11]

Past data also showed lower hardness concentrations in borehole water in Enugu state and some parts of south-east Nigeria when compared to the recommended guideline value [136, 141, 146 150 153 and 154] but was above the set guideline value in some borehole water samples in Ebonyi area of Nigeria. [155]

4.2.4 Metals: Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Zinc (Zn), Potassium (K) and Sodium (Na).

4.2.4.1. Cd:

Cd was not detectable in all the unspiked water samples during dry season and rainy season as shown in Tables 4.1 and 4.2a - 4.2d. Several studies of borehole water in some parts of south-east Nigeria and Enugu state in particular showed similar results of the absence of Cd (or below detection limit) but was detectable in some water samples from different sources as reported in other studies. [125, 141, 142, 146, 148, 149, and 155]

The percent recovery of cadmium and all other metals in spiked samples is given in Tables 4.2a – 4.2e.

4.2.4.2. Cu:

As shown in Table 4.1 Cu ranged between 0.000- 23.01 mg/L during the dry season with a mean concentration of 8.961±9.371 mg/L which increased to 11.08±11.52 mg/L during rainy season. This increase could be due to a change in corrosive water characteristics that leads to increase in copper solubility such as a decrease in pH below 6.5 and an increase in acidity of the borehole water samples leading to corrosion of copper-containing distribution piping systems (that is corrosion due to increased *cuprosolveny* of the water). The range of Cu content in the water in rainy season was 0.030- 28.37 mg/L. The dry season and rainy season mean content of Cu

in the water samples were above the recommended guideline value of 1.00 mg/L. [11] The range of Cu content is also above those obtained in borehole water samples from some parts of the south-east area of Nigeria as shown by some previous studies. [125, 141, 142, 146, 148, 153 and 154]

4.2.4.3. Fe:

The levels of Fe in the water samples during dry season and rainy season were in the range between 0.000 - 11.03 mg/L and 0.000 - 12.29 mg/L respectively. The dry season and rainy season Fe mean concentrations were 1.244±2.978 mg/L and 1.499±3.448 mg/L indicating a slight rise in iron content during rainy season; and these were above the recommended guideline value of 0.30 mg/L.[11] Similar findings include Nwachukwu et. al (2014) that recorded higher iron concentrations in shallow hand dug wells, lake/ponds and rivers in some rural regions of South-east Nigeria, [125] Uzoije, et. al (2014) recorded high Fe content in shallow aquifers (hand-dug wells and springs of the discharge farmland settlement) and some deep aquifers (boreholes) in Nsukka south-east [153.] A study by WHO and UNICEF (2010) reported that although there was 86% national compliance to standard regulations of Fe in potable water from borehole source, high Fe concentrations were recorded in a number of areas in Nigeria with extreme high levels upto 13.5 mg/L. [156] Similar seasonal variability in Fe content in borehole water as found in this study was also observed by Idoko (2012) with Fe concentration increasing during rainy season. [157] However, Engwa et. al (2015) recorded "not detected" in all the water sources from Enugu metropolis studied for Fe content (including water from borehole source) [141] while Okoye and Adiele (2014) recorded Fe concentrations in borehole water sample in an area in Imo state Nigeria lower than the recommended guideline value. [142] Fe in borehole water was

also found to be at lower concentrations in some borehole water samples from Abia [148] and Akwa-ibom. [140 and 158]

4.2.4.4. Pb:

Pb was not detectable in all the unspiked water samples during dry season and rainy season as shown in Tables 4.1. A similar observation was made by Onwugara, et. al (2013) in where Pb was not found in all but one borehole water sample collected from various locations within a community in Ebonyi, Nigeria. [154] However, a study in 2010 detected Pb above the standard maximum permissible level of 0.01 mg/L set by the SON [11] in some of the borehole water samples from Enugu Urban studied [149] and in some shallow hand-dug wells, rivers and lakes/ponds clusters in some rural regions of south-east Nigeria. [125]

4.2.4.5. Zn:

Zn content was in the range between 0.010- 3.000 mg/L during dry season and 0.020-3.610 mg/L in rainy season. The mean Zn content slightly increased from 1.317±1.251 mg/L recorded in dry season to 1.437±1.422 mg/L in rainy season. The mean Zn content was below the maximum permissible level of 3.00 mg/L set by WHO [82, 111; 151] NAFDAC[18] and SON [11]. This low content of Zn in most of the water samples could be due its low solubility in water but Zn is used in some fertilizers which may leach into groundwater. Similar studies also recorded low Zn content in borehole water from Enugu urban [149] and Imo state [142] but found above the recommended guideline value in some Benin water from boreholes and hand-dug well studied in 2002. [159]

4.2.4.6 . Na:

Na concentration ranged between 0.000- 22.44 mg/L and between 0.000- 21.28 mg/L during dry season and rainy season respectively. The mean Na contents during both

seasons are considerably comparable: a dry season value of 11.81 ± 6.608 mg/L and a rainy season value of 11.97±6.193 mg/L. The mean values were below the recommended maximum permissible level of 200 mg/L set by SON [11] and the European Union (EU) [160] Similar results were recorded in Imo [142] and Nsukka south-east. [153]

4.2.4.7. K:

During dry season the range of potassium in the water samples was 0.000 - 12.03 mg/L and in rainy season, it was 1.320 - 15.11 mg/L. The mean content of K increased from 6.408±3.711 to 10.17±4.240 mg/L. This may be due to the leaching of dissolved potassium from fertilizers into groundwater during the rainy season planting season. The rainy season mean value is slightly above the standard guideline value of 10.0 mg/L recommended by the EU. [160] The content of potassium in some hand-dug wells and springs of discharge farmland settlement in Nsukka south-east were in the range of 0.000 - 10.0 mg/L [153] while another report showed a range of 1.00 – 12.00 mg/L potassium in borehole water from Imo state. [142]

4.2.5. Recovery Studies for the Metals:

As shown in Tables 4.2a – 4.2e, most of the water samples showed metal mean percent recoveries above 98.21 % with exception to Zn with a mean percent recovery of 96.36 %. A mean recovery of 100.05 % was recorded for sodium. The repeatedly monthly high percentages of metals recovered in the selected water samples studied validate the accuracy of the methods and instruments as well the reliability of the results obtained.

Table 4.2a Metal Percent Recovery (% R) for the month of December:
Sample ID: BH8

Metal	Concentration (mg/L) in Unspiked Sample	Concentration (mg/L) added	Concentration in Spiked Sample	(% R)
Cadmium (Cd)	ND	0.524	0.5238	99.96
Copper (Cu)	10.77	0.514	11.283	99. 87
Iron (Fe)	0.187	0.513	0.6996	99.92
Lead (Pb)	ND	0.502	0.5019	99.98
Zinc (Zn)	1.414	0.529	1.9201	95.68
Potassium (K)	9.27	1.00	10.26	99.00
Sodium (Na)	13.97	2.00	15.95	99.25

Table 4.2b Metal Percent Recovery (% R) for the month of April:
Sample ID: BH5

Metal	Concentration (mg/L) in Unspiked Sample	Concentration (mg/L) added	Concentration (mg/L) in Spiked Sample	(% R)
Cadmium (Cd)	ND	0.524	0.518	98.85
Copper (Cu)	0.034	0.514	0.5476	99.93
Iron (Fe)	ND	0.513	0.5126	99.96
Lead (Pb)	ND	0.502	0.5013	99.86
Zinc (Zn)	0.025	0.529	0.510	91.68
Potassium (K)	1.33	1.00	2.3239	99.39
Sodium (Na)	6.03	2.00	8.01	99.00

Table 4.2c Metal Percent Recovery (% R) for the month of May:
Sample ID: BH7

Metal	Concentration (mg/L) in Unspiked Sample	Concentration (mg/L) added	Concentration in Spiked Sample	(% R)
Cadmium (Cd)	ND	0.524	0.522	99.62
Copper (Cu)	18.21	0.514	18.67	89.49
Iron (Fe)	12.331	0.513	12.843	99.90
Lead (Pb)	ND	0.502	0.5017	99.94
Zinc (Zn)	0.030	0.529	0.522	93.01
Potassium (K)	15.10	1.00	16.06	96.00
Sodium (Na)	21.22	2.00	23.20	99.37

Table 4.2d Metal Percent Recovery (% R) for the month of June:
Sample ID: BH12

Metal	Concentration (mg/L) in Unspiked Sample	Concentration (mg/L) added	Concentration in Spiked Sample	(% R)
Cadmium (Cd)	ND	0.524	0.522	99.62
Copper (Cu)	0.12	0.514	0.633	99.77
Iron (Fe)	0.072	0.513	0.581	99.22
Lead (Pb)	ND	0.502	0.5017	99.95
Zinc (Zn)	2.861	0.529	3.389	99.81
Potassium (K)	14.00	1.00	14.981	98.10
Sodium (Na)	19.00	2.00	20.984	99.20

Table 4.2e Mean Percent Recovery (Mean % R) for the Study of Metals in four randomly selected samples for both dry season and rainy season.

Metal	Mean % R	Range of % R
Cadmium (Cd)	99.51	98.85 – 99.96
Coppe r (Cu)	98.21	89.49 – 99.97
Iron (Fe)	99.83	99.22 – 99.96
Lead (Pb)	99.96	99.86 – 99.98
Zinc (Zn)	96.36	91.68 – 99. 81
Potassium (K)	98.53	96.00 – 99.39
Sodium (Na)	100.05	99.00 – 99.37

4.3 WATER QUALITY INDEX (WQI):

The water quality ratings assigned to water quality index values are given below:

Table 4.3a: Standard Ratings for Drinking Water Quality. [161]

Water Quality Index	Water Quality Rating
0 – 25	Excellent
26 – 50	Good
50 – 75	Poor
76 – 100	Very Poor
› 100	Unfit for Drinking

Table 4.3b: Water Quality Indices (WQI) and Ratings of the 12 borehole water samples for dry season and rainy season.

Sample ID	WQI (dry season)	Quality rating	WQI(rainy season)	Quality rating
BH1	5.9668	Excellent	25.4292	Excellent
BH2	0.7984	Excellent	0.5996	Excellent
BH3	6.1838	Excellent	12.6710	Excellent
BH4	2.4802	Excellent	32.2556	Good
BH5	0.6445	Excellent	3.0032	Excellent
BH6	6.1106	Excellent	9.7854	Excellent
BH7	29.2698	Good	32.5691	Good
BH8	3.5701	Excellent	5.5693	Excellent
BH9	3.4182	Excellent	4.3098	Excellent
BH10	0.8754	Excellent	0.9823	Excellent
BH11	5.2627	Excellent	3.6867	Excellent
BH12	5.8747	Excellent	2.6911	Excellent

Table 4.3c: Ratings of the 12 boreholes in terms of WQI in dry season and rainy season:

Dry season rating	Borehole	Dry season WQI	Rainy season rating	Borehole	Rainy season WQI
1.	BH5	0.6445	1.	BH2	0.5996
2.	BH2	0.7984	2.	BH10	0.9823
3.	BH10	0.8754	3.	BH12	2.6911
4.	BH4	2.4802	4.	BH5	3.0032
5.	BH9	3.4182	5.	BH11	3.6867
6.	BH8	3.5701	6.	BH9	4.3098
7	BH11	5.2627	7	BH8	5.5693
8	BH12	5.8747	8	BH6	9.7854
9	BH1	5.9668	9	BH3	12.6710
10.	BH6	6.1106	10.	BH1	25.4292
11.	BH3	6.1838	11.	BH4	32.2556
12.	BH7	29.2698	12.	BH7	32.5691

4.4 Inferential Statistics of the Findings:

4.4.1 Variation between the qualities of the 12 boreholes water samples during dry season.

A two-way ANOVA conducted showed a statistically significant difference between the mean concentrations of parameters indicating general degree of pollution (BOD, COD and temperature) in the 12 boreholes water samples during dry season ($F(2, 33) = 2912.56$, $p < .05$). Post-hoc analyses of multiple comparisons using Dunett's T3

indicated a significant difference between the 12 water samples in terms of mean values of BOD ($p < .05$), COD ($p < .05$) and Temperature ($p < .05$) during dry season. Also during dry season, the ANOVA indicated a significant difference in the 12 borehole water samples in terms of parameters due to soil type and geological differences: pH, electrical conductivity, TSS, TDS, TS, total acidity, total alkalinity, total hardness, sulphate, and turbidity (F (9, 110) = 21.47, $p < .05$) Dunett's T3 post-hoc test showed that the water samples were significantly different due to TSS($p < .05$) , TS ($p < .05$), total alkalinity ($p < .05$) , total acidity ($p < .05$), total hardness ($p < .05$) and sulphate($p < .05$) but turbidity (p =1.00), pH (p =.10), TDS (p =.27) and electrical conductivity were relatively the same in the 12 samples of borehole water studied during dry season.

The ANOVA of the metal contents during dry season showed significant difference between the 12 boreholes water samples (F (6, 77) = 12.39, $p < .05$). A Dunett's T3 post-hoc test of the dry season metal results revealed a significant difference due to Cu ($p < .05$), potassium ($p < .05$) and sodium ($p < .05$) mean contents while each of the mean concentrations of iron and zinc metals were relatively the same in the 12 water samples: Fe ($p < .93$), Zn ($p < .06$).

From the ANOVA results, there is a significant variation between the 12 water samples quality during dry season.

4.4.2 Variation between the qualities of the 12 boreholes water samples during rainy season.

From the two-way ANOVA of the rainy season results, there was a statistical significant difference in the 12 borehole water samples with respect to BOD, COD and temperature i.e. parameters indicating general degree of pollution (F(2, 33) = 3954.82, $p < .05$). From the post- hoc test conducted, all the 12 borehole water

samples were significantly different in terms of BOD, COD and temperature ($p < .05$).

Parameters due to soil type and geological differences also varied significantly in the water samples during rainy season (F (9, 110) = 35.04, $p < .05$). The post-hoc test revealed a significant difference in the rainy season electrical conductivity ($p < .05$), sulphate ($p < .05$), TS ($p < .05$), pH ($p < .05$), total hardness ($p < .05$) and total alkalinity ($p < .05$) but the mean concentrations of some parameters in the 12 water samples [total acidity ($p = .73$), turbidity ($p = 1.00$), TDS ($p = .98$) and TSS ($p = 1.00$)] were relatively the same.

There was also significant difference in the 12 water samples during rainy season due to their metals contents as shown by the ANOVA result ($F(6, 77) = 12.91$, $p < .05$). A Dunett's T3 post-hoc test of multiple comparison showed that the mean contents of the heavy metals: Cu ($p < .10$), Fe, ($p < .91$), Zn ($p < .08$), Cd ($p < .10$) and Pb ($p < .10$) in the 12 water samples were relatively the same but the samples significantly varied due to the mean contents of potassium ($p < .05$) and sodium ($p < .05$).

From the ANOVA results, there is a significant variation between the 12 water samples quality during rainy season.

4.4.3 Variation between the rainy season and dry season mean concentration values of the physicochemical parameters in the 12 borehole water samples.

There was a statistically significant difference between the dry season and rainy season results with respect to BOD, COD, and temperature as revealed by the ANOVA (F (5, 66) = 2712.84, $p < .05$). Dunett's T3 post- hoc test showed a significant difference between the dry season and rainy season mean contents of BOD ($p < .05$) and COD ($p < .05$) in all the 12 sample but temperature was relatively the same ($p < 1.00$).

Nitrates and phosphates varied significantly in all the 12 water samples during dry season and rainy season (F (4, 44) =3.10, p < .04). The post-hoc test revealed a significance difference between the dry season and rainy season nitrates (p =.02) and phosphate (p =.01) in the 12 water samples.

The dry season and rainy season mean concentrations of the parameters due to soil type and geological differences also varied significantly in the 12 water samples as revealed by the ANOVA (F (19, 220) = 27.46, p < .05). Dunett's post-hoc tests indicated that the dry season water samples and rainy season water samples did not vary significantly in terms of pH (p = .99), TSS (p = 1.00), sulphate (p = .97), turbidity (p = 1.00), total acidity (p = .97) and total hardness (p = 1.00), TDS (p = .96), TS(p = 1.00) and electrical conductivity (p = 1.00) in all the 12 samples analysed but varied significantly due to total alkalinity (p < .05).

The concentration of metals in the samples during dry season is significantly different from the rainy season metals results as revealed by the ANOVA (F (13, 154) = 11.81, p < .05). Dunett's T3 showed Cu (p = 1.00), Fe (p = .100), Zn (p = .100), potassium (p = .79), Sodium (p = .100).

From the ANOVA results, there is a significant variation between the rainy season and dry season mean concentration values of the physicochemical parameters in the 12 borehole water samples.

4.4.4 Linear correlations between the water quality parameters studied.

The measure of the strength of association of the water quality parameters was determined using Pearson's correlation coefficient (r).

During rainy season, pH was weakly positively correlated with electrical conductivity: Pearson's r (12) = .32, p = .31; TDS: r (12) = .36, p = .24, TSS: r (12)

=.11, p = .73, TS: r (12) = .32, p = .32 and weakly negatively correlated with temperature: r (12) =.17, p = .60.

Electrical conductivity strongly positively correlated with TDS: r (12) = .74, p < .05, and TS: r (12) = .74, p < .05; weakly positively correlated with temperature: r (12) = .34, p = .28, turbidity: r (12) = .41, p = .19 and TSS: r (12) = .32, p = .32.

Turbidity was moderately correlated with TSS: r (12) = .58, p = .05, weakly positively correlated with TDS: r (12) = .12, p = .70 and TS: r (12) = .38, p = .22 and then weakly negatively correlated with temperature r (12) = .94, p = .03.

Temperature was weakly positively correlated with TDS: r (12) = .34, p = .28 and TS: r (12) = .20, p =.54 and weakly negatively correlated with TS: r (12) = .08, p = .80.

There was a strong linear positive relationship between TS and TDS: r (12) = .73, p < .05 a well as with TSS: r (12) = .86, p < .05.

Total acidity showed weak negative correlations with pH: r (12) = .08, p = .80 and turbidity: r (12) = .09, p = .78 but was weakly positively correlated with electrical conductivity r (12) = .41, p = .19, temperature r (12) = .19, p = .56, TDS r (12) = .44, p = .15, TSS: r (12) = .26, p = .42 and TS: r (12) = .44**, p = .16.

Total alkalinity weakly negatively correlated with pH: r (12) = .42, p = .18, electrical conductivity: r (12) = .42, p = .18, temperature: r (12) = .23, p = .48, TSS: r (12) = .36, p = .24, and turbidity: r (12) = .19, p = .54, and moderately negatively correlated with TDS: r (12) = .62, p = .03 and TS: r (12) = .65, p = .02.

Total hardness showed weak negative correlation with pH: r (12) = .03, p = .93, electrical conductivity: r (12) = .48, p = .11, TDS: r (12) = .18, p = .57, TSS: r (12) = .34, p = .28, TS: r (12) = .33, p = .29 and turbidity: r (12) = .32, p = .31 but showed weak positive correlation with temperature: r (12) = .12, p = .70.

Nitrate was strongly positively correlated with turbidity: r (12) = .96, p < .05, weakly positively correlated with pH: r (12) = .39, p = .21, electrical conductivity: r (12) = .21, p = .50, TDS: r (12) = .22, p = .50, TSS: r (12) = .46, p = .12, TS: r (12) = .45**, p = .15, temperature: r (12) = .09, p = .78 and total acidity: r (12) = .06, p = .31.

Sulphate was weakly negatively correlated with pH: r (12) = .09, p = .77, TSS: r (12) = .37, p = .24, total acidity: r (12) = .23, p = .79 and turbidity: r (12) = .09, p = .80 and weakly positively correlated with electrical conductivity: r (12) = .11, p = .73, temperature: r (12) = .16, p = .63

Phosphate was weakly negatively correlated with pH: r (12) = .14, p = .67, turbidity: r (12) = .09, p = .80; moderately positively correlated with electrical conductivity: r (12) = .55, p = .07, TDS: r (12) = .51**, p = .09, TS: r (12) = .55**, p = .06, total acidity: r (12) = .59, p = .69; and weakly positively correlated with temperature: r (12) = .34, p = .29, and TSS r (12) = .36, p = .25.

BOD showed strong negative correlations with electrical conductivity: r (12) = .77, p < .05, TDS: r (12) = .84, p < .05, TSS: r (12) = .72, p = .01 and TS: r (12) = .98, p <.05; weak negative correlations with pH: r (12) = .24, p = .46, temperature: r (12) = .21, p = .45, total acidity: r (12) = .43, p = .23 and turbidity: r (12) = .38, p = .23.

COD strongly negatively correlated with electrical conductivity: r (12) = .78, p < .05, TSS: r (12) = .72, p = .01, TS: r (12) = .38, p = .23; weakly negatively correlated with pH: r (12) = .21, p = .52, temperature: r (12) = .24, p = .45, turbidity: r (12) = .26, p = .26 and total acidity: r (12) = .44, p = .26.

Cu weakly negatively correlated with pH: r (12) = .31, p = .20 and turbidity: r (12) = .22, p = .48 and weakly positively correlated with electrical conductivity: r (12) = .12, p = .71, temperature: r (12) = .44, p = .15, TDS: r (12) = .50, p = .10, TSS: r (12) =

.43, p = .17, total acidity : r (12) = .48, p = .48 and moderately positively correlated with TS: r (12) = .56, p = .07.

Fe weakly negatively correlated with pH: r (12) = .29, p = .37 and turbidity: r (12) = .06, p = .86; weakly positively correlated with electrical conductivity: r (12) = .46, p = .13, temperature: r (12) = .35, p = .26, TSS: r (12) = .32, p = .32, and moderately positively correlated with TS: r (12) = .51**, p = .09 and total acidity: r (12) = .51, p = .86.

There was a weak positive correlation between Zn and pH: r (12) = .13, p = .70, electrical conductivity: r (12) = .17, p = .59**, temperature: r (12) = .30, p = .35, TDS: r (12) = .30, p = .34, TS: r (12) = .39**, p = .21, turbidity: r (12) = .32, p = .31, and total acidity: r (12) = .18, p = .31.

Potassium showed strong positive correlation with electrical conductivity: r (12) = .86, $p < .05$, TDS: r (12) = .78, $p < .05$, and TS: r (12) = .93, $p < .05$; moderate positive correlation with TSS: r (12) = .69, p = .01 and total acidity: r (12) = .32, p = .22; weak positive correlation with pH: r (12) = .24, p = .46, turbidity: r (12) = .39, p = .22.

Sodium was strongly positively correlated with TS: r (12) = .70, p = .01; moderately positively correlated with pH: r (12) = .55, p = .06, electrical conductivity: r (12) = .55, p = .08, TDS: r (12) = .55, p = .07, TSS: r (12) = .60, p = .04, turbidity: r (12) = .46, p = .13, and total acidity: r (12) = .44, p = .13; and weakly positively correlated with temperature: r (12) = .10, p = .77.

From the Pearson's correlation coefficients of the water quality parameters obtained in this study, linear relationships such as weak negative or positive correlations, moderate negative or positive correlations or strong negative or positive correlations exist between some of the water quality parameters of the 12 samples.

**. Correlation is significant at the 0.01 level (2-tailed).

4.4.5 Variation between the physicochemical overall Water Quality Index (WQI) of the study area during dry season and WQI during rainy season.

An independent T-test (Levene's test) showed that there is no significant difference between the overall physicochemical Water Quality Index (WQI) of the study area during dry season and WQI during rainy season t (18.67) = -1.27, p = .22.

However, as shown in Table 4.5b, based on the physicochemical WQI computed, BH7 (dry season *WQI* = 29.2698, rainy season *WQI* = 32.5691) was rated as having the poorest physicochemical quality in both seasons while BH5 (*WQI* = 0.6445) and BH2 (*WQI* = 0.5996) had the best physicochemical quality in dry season and rainy season respectively.

4.5 CONCLUSION

The findings of this study revealed a difference in the quality of water in the 12 boreholes studied in terms of their content of the 22 physicochemical water parameters considered in dry season and rainy season. The rainy season and dry season mean concentration values of the physicochemical parameters in the 12 borehole water samples also significantly varied, indicative of seasonal variation due possibly to ground water pollution arising from recharge or infiltration of leachates from contaminated runoff during rainy season. There are linear relationships such as weak negative or positive correlations, moderate negative or positive correlations and strong negative or positive correlations between some water quality parameters of

boreholes in Enugu north Senatorial District. This indicates an association among the pollution indices in the samples. The overall physicochemical Water Quality Index (WQI) of the study area is significantly the same during dry season and rainy season. Although the overall physicochemical WQI gave positive quality ratings of the borehole water from all the samples in rainy season and dry season, the mean values and range of values of some potable water quality parameters such as BOD (possibly due to percolation of biodegradable organic matter and leaching of inorganic iron and/or manganese into groundwater aquifers), nitrate, phosphate, pH, copper, iron and potassium, were found to fall outside standard limits recommended by regulatory bodies such as W.H.O., S.O.N., NAFDAC and the EU in some of the samples, hence the potability of water from the studied boreholes is unfit (i.e. unsafe for drinking). Since BOD and temperature mean values fell outside the standard guideline values, it is strongly indicative of negative bacteriological pollution.

Based on this study, the overall ranking of the 12 boreholes' water quality in dry season is as follows: BH5 > BH2 > BH10 > BH4 > BH9 > BH8 > BH11 > BH12 > BH1 > BH6 > BH3 > BH7.

Similarly, the boreholes in the rainy season were ranked as: BH2 > BH10 > BH12 > BH5 > BH11 > BH9 > BH8 > BH6 > BH3 > BH1 > BH4 > BH7.

4.6 RECOMMENDATIONS:

Based on the findings of this study, the following recommendations are made:

1. Since the BOD of the water samples from all the 12 boreholes were above standard limits, contamination may be due to biological or microbial sources, hence, a study of bacteriological parameters should be conducted in Enugu North Senatorial District.

2. Before using water from borehole sources in the study area for drinking, it should be assessed and/or treated for their content of BOD, nitrate, phosphate, pH, copper, iron, potassium and possibly content of bacteriological parameters. Potable water should be certified as safe only when tested and the quality parameters have been found to be within the guidelines values set by regulatory bodies.
3. Since there are seasonal fluctuations in the ground water quality parameters in Enugu North Senatorial District, regular intensive and elaborate water quality tests need to be conducted to measure the trends of variability of the water quality parameters. This will also help to further ascertain the causes and permanence of spatial variability of the borehole water quality as well as contribute to establishing the geochemical features of the area.
4. It is also pertinent to conduct a comparative analysis of soil samples from the study area for their content of possible water quality parameters such as metals, pH, nitrate, sulphate and phosphate during rainy season and dry season as part of geochemical studies.
5. There is a need for government, policy makers, non-governmental organisations and other stakeholders in the water sector to make more concerted efforts toward provision of safe potable water from borehole source for the people of Enugu North Senatorial District as well as to create awareness of the causes/effects of polluting their ground water sources with the view to preventing future contamination and thus forestall future danger and health-risks associated with long-time drinking contaminated water.

6. The government should also collaborate with relevant institutions to regularly conduct seasonal and routine studies of water quality from various sources, especially ground water.
7. In a case where the physicochemical WQI disagrees with standard guidelines for drinking water, (such as in this study where the physicochemical WQI in both seasons rated the water samples as good even when some parameters were outside guideline values), WQI should be used only in the relative rating of a given set of water samples and not to determine drinking water safety and portability due to quality parameters.

4.7. CONTRIBUTIONS TO KNOWLEDGE

This study has made the following major contributions to knowledge:

(i) Provides baseline information on borehole water quality on Enugu North Senatorial District.

(ii) Serves as a framework for planning, further assessment, monitoring, and an aid for Environment Impact Assessment (EIA) in the area.

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APPENDIX 1.1A: QW values for all the parameters in Borehole 1 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	pH	5.07	†*#8.50	7.0	0.000268	-128.8867	-0.0345
2	Electrical Conductivity (µS/cm)	23.333	#1000	0.0	0.0000028	2.3333	0.00000653
3	Temperature (° C)	30.8	#Ambient	0.0	0.000112	123.2	0.0138
4	TDS (mg/L)	10.0000	†#500.00	0.0	0.00000456	2.0	0.00000912
5	TSS (mg/L)	250.0000		0.0	-		
6	TS (mg/L)	360.0000	†500.00	0.0	0.00000456	72.0	0.000328
7	Total Acidity (mg/L)	0.3567	[a] 0.30	0.0	0.0076	118.9	0.9036
8	Total Alkalinity (mg/L)	28.0333	80.00	0.0	0.0000285	35.0416	0.000999
9	Nitrate, NO_3^- (mg/L)	1.7333	†#50.00	0.0	0.0000456	3.4666	0.00158
10	Phosphate, PO_4^{3-} (mg/L)	0.15000	†10.00	0.0	0.000228	1.50	0.000342
11	Sulphate, SO_4^{2-} (mg/L)	21.8333	†*#200.00	0.0	0.0000114	10.9167	0.000124
12	BOD (mg/L)	5.0700	†*3.00	0.0	0.00076	169	0.12844
13	COD (mg/L)	6.8833	†*294.00	0.0	0.00000776	2.3413	0.0000182
14	Turbidity (NTU)	8.7000	†#5	0.0	0.000456	174.0	0.07934
15	Hardness (mg/L)	126.0333	#150	0.0	0.0000152	84.0222	0.00128
16	Cadmium (Cd) (mg/L)	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	Copper(Cu^{2+}) (mg/L)	22.2667	#1.00	0.0	0.00228	2226.67	5.0768
18	Iron (Fe^{2+}) (mg/L)	0.0680	#0.30	0.0	0.0076	22.6667	0.1723
19	Lead (Pb) (mg/L)	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	Zinc (Zn) (mg/L)	2.6400	†*#3.00	0.0	0.00076	88.0	0.06688
21	Sodium (Na) (mg/L)	10.020	#200.00	0.0	0.0000114	5.01	0.0000571
22	Potassium (K) (mg/L)	6.0067	[a] 10.00	0.0	0.000228	60.067	0.0137
					∑W = 1.0768		**∑WQ= 6.425104**

WQI_1 = 5.9668.

† Values are given by World Health Organisation.
*Values are given by National Agency for Food and drugs Administration and Control.
Values are given by Nigerian Standard for Drinking Water Quality (NSDWQ).
[a] Value is given by the European Union (EU).
k = 0.00228.

APPENDIX 1.1B: QW values for all the parameters in Borehole 2 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	5.07	†*#8.50	7.0	0.000268	-128.8867	-0.0345
2	**Electrical Conductivity (µS/cm)**	20.0000	#1000	0.0	0.0000028	2.0	0.0000056
3	**Temperature (º C)**	31.7	#Ambient	0.0	0.000112	127.0668	0.01423
4	**TDS (mg/L)**	0.0000	†#500.00	0.0	0.00000456	0.0000	0.0000
5	**TSS (mg/L)**	120.000		0.0	-		
6	**TS (mg/L)**	120.0000	†500.00	0.0	0.00000456	24.0	0.000109
7	**Total Acidity (mg/L)**	0.15333	[a] 0.30	0.0	0.0076	51.11	0.3884
8	**Total Alkalinity (mg/L)**	40.0000	80.00	0.0	0.0000285	50.0	0.001425
9	**Nitrate, NO_3^- (mg/L)**	1.7667	†#50.00	0.0	0.0000456	3.534	0.0001612
10	**Phosphate, PO_4^{3-} (mg/L)**	0.2567	†10.00	0.0	0.000228	2.567	0.000585
11	**Sulphate, SO_4^{2-} (mg/L)**	20.1367	†*#200.00	0.0	0.0000114	10.0684	0.000115
12	**BOD (mg/L)**	5.7200	†*3.00	0.0	0.00076	190.6667	0.1449
13	**COD (mg/L)**	7.1900	†*294.00	0.0	0.00000776	2.4456	0.0000190
14	**Turbidity (NTU)**	4.2700	†#5	0.0	0.000456	85.40	0.03894
15	**Total Hardness (mg/L)**	130.0800	#150	0.0	0.0000152	86.72	0.001318
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.0123	#1.00	0.0	0.00228	1.23	0.0028
18	**Iron (Fe^{2+}) (mg/L)**	0.0787	#0.30	0.0	0.0076	26.2333	0.1994
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.0213	†*#3.00	0.0	0.00076	0.71	0.000540
21	**Sodium (Na) (mg/L)**	3.3100	#200.00	0.0	0.0000114	1.655	0.0000189
22	**Potassium (K) (mg/L)**	1.9067	[a] 10.00	0.0	0.000228	19.067	0.004347
					∑W = 1.0768		**∑WQ= 0.762814**

WQI_2 = 0.7084

APPENDIX 1.1C: QW values for all the parameters in Borehole 3 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	4.9	†*#8.50	7.0	0.000268	-140.0000	-0.0375
2	**Electrical Conductivity (µS/cm)**	40.0000	#1000	0.0	0.0000028	4.0	0.0000112
3	**Temperature (° C)**	31.3	#Ambient	0.0	0.000112	125.0668	0.01401
4	**TDS (mg/L)**	190.0000	†#500.00	0.0	0.00000456	38.0	0.0001733
5	**TSS (mg/L)**	10.0000		0.0	-		
6	**TS (mg/L)**	200.0000	†500.00	0.0	0.00000456	40.0	0.0001824
7	**Total Acidity (mg/L)**	0.2367	[a] 0.30	0.0	0.0076	78.9	0.59964
8	**Total Alkalinity (mg/L)**	36.0800	80.00	0.0	0.0000285	45.0	0.001283
9	**Nitrate, NO_3^- (mg/L)**	1.7300	†#50.00	0.0	0.0000456	3.46	0.0001578
10	**Phosphate, PO_4^{3-} (mg/L)**	0.8500	†10.00	0.0	0.000228	8.5	0.001938
11	**Sulphate, SO_4^{2-} (mg/L)**	22.1333	†*#200.00	0.0	0.0000114	11.06665	0.0001262
12	**BOD (mg/L)**	5.9533	†*3.00	0.0	0.00076	198.4433	0.1508
13	**COD (mg/L)**	9.5867	†*294.00	0.0	0.00000776	3.2608	0.0000253
14	**Turbidity (NTU)**	5.0500	†#5	0.0	0.000456	101.0	0.046056
15	**Hardness (mg/L)**	140.0400	#150	0.0	0.0000152	93.36	0.001419
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	22.5100	#1.00	0.0	0.00228	2251	5.13228
18	**Iron (Fe^{2+}) (mg/L)**	0.2803	#0.30	0.0	0.0076	93.4333	0.71009
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.8607	†*#3.00	0.0	0.00076	28.69	0.0218
21	**Sodium (Na) (mg/L)**	12.3167	#200.00	0.0	0.0000114	6.15835	0.000070205
22	**Potassium (K) (mg/L)**	7.0800	[a] 10.00	0.0	0.000228	70.800	0.0161424
					∑W = 1.0768		**∑WQ= 6.658705**

WQI_3 = 6.1838

APPENDIX 1.1D: values for all the parameters in Borehole 4 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	5.37	†*#8.50	7.0	0.000268	-108.8867	-0.0292
2	**Electrical Conductivity (µS/cm)**	60.0000	#1000	0.0	0.0000028	6.0	0.0000168
3	**Temperature (° C)**	30.5	#Ambient	0.0	0.000112	122.0	0.013664
4	**TDS (mg/L)**	20.0000	†#500.00	0.0	0.00000456	4.0	0.00001824
5	**TSS (mg/L)**	150.0000		0.0	-		
6	**TS (mg/L)**	170.0000	†500.00	0.0	0.00000456	34.0	0.000155
7	**Total Acidity (mg/L)**	0.0667	[a] 0.30	0.0	0.0076	22.2333	0.16897
8	**Total Alkalinity (mg/L)**	52.1000	80.00	0.0	0.0000285	65.125	0.0019
9	**Nitrate, NO_3^- (mg/L)**	1.7767	†#50.00	0.0	0.0000456	3.5534	0.000162
10	**Phosphate, PO_4^{3-} (mg/L)**	0.1300	†10.00	0.0	0.000228	1.30	0.0002964
11	**Sulphate, SO_4^{2-} (mg/L)**	20.1100	†*#200.00	0.0	0.0000114	10.055	0.000115
12	**BOD (mg/L)**	5.6067	†*3.00	0.0	0.00076	186.89	0.1420
13	**COD (mg/L)**	7.3800	†*294.00	0.0	0.00000776	2.5102	0.0000195
14	**Turbidity (NTU)**	4.5000	†#5	0.0	0.000456	90.0	0.04104
15	**Hardness (mg/L)**	120.1400	#150	0.0	0.0000152	80.0933	0.00122
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	1.6700	#1.00	0.0	0.00228	167.0	0.38076
18	**Iron (Fe^{2+}) (mg/L)**	0.7617	#0.30	0.0	0.0076	253.90	1.92964
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.0097	†*#3.00	0.0	0.00076	0.970	0.0007372
21	**Sodium (Na) (mg/L)**	2.0367	#200.00	0.0	0.0000114	1.01835	0.000011609
22	**Potassium (K) (mg/L)**	8.3700	[a] 10.00	0.0	0.000228	83.700	0.0191
					∑W = 1.0768		**∑WQ= 2.670626**

WQI_4 = 2.4802

APPENDIX 1.1E: QW values for all the parameters in Borehole 5 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	pH	5.27	†*#8.50	7.0	0.000268	-115.5533	-0.0310
2	Electrical Conductivity (µS/cm)	16.6667	#1000	0.0	0.0000028	1.66667	0.00000467
3	Temperature (° C)	30.1	#Ambient	0.0	0.000112	120.5332	0.0134997
4	TDS (mg/L)	0.0000	†#500.00	0.0	0.00000456	0.0000	0.0000
5	TSS (mg/L)	70.0000		0.0	-		
6	TS (mg/L)	70.0000	†500.00	0.0	0.00000456	14.0	0.00006384
7	Total Acidity (mg/L)	0.2033	[a] 0.30	0.0	0.0076	67.7667	0.51503
8	Total Alkalinity (mg/L)	47.0333	80.00	0.0	0.0000285	58.7916	0.00168
9	Nitrate, NO_3^- (mg/L)	1.8867	†#50.00	0.0	0.0000456	3.7734	0.00017207
10	Phosphate, PO_4^{3-} (mg/L)	0.6200	†10.00	0.0	0.000228	6.20	0.0014136
11	Sulphate, SO_4^{2-} (mg/L)	22.1667	†*#200.00	0.0	0.0000114	11.08335	0.00012635
12	BOD (mg/L)	5.9733	†*3.00	0.0	0.00076	199.11	0.1513236
13	COD (mg/L)	7.3933	†*294.00	0.0	0.00000776	2.51473	0.0000195
14	Turbidity (NTU)	3.4500	†#5	0.0	0.000456	69.0	0.031464
15	Hardness (mg/L)	125.0367	#150	0.0	0.0000152	83.3578	0.001267
16	Cadmium (Cd) (mg/L)	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	Copper(Cu^{2+}) (mg/L)	0.0083	#1.00	0.0	0.00228	0.83	0.0018924
18	Iron (Fe^{2+}) (mg/L)	0.0020	#0.30	0.0	0.0076	0.6667	0.0050667
19	Lead (Pb) (mg/L)	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	Zinc (Zn) (mg/L)	0.0207	†*#3.00	0.0	0.00076	0.69	0.0005244
21	Sodium (Na) (mg/L)	6.0133	#200.00	0.0	0.0000114	3.00665	0.000034275
22	Potassium (K) (mg/L)	0.6300	[a] 10.00	0.0	0.000228	6.30	0.0014364
					∑W = 1.0768		**∑WQ= 0.684019**

WQI_5 = 0.6445

APPENDIX 1.1F: QW values for all the parameters in Borehole 6 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	5.37	†*#8.50	7.0	0.000268	-108.8867	-0.0292
2	**Electrical Conductivity (µS/cm)**	6.6667	#1000	0.0	0.0000028	0.66667	0.000001866
3	**Temperature (° C)**	30.7	#Ambient	0.0	0.000112	1.229332	0.0001377
4	**TDS (mg/L)**	20.0000	†#500.00	0.0	0.00000456	4.0	0.00001824
5	**TSS (mg/L)**	130.0000		0.0	-		
6	**TS (mg/L)**	150.0000	†500.00	0.0	0.00000456	30.0	0.0001368
7	**Total Acidity (mg/L)**	0.3267	[a] 0.30	0.0	0.0076	108.9	0.82764
8	**Total Alkalinity (mg/L)**	34.0333	80.00	0.0	0.0000285	42.54163	0.0012124
9	**Nitrate, NO_3^- (mg/L)**	1.8533	†#50.00	0.0	0.0000456	3.7066	0.00016902
10	**Phosphate, PO_4^{3-} (mg/L)**	0.2300	†10.00	0.0	0.000228	2.3	0.0005244
11	**Sulphate, SO_4^{2-} (mg/L)**	24.1833	†*#200.00	0.0	0.0000114	12.09165	
12	**BOD (mg/L)**	4.8933	†*3.00	0.0	0.00076	163.11	0.1239636
13	**COD (mg/L)**	8.6700	†*294.00	0.0	0.00000776	2.948979	0.00002241
14	**Turbidity (NTU)**	4.7500	†#5	0.0	0.000456	95	0.04332
15	**Hardness (mg/L)**	100.0333	#150	0.0	0.0000152	66.6667	0.001013
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	19.2767	#1.00	0.0	0.00228	1927.67	4.3951
18	**Iron (Fe^{2+}) (mg/L)**	0.4560	#0.30	0.0	0.0076	152.0	1.1552
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.3917	†*#3.00	0.0	0.00076	79.7233	0.06059
21	**Sodium (Na) (mg/L)**	3.1233	#200.00	0.0	0.0000114	1.56165	0.0000178
22	**Potassium (K) (mg/L)**	0.0000	[a] 10.00	0.0	0.000228	0.0000	0.0000
					∑W = 1.0768		**∑WQ= 6.579867**

WQI_6 = 6.1106

APPENDIX 1.1G: QW values for all the parameters in Borehole 7 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	6.9	†*#8.50	7.0	0.000268	-6.6667	-0.0018
2	**Electrical Conductivity (µS/cm)**	130.0000	#1000	0.0	0.0000028	13.0	0.0000368
3	**Temperature (° C)**	29.9	#Ambient	0.0	0.000112	119.6	0.013395
4	**TDS (mg/L)**	60.0000	†#500.00	0.0	0.00000456	12.0	0.00005472
5	**TSS (mg/L)**	190.0000		0.0	-		
6	**TS (mg/L)**	250.0000	†500.00	0.0	0.00000456	50.0	0.000228
7	**Total Acidity (mg/L)**	0.2433	[a] 0.30	0.0	0.0076	81.10	0.61636
8	**Total Alkalinity (mg/L)**	35.0333	80.00	0.0	0.0000285	43.7916	0.001248
9	**Nitrate, NO_3^- (mg/L)**	1.7267	†#50.00	0.0	0.0000456	3.4534	0.000157
10	**Phosphate, PO_4^{3-} (mg/L)**	0.2467	†10.00	0.0	0.000228	2.467	0.000562
11	**Sulphate, SO_4^{2-} (mg/L)**	22.2133	†*#200.00	0.0	0.0000114	11.10665	0.00012662
12	**BOD (mg/L)**	5.5133	†*3.00	0.0	0.00076	183.777	0.13967
13	**COD (mg/L)**	9.2300	†*294.00	0.0	0.00000776	3.13946	0.00002436
14	**Turbidity (NTU)**	8.9000	†#5	0.0	0.000456	178.0	0.081168
15	**Hardness (mg/L)**	140.1133	#150	0.0	0.0000152	93.40887	0.0014198
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	16.6367	#1.00	0.0	0.00228	1663.67	3.793168
18	**Iron (Fe^{2+}) (mg/L)**	10.5797	#0.30	0.0	0.0076	3526.5667	26.80
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.1427	†*#3.00	0.0	0.00076	71.42333	0.05428
21	**Sodium (Na) (mg/L)**	22.4267	#200.00	0.0	0.0000114	11.21335	0.0000128
22	**Potassium (K) (mg/L)**	7.7400	[a] 10.00	0.0	0.000228	77.400	0.0176472
					∑W = 1.0768		**∑WQ= 31.51776**

WQI_7 = 29.2698

APPENDIX 1.1H: QW values for all the parameters in Borehole 8 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	pH	6.65	†*#8.50	7.0	0.000268	-23.3333	-0.0063
2	Electrical Conductivity (µS/cm)	220.0000	#1000	0.0	0.0000028	2200.0	0.00616
3	Temperature (° C)	29.9	#Ambient	0.0	0.000112	119.4668	0.01338
4	TDS (mg/L)	110.0000	†#500.00	0.0	0.00000456	22.0	0.00010
5	TSS (mg/L)	250.0000		0.0	-		
6	TS (mg/L)	360.0000	†500.00	0.0	0.00000456	72.0	0.000328
7	Total Acidity (mg/L)	0.3667	[a] 0.30	0.0	0.0076	122.2333	0.92897
8	Total Alkalinity (mg/L)	28.1400	80.00	0.0	0.0000285	35.175	0.0010
9	Nitrate, NO_3^- (mg/L)	1.7367	†#50.00	0.0	0.0000456	3.4734	0.000158
10	Phosphate, PO_4^{3-} (mg/L)	0.3667	†10.00	0.0	0.000228	3.667	0.000836
11	Sulphate, SO_4^{2-} (mg/L)	21.2300	†*#200.00	0.0	0.0000114	10.615	0.000121
12	BOD (mg/L)	4.4867	†*3.00	0.0	0.00076	149.5567	0.1137
13	COD (mg/L)	6.1800	†*294.00	0.0	0.00000776	2.102	0.0000163
14	Turbidity (NTU)	8.9000	†#5	0.0	0.000456	178.0	0.081168
15	Hardness (mg/L)	100.0667	#150	0.0	0.0000152	66.7111	0.001014
16	Cadmium (Cd) (mg/L)	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	Copper(Cu^{2+}) (mg/L)	10.7600	#1.00	0.0	0.00228	1076.0	2.45328
18	Iron (Fe^{2+}) (mg/L)	0.0736	#0.30	0.0	0.0076	24.5333	0.1864
19	Lead (Pb) (mg/L)	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	Zinc (Zn) (mg/L)	1.6847	†*#3.00	0.0	0.00076	56.15667	0.042679
21	Sodium (Na) (mg/L)	13.9000	#200.00	0.0	0.0000114	6.9500	0.00007923
22	Potassium (K) (mg/L)	9.2800	[a] 10.00	0.0	0.000228	92.800	0.0211584
					∑W = 1.0768		**∑WQ= 3.844248**

WQI_8 = 3.5701

APPENDIX 1.1I: QW values for all the parameters in Borehole 8 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	7.20	†*#8.50	7.0	0.000268	13.3333	0.0036
2	**Electrical Conductivity (µS/cm)**	410.000	#1000	0.0	0.0000028	41.00.0001148	
3	**Temperature (° C)**	29.0	#Ambient	0.0	0.000112	116.1332	0.0130
4	**TDS (mg/L)**	210.0000	†#500.00	0.0	0.00000456	42.0	0.000192
5	**TSS (mg/L)**	160.0000		0.0	-		
6	**TS (mg/L)**	370.0000	†500.00	0.0	0.00000456	74.0	0.000337
7	**Total Acidity (mg/L)**	1.2333	[a] 0.30	0.0	0.0076	411.10	3.12436
8	**Total Alkalinity (mg/L)**	28.1133	80.00	0.0	0.0000285	35.1416	0.001
9	**Nitrate, NO_3^- (mg/L)**	1.2533	†#50.00	0.0	0.0000456	2.5066	0.000114
10	**Phosphate, PO_4^{3-} (mg/L)**	0.1433	†10.00	0.0	0.000228	1.43	0.000326
11	**Sulphate, SO_4^{2-} (mg/L)**	23.2000	†*#200.00	0.0	0.0000114	11.6	0.0001322
12	**BOD (mg/L)**	4.3033	†*3.00	0.0	0.00076	143.4433	0.10902
13	**COD (mg/L)**	6.4300	†*294.00	0.0	0.00000776	2.1871	0.000017
14	**Turbidity (NTU)**	8.9500	†#5	0.0	0.000456	179.0	0.081624
15	**Hardness (mg/L)**	100.2433	#150	0.0	0.0000152	66.8289	0.001016
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper (Cu^{2+}) (mg/L)**	0.3267	#1.00	0.0	0.00228	32.67	0.07449
18	**Iron (Fe^{2+}) (mg/L)**	0.0960	#0.30	0.0	0.0076	32.0	0.2432
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.0313	†*#3.00	0.0	0.00076	1.043333	0.0007929
21	**Sodium (Na) (mg/L)**	17.2800	#200.00	0.0	0.0000114	8.640	0.0000985
22	**Potassium (K) (mg/L)**	12.0133	[a] 10.00	0.0	0.000228	120.133	0.0274
					$\sum W$ = 1.0768		**$\sum WQ$ = 3.68072**

WQI_9 = 3.4182.

APPENDIX 1.1J: QW values for all the parameters in Borehole 10 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	7.1	†*#8.50	7.0	0.000268	6.6667	0.0018
2	**Electrical Conductivity (µS/cm)**	180.000	#1000	0.0	0.0000028	18.0	0.0000504
3	**Temperature (° C)**	30.1	#Ambient	0.0	0.000112	120.4	0.013485
4	**TDS (mg/L)**	90.0000	†#500.00	0.0	0.00000456	18.0	0.00008201
5	**TSS (mg/L)**	70.0000		0.0	-		
6	**TS (mg/L)**	160.0000	†500.00	0.0	0.00000456	32.0	0.00014592
7	**Total Acidity (mg/L)**	0.2033	[a] 0.30	0.0	0.0076	67.7667	0.515
8	**Total Alkalinity (mg/L)**	37.0367	80.00	0.0	0.0000285	46.286	0.001319
9	**Nitrate, NO_3^- (mg/L)**	1.8867	†#50.00	0.0	0.0000456	3.7734	0.00017207
10	**Phosphate, PO_4^{3-} (mg/L)**	0.4200	†10.00	0.0	0.000228	4.20	0.000958
11	**Sulphate, SO_4^{2-} (mg/L)**	22.2000	†*#200.00	0.0	0.0000114	11.10	0.0001265
12	**BOD (mg/L)**	3.1900	†*3.00	0.0	0.00076	106.333	0.0808
13	**COD (mg/L)**	6.6167	†*294.00	0.0	0.00000776	2.25068	0.0000175
14	**Turbidity (NTU)**	4.7000	†#5	0.0	0.000456	94.0	0.04286
15	**Hardness (mg/L)**	105.1400	#150	0.0	0.0000152	70.0933	0.001065
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.1197	#1.00	0.0	0.00228	11.97	0.0273
18	**Iron (Fe^{2+}) (mg/L)**	0.0917	#0.30	0.0	0.0076	30.5667	0.2323
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.1563	†*#3.00	0.0	0.00076	5.21	0.00396
21	**Sodium (Na) (mg/L)**	17.0100	#200.00	0.0	0.0000114	8.505	0.000119
22	**Potassium (K) (mg/L)**	9.2733	[a] 10.00	0.0	0.000228	92.733	0.0211
					$\sum W = 1.0768$		**$\sum WQ = 0.94266$**

$WQI_{10} = 0.8754$.

APPENDIX 1.1K: QW values for all the parameters in Borehole 11 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	7.2	†*#8.50	7.0	0.000268	13.3333	0.0036
2	**Electrical Conductivity (µS/cm)**	200.000	#1000	0.0	0.0000028	2000	0.0056
3	**Temperature (° C)**	31.13	#Ambient	0.0	0.000112	124.5332	0.0139
4	**TDS (mg/L)**	100.0000	†#500.00	0.0	0.00000456	20.0	0.000912
5	**TSS (mg/L)**	120.0000		0.0	-		
6	**TS (mg/L)**	220.0000	†500.00	0.0	0.00000456	44.0	0.0002
7	**Total Acidity (mg/L)**	0.1667	[a] 0.30	0.0	0.0076	55.567	0.4223
8	**Total Alkalinity (mg/L)**	38.8067	80.00	0.0	0.0000285	48.508	0.00138
9	**Nitrate, NO_3^- (mg/L)**	1.7333	†#50.00	0.0	0.0000456	3.4666	0.000158
10	**Phosphate, PO_4^{3-} (mg/L)**	0.3100	†10.00	0.0	0.000228	3.10	0.000707
11	**Sulphate, SO_4^{2-} (mg/L)**	20.1400	†*#200.00	0.0	0.0000114	10.07	0.000115
12	**BOD (mg/L)**	5.5933	†*3.00	0.0	0.00076	186.443	0.1417
13	**COD (mg/L)**	7.6733	†*294.00	0.0	0.00000776	2.60997	0.0000203
14	**Turbidity (NTU)**	4.7400	†#5	0.0	0.000456	94.8	0.04322
15	**Hardness (mg/L)**	130.1667	#150	0.0	0.0000152	86.7778	0.001319
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	12.4700	#1.00	0.0	0.00228	1247	2.84316
18	**Iron (Fe^{2+}) (mg/L)**	0.8280	#0.30	0.0	0.0076	276.0	2.0976
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	3.0000	†*#3.00	0.0	0.00076	100.0	0.076
21	**Sodium (Na) (mg/L)**	13.9600	#200.00	0.0	0.0000114	6.98	0.0000796
22	**Potassium (K) (mg/L)**	6.5333	[a] 10.00	0.0	0.000228	65.330	0.0149
					∑W = 1.0768		**∑WQ = 5.666871**

WQI_{11} = 5.2627

APPENDIX 1.1L: QW values for all the parameters in Borehole 12 during dry season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	7.5	†*#8.50	7.0	0.000268	33.3333	0.0089
2	**Electrical Conductivity (µS/cm)**	240.0000	#1000	0.0	0.0000028	24.0	0.0000672
3	**Temperature (^{o} C)**	30.0	#Ambient	0.0	0.000112	120.1332	0.01345
4	**TDS (mg/L)**	120.0000	†#500.00	0.0	0.00000456	24.0	0.0001094
5	**TSS (mg/L)**	270.0000		0.0	-		
6	**TS (mg/L)**	390.0000	†500.00	0.0	0.00000456	78.0	0.0003557
7	**Total Acidity (mg/L)**	0.6033	[a] 0.30	0.0	0.0076	201.0	1.5276
8	**Total Alkalinity (mg/L)**	33.4067	80.00	0.0	0.0000285	41.758	0.00119
9	**Nitrate, NO_3^- (mg/L)**	8.7100	†#50.00	0.0	0.0000456	17.42	0.000794
10	**Phosphate, PO_4^{3-} (mg/L)**	0.3200	†10.00	0.0	0.000228	3.20	0.000730
11	**Sulphate, SO_4^{2-} (mg/L)**	22.4033	†*#200.00	0.0	0.0000114	11.202	0.000128
12	**BOD (mg/L)**	5.5600	†*3.00	0.0	0.00076	185.333	0.1409
13	**COD (mg/L)**	7.2567	†*294.00	0.0	0.00000776	2.4683	0.0000192
14	**Turbidity (NTU)**	50.0000	†#5	0.0	0.000456	1000	0.456
15	**Hardness (mg/L)**	110.0833	#150	0.0	0.0000152	73.3889	0.001115
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.0407	#1.00	0.0	0.00228	4.07	0.00928
18	**Iron (Fe^{2+}) (mg/L)**	1.6083	#0.30	0.0	0.0076	536.10	4.07436
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.8580	†*#3.00	0.0	0.00076	95.2667	0.0724
21	**Sodium (Na) (mg/L)**	18.6167	#200.00	0.0	0.0000114	9.30835	0.000106
22	**Potassium (K) (mg/L)**	8.0633	[a] 10.00	0.0	0.000228	80.633	0.0184
					∑W = 1.0768		**∑WQ = 6.325905**

WQI_{12} = 5.8747

APPENDIX 1.2A: QW values for all the parameters in Borehole 1 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	4.63	†*#8.50	7.0	0.000268	-157.7800	-0.0423
2	**Electrical Conductivity (µS/cm)**	63.3333	#1000	0.0	0.0000028	6.33333	0.0000177
3	**Temperature (° C)**	29.1	#Ambient	0.0	0.000112	116.2668	0.01302
4	**TDS (mg/L)**	93.3333	†#500.00	0.0	0.00000456	18.6667	0.0000851
5	**TSS (mg/L)**	256.667		0.0	-		
6	**TS (mg/L)**	350.0000	†500.00	0.0	0.00000456	70.0000	0.000319
7	**Total Acidity (mg/L)**	8.4467	[a] 0.30	0.0	0.0076	2815.5667	21.3983
8	**Total Alkalinity (mg/L)**	26.0333	80.00	0.0	0.0000285	32.5416	0.000927
9	**Nitrate, NO_3^- (mg/L)**	12.1667	†#50.00	0.0	0.0000456	24.3334	0.00111
10	**Phosphate, PO_4^{3-} (mg/L)**	6.0000	†10.00	0.0	0.000228	60.0000	0.01368
11	**Sulphate, SO_4^{2-} (mg/L)**	26.2333	†*#200.00	0.0	0.0000114	13.11665	0.000150
12	**BOD (mg/L)**	4.1767	†*3.00	0.0	0.00076	139.2233	0.105809
13	**COD (mg/L)**	5.0067	†*294.00	0.0	0.00000776	1.70296	0.0000132
14	**Turbidity (NTU)**	8.8667	†#5	0.0	0.000456	177.334	0.0809
15	**Hardness (mg/L)**	110.000	#150	0.0	0.0000152	73.3333	0.0011147
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	24.2033	#1.00	0.0	0.00228	2420.33	5.5183524
18	**Iron (Fe^{2+}) (mg/L)**	0.0770	#0.30	0.0	0.0076	25.6667	0.1951
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.8567	†*#3.00	0.0	0.00076	95.2233	0.0724
21	**Sodium (Na) (mg/L)**	12.967	#200.00	0.0	0.0000114	4.3223	0.0000493
22	**Potassium (K) (mg/L)**	10.1233	[a] 10.00	0.0	0.000228	101.233	0.023081
					∑W = 1.0768		**∑WQ =27.38213**

WQI_{S1} = 25.4292

APPENDIX 1.2B: QW values for all the parameters in Borehole 2 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	5.67	†*#8.50	7.0	0.000268	-128.8867	-0.0345
2	**Electrical Conductivity (µS/cm)**	23.3333	#1000	0.0	0.0000028	2.33333	0.00000653
3	**Temperature (° C)**	30.1333	#Ambient	0.0	0.000112	120.5332	0.0135
4	**TDS (mg/L)**	3.3333	†#500.00	0.0	0.00000456	0.66667	0.00000304
5	**TSS (mg/L)**	130.0000		0.0	-		
6	**TS (mg/L)**	133.3333	†500.00	0.0	0.00000456	26.6667	0.000122
7	**Total Acidity (mg/L)**	0.1667	[a] 0.30	0.0	0.0076	55.5667	0.422306
8	**Total Alkalinity (mg/L)**	29.0333	80.00	0.0	0.0000285	36.29163	0.00103431
9	**Nitrate, NO_3^- (mg/L)**	1.7000	†#50.00	0.0	0.0000456	3.4000	0.000155
10	**Phosphate, PO_4^{3-} (mg/L)**	0.3433	†10.00	0.0	0.000228	3.4330	0.000783
11	**Sulphate, SO_4^{2-} (mg/L)**	20.5333	†*#200.00	0.0	0.0000114	10.2667	0.000117
12	**BOD (mg/L)**	5.1567	†*3.00	0.0	0.00076	171.89	0.131
13	**COD (mg/L)**	6.5500	†*294.00	0.0	0.00000776	2.22789	0.0000173
14	**Turbidity (NTU)**	4.2967	†#5	0.0	0.000456	85.934	0.0392
15	**Hardness (mg/L)**	120.000	#150	0.0	0.0000152	80.0000	0.001216
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.0337	#1.00	0.0	0.00228	3.370	0.007684
18	**Iron (Fe^{2+}) (mg/L)**	0.0227	#0.30	0.0	0.0076	7.5667	0.0575
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.0280	†*#3.00	0.0	0.00076	0.9333	0.000709
21	**Sodium (Na) (mg/L)**	3.4233	#200.00	0.0	0.0000114	1.71165	0.0000195
22	**Potassium (K) (mg/L)**	2.0867	[a] 10.00	0.0	0.000228	20.867	0.00476
					∑W = 1.0768		**∑WQ =0.645633**

WQI_{S2} = 0.5996

APPENDIX 1.2C: QW values for all the parameters in Borehole 3 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	5.1667	†*#8.50	7.0	0.000268	-122.22	-0.03275
2	**Electrical Conductivity (µS/cm)**	123.3333	#1000	0.0	0.0000028	12.3333	0.0000345
3	**Temperature (° C)**	31.7667	#Ambient	0.0	0.000112	127.0668	0.0142315
4	**TDS (mg/L)**	143.0000	†#500.00	0.0	0.00000456	28.6000	0.00013042
5	**TSS (mg/L)**	200.0000		0.0	-		
6	**TS (mg/L)**	343.0000	†500.00	0.0	0.00000456	68.600	0.000313
7	**Total Acidity (mg/L)**	0.4967	[a] 0.30	0.0	0.0076	165.5667	1.258307
8	**Total Alkalinity (mg/L)**	30.0667	80.00	0.0	0.0000285	37.58338	0.0107113
9	**Nitrate, NO_3^- (mg/L)**	2.2667	†#50.00	0.0	0.0000456	4.5334	0.000207
10	**Phosphate, PO_4^{3-} (mg/L)**	2.2667	†10.00	0.0	0.000228	22.667	0.00517
11	**Sulphate, SO_4^{2-} (mg/L)**	24.3333	†*#200.00	0.0	0.0000114	12.1667	0.000139
12	**BOD (mg/L)**	4.1967	†*3.00	0.0	0.00076	139.890	0.10632
13	**COD (mg/L)**	4.9367	†*294.00	0.0	0.00000776	1.67915	0.0000130
14	**Turbidity (NTU)**	5.8667	†#5	0.0	0.000456	117.334	0.053504
15	**Hardness (mg/L)**	126.6667	#150	0.0	0.0000152	84.4447	0.001284
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	27.5633	#1.00	0.0	0.00228	2756.330	6.2844324
18	**Iron (Fe^{2+}) (mg/L)**	1.3243	#0.30	0.0	0.0076	441.4333	3.3549
19	**Lead (Pb) (mg/L)**	0.0011	†#0.01	0.0	0.228	11.0	2.508
20	**Zinc (Zn) (mg/L)**	2.1200	†*#3.00	0.0	0.00076	70.6667	0.0537
21	**Sodium (Na) (mg/L)**	13.3367	#200.00	0.0	0.0000114	6.66835	0.000076
22	**Potassium (K) (mg/L)**	11.1400	[a] 10.00	0.0	0.000228	111.400	0.0254
					$\sum W$ = 1.0768		**$\sum WQ$ = 13.64412**

WQI_{S3} = 12.6710

APPENDIX 1.2D: QW values for all the parameters in Borehole 4 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	4.1333	†*#8.50	7.0	0.000268	-191.1333	-0.0512
2	**Electrical Conductivity (µS/cm)**	236.6667	#1000	0.0	0.0000028	23.66667	0.0000663
3	**Temperature (° C)**	30.1333	#Ambient	0.0	0.000112	120.5332	0.1349972
4	**TDS (mg/L)**	53.3333	†#500.00	0.0	0.00000456	10.6667	0.0000486
5	**TSS (mg/L)**	173.3333		0.0	-		
6	**TS (mg/L)**	226.6667	†500.00	0.0	0.00000456	45.33334	0.0002067
7	**Total Acidity (mg/L)**	0.1033	[a] 0.30	0.0	0.0076	34.4333	0.2616933
8	**Total Alkalinity (mg/L)**	52.0333	80.00	0.0	0.0000285	65.041625	0.001854
9	**Nitrate, NO_3^- (mg/L)**	7.3333	†#50.00	0.0	0.0000456	14.6667	0.000669
10	**Phosphate, PO_4^{3-} (mg/L)**	4.3667	†10.00	0.0	0.000228	43.6670	0.00996
11	**Sulphate, SO_4^{2-} (mg/L)**	26.2667	†*#200.00	0.0	0.0000114	13.13335	0.0001497
12	**BOD (mg/L)**	4.6467	†*3.00	0.0	0.00076	154.89	1.177164
13	**COD (mg/L)**	5.4467	†*294.00	0.0	0.00000776	1.852619	0.0000144
14	**Turbidity (NTU)**	4.8667	†#5	0.0	0.000456	97.3340	0.0444
15	**Hardness (mg/L)**	110.0000	#150	0.0	0.0000152	73.3333	0.001115
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	2.6733	#1.00	0.0	0.00228	267.33	0.6095124
18	**Iron (Fe^{2+}) (mg/L)**	1.0867	#0.30	0.0	0.0076	362.2333	27.529733
19	**Lead (Pb) (mg/L)**	0.0011	†#0.01	0.0	0.228	11.0000	2.508
20	**Zinc (Zn) (mg/L)**	0.0807	†*#3.00	0.0	0.00076	2.6900	0.0020444
21	**Sodium (Na) (mg/L)**	2.1367	#200.00	0.0	0.0000114	1.06835	0.0000122
22	**Potassium (K) (mg/L)**	11.0333	[a] 10.00	0.0	0.000228	110.333	0.0252
					$\sum W = 1.0768$		**$\sum WQ = 32.2556$**

$WQI_{S4} = 32.2556$

APPENDIX 1.2E: QW values for all the parameters in Borehole 5 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	4.9667	†*#8.50	7.0	0.000268	-135.553	-0.03632
2	**Electrical Conductivity (µS/cm)**	20.0000	#1000	0.0	0.0000028	2.0000	0.0000056
3	**Temperature (° C)**	29.9000	#Ambient	0.0	0.000112	119.600	0.0133952
4	**TDS (mg/L)**	6.6667	†#500.00	0.0	0.00000456	1.33334	0.00000608
5	**TSS (mg/L)**	103.3333		0.0	-		
6	**TS (mg/L)**	110.0000	†500.00	0.0	0.00000456	22.0000	0.00010032
7	**Total Acidity (mg/L)**	0.2167	[a] 0.30	0.0	0.0076	72.2333	0.54897333
8	**Total Alkalinity (mg/L)**	47.0000	80.00	0.0	0.0000285	58.750	0.00167438
9	**Nitrate, NO_3^- (mg/L)**	1.8967	†#50.00	0.0	0.0000456	3.7934	0.00017298
10	**Phosphate, PO_4^{3-} (mg/L)**	0.6467	†10.00	0.0	0.000228	6.4670	0.00147448
11	**Sulphate, SO_4^{2-} (mg/L)**	37.2000	†*#200.00	0.0	0.0000114	18.600	0.00021204
12	**BOD (mg/L)**	5.7600	†*3.00	0.0	0.00076	192.000	0.14592
13	**COD (mg/L)**	7.0467	†*294.00	0.0	0.00000776	2.39684	0.00001860
14	**Turbidity (NTU)**	3.8333	†#5	0.0	0.000456	76.6660	0.03495970
15	**Hardness (mg/L)**	120.0000	#150	0.0	0.0000152	80.0000	0.001216
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.0453	#1.00	0.0	0.00228	4.5300	0.0103284
18	**Iron (Fe^{2+}) (mg/L)**	0.0000	#0.30	0.0	0.0076	0.0000	0.0000
19	**Lead (Pb) (mg/L)**	0.0011	†#0.01	0.0	0.228	11.0	2.508
20	**Zinc (Zn) (mg/L)**	0.0253	†*#3.00	0.0	0.00076	0.84333	0.000641
21	**Sodium (Na) (mg/L)**	6.0767	#200.00	0.0	0.0000114	3.03835	0.00003464
22	**Potassium (K) (mg/L)**	1.3267	[a] 10.00	0.0	0.000228	13.2670	0.003025
					∑W = 1.0768		**∑WQ =3.233838**

WQI_{S5} = 3.0032

APPENDIX 1.2F: QW values for all the parameters in Borehole 6 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	4.8333	†*#8.50	7.0	0.000268	-144.4467	-0.0387
2	**Electrical Conductivity (µS/cm)**	236.6667	#1000	0.0	0.0000028	23.66667	0.0000663
3	**Temperature (° C)**	30.9333	#Ambient	0.0	0.000112	123.7332	0.01385812
4	**TDS (mg/L)**	220.0000	†#500.00	0.0	0.00000456	44.0000	0.00020064
5	**TSS (mg/L)**	140.0000		0.0	-		
6	**TS (mg/L)**	360.0000	†500.00	0.0	0.00000456	72.0000	0.00032832
7	**Total Acidity (mg/L)**	0.4033	[a] 0.30	0.0	0.0076	134.4333	1.02169333
8	**Total Alkalinity (mg/L)**	28.6667	80.00	0.0	0.0000285	35.83338	0.00102125
9	**Nitrate, NO_3^- (mg/L)**	6.3333	†#50.00	0.0	0.0000456	12.6666	0.00057760
10	**Phosphate, PO_4^{3-} (mg/L)**	7.5333	†10.00	0.0	0.000228	75.3333	0.17175992
11	**Sulphate, SO_4^{2-} (mg/L)**	82.6333	†*#200.00	0.0	0.0000114	41.31665	0.00047101
12	**BOD (mg/L)**	4.0367	†*3.00	0.0	0.00076	134.5567	0.10226307
13	**COD (mg/L)**	4.9467	†*294.00	0.0	0.00000776	1.682551	0.00001306
14	**Turbidity (NTU)**	4.8233	†#5	0.0	0.000456	96.4460	0.0439885
15	**Hardness (mg/L)**	100.000	#150	0.0	0.0000152	66.6667	0.0010133
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper (Cu^{2+}) (mg/L)**	21.5833	#1.00	0.0	0.00228	2158.33	4.9209924
18	**Iron (Fe^{2+}) (mg/L)**	1.6507	#0.30	0.0	0.0076	550.2333	4.1817733
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	3.3867	†*#3.00	0.0	0.00076	112.8900	0.0857964
21	**Sodium (Na) (mg/L)**	4.1533	#200.00	0.0	0.0000114	207.6650	0.0023674
22	**Potassium (K) (mg/L)**	12.0200	[a] 10.00	0.0	0.000228	120.2000	0.0274056
					∑W = 1.0768		**∑WQ = 10.53689**

WQI_{S6} = 9.7854

APPENDIX 1.2G: QW values for all the parameters in Borehole 7 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	4.8333	†*#8.50	7.0	0.000268	-144.4467	-0.0387
2	**Electrical Conductivity (µS/cm)**	340.0000	#1000	0.0	0.0000028	34.0000	0.0000952
3	**Temperature (° C)**	31.0667	#Ambient	0.0	0.000112	124.2668	0.013919
4	**TDS (mg/L)**	250.0000	†#500.00	0.0	0.00000456	50.0000	0.000228
5	**TSS (mg/L)**	253.3333		0.0	-		
6	**TS (mg/L)**	503.3333	†500.00	0.0	0.00000456	100.6667	0.000459
7	**Total Acidity (mg/L)**	10.4333	[a] 0.30	0.0	0.0076	3477.7667	26.431027
8	**Total Alkalinity (mg/L)**	15.4333	80.00	0.0	0.0000285	19.291625	0.0005498
9	**Nitrate, NO_3^- (mg/L)**	14.0667	†#50.00	0.0	0.0000456	28.1334	0.0012829
10	**Phosphate, PO_4^{3-} (mg/L)**	9.9333	†10.00	0.0	0.000228	99.3330	0.02265
11	**Sulphate, SO_4^{2-} (mg/L)**	21.4333	†*#200.00	0.0	0.0000114	10.716665	0.0001222
12	**BOD (mg/L)**	2.9500	†*3.00	0.0	0.00076	98.3333	0.074733
13	**COD (mg/L)**	3.6500	†*294.00	0.0	0.00000776	1.2414966	0.0000096
14	**Turbidity (NTU)**	10.5767	†#5	0.0	0.000456	211.534	0.0964504
15	**Hardness (mg/L)**	113.3333	#150	0.0	0.0000152	8.8889	0.0001351
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	24.6933	#1.00	0.0	0.00228	2469.3300	5.6300724
18	**Iron (Fe^{2+}) (mg/L)**	12.2883	#0.30	0.0	0.0076	368.6490	2.8017324
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.0437	†*#3.00	0.0	0.00076	1.45667	0.0011071
21	**Sodium (Na) (mg/L)**	21.2367	#200.00	0.0	0.0000114	10.61835	0.0001210
22	**Potassium (K) (mg/L)**	15.1033	[a] 10.00	0.0	0.000228	151.033	0.03444
					$\sum W$ = 1.0768		**$\sum WQ$ = 35.07043**

WQI_{S7} = 32.5691

APPENDIX 1.2H: QW values for all the parameters in Borehole 8 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	6.0333	†*#8.50	7.0	0.000268	-64.4467	-0.0173
2	**Electrical Conductivity (µS/cm)**	220.0000	#1000	0.0	0.0000028	22.0000	0.0000616
3	**Temperature (° C)**	29.9333	#Ambient	0.0	0.000112	2993.330	0.335253
4	**TDS (mg/L)**	123.3333	†#500.00	0.0	0.00000456	24.6667	0.0001125
5	**TSS (mg/L)**	260.0000		0.0	-		
6	**TS (mg/L)**	383.3333	†500.00	0.0	0.00000456	76.6667	0.000350
7	**Total Acidity (mg/L)**	0.3167	[a] 0.30	0.0	0.0076	105.5667	0.8023067
8	**Total Alkalinity (mg/L)**	27.3333	80.00	0.0	0.0000285	34.1667	0.000974
9	**Nitrate, NO_3^- (mg/L)**	2.0000	†#50.00	0.0	0.0000456	4.0000	0.0001824
10	**Phosphate, PO_4^{3-} (mg/L)**	10.3333	†10.00	0.0	0.000228	103.3330	0.023560
11	**Sulphate, SO_4^{2-} (mg/L)**	21.5333	†*#200.00	0.0	0.0000114	10.76665	0.0001227
12	**BOD (mg/L)**	4.0233	†*3.00	0.0	0.00076	134.110	0.1019236
13	**COD (mg/L)**	4.9033	†*294.00	0.0	0.00000776	1.667789	0.0000129
14	**Turbidity (NTU)**	10.9067	†#5	0.0	0.000456	218.134	0.0995
15	**Hardness (mg/L)**	100.000	#150	0.0	0.0000152	66.6667	0.0010133
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	18.3033	#1.00	0.0	0.00228	1830.33	4.1731524
18	**Iron (Fe^{2+}) (mg/L)**	0.1523	#0.30	0.0	0.0076	50.7667	0.3858267
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.4390	†*#3.00	0.0	0.00076	81.3000	0.061788
21	**Sodium (Na) (mg/L)**	14.1667	#200.00	0.0	0.0000114	7.08335	0.0000808
22	**Potassium (K) (mg/L)**	13.2200	[a] 10.00	0.0	0.000228	132.200	0.0280896
					∑W = 1.0768		**∑WQ = 5.99701**

WQI_{S8} = 5.5693

APPENDIX 1.2I: QW values for all the parameters in Borehole 9 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	7.1000	†*#8.50	7.0	0.000268	6.6667	0.0018
2	**Electrical Conductivity (µS/cm)**	220.0000	#1000	0.0	0.0000028	22.0000	0.0000616
3	**Temperature (°C)**	29.0333	#Ambient	0.0	0.000112	116.1332	0.0130069
4	**TDS (mg/L)**	216.6667	†#500.00	0.0	0.00000456	43.33334	0.000198
5	**TSS (mg/L)**	166.6667		0.0	-		
6	**TS (mg/L)**	383.3333	†500.00	0.0	0.00000456	76.66667	0.0003496
7	**Total Acidity (mg/L)**	1.2133	[a] 0.30	0.0	0.0076	404.4333	3.0736933
8	**Total Alkalinity (mg/L)**	28.0000	80.00	0.0	0.0000285	35.0000	0.000998
9	**Nitrate, NO_3^- (mg/L)**	1.3000	†#50.00	0.0	0.0000456	2.6	0.000119
10	**Phosphate, PO_4^{3-} (mg/L)**	0.1533	†10.00	0.0	0.000228	1.5330	0.000350
11	**Sulphate, SO_4^{2-} (mg/L)**	33.5000	†*#200.00	0.0	0.0000114	16.750	0.000191
12	**BOD (mg/L)**	3.9700	†*3.00	0.0	0.00076	132.3333	1.005733
13	**COD (mg/L)**	4.8467	†*294.00	0.0	0.00000776	1.648537	0.0000128
14	**Turbidity (NTU)**	10.0333	†#5	0.0	0.000456	200.0000	0.0912
15	**Hardness (mg/L)**	120.2333	#150	0.0	0.0000152	80.1555	0.00122
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.4600	#1.00	0.0	0.00228	46.0000	0.10488
18	**Iron (Fe^{2+}) (mg/L)**	0.1243	#0.30	0.0	0.0076	41.4333	0.314893
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.0447	†*#3.00	0.0	0.00076	1.4900	0.0011324
21	**Sodium (Na) (mg/L)**	15.1867	#200.00	0.0	0.0000114	7.59335	0.0000866
22	**Potassium (K) (mg/L)**	11.0067	[a] 10.00	0.0	0.000228	110.067	0.03082
					∑W = 1.0768		**∑WQ = 4.640745**

WQI_{S9} = 4.3098

APPENDIX 1.2J: QW values for all the parameters in Borehole 10 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	5.5667	†*#8.50	7.0	0.000268	-95.5533	-0.0256
2	**Electrical Conductivity (µS/cm)**	206.667	#1000	0.0	0.0000028	20.6667	0.0000579
3	**Temperature (° C)**	30.0333	#Ambient	0.0	0.000112	120.1332	0.0135
4	**TDS (mg/L)**	100.0000	†#500.00	0.0	0.00000456	20.0000	0.0000912
5	**TSS (mg/L)**	153.3333		0.0	-		
6	**TS (mg/L)**	253.3333	†500.00	0.0	0.00000456	50.6667	0.000231
7	**Total Acidity (mg/L)**	0.2467	[a] 0.30	0.0	0.0076	82.2333	0.6250
8	**Total Alkalinity (mg/L)**	20.0333	80.00	0.0	0.0000285	25.04163	0.000714
9	**Nitrate, NO_3^- (mg/L)**	7.6667	†#50.00	0.0	0.0000456	15.3334	0.0006992
10	**Phosphate, PO_4^{3-} (mg/L)**	3.8833	†10.00	0.0	0.000228	38.8330	0.008854
11	**Sulphate, SO_4^{2-} (mg/L)**	25.7333	†*#200.00	0.0	0.0000114	12.8667	0.000147
12	**BOD (mg/L)**	4.4000	†*3.00	0.0	0.00076	146.6667	0.1115
13	**COD (mg/L)**	5.3267	†*294.00	0.0	0.00000776	1.811803	0.0000141
14	**Turbidity (NTU)**	4.9833	†#5	0.0	0.000456	99.666	0.04545
15	**Hardness (mg/L)**	103.3333	#150	0.0	0.0000152	68.8889	0.00105
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.0317	#1.00	0.0	0.00228	3.1700	0.00723
18	**Iron (Fe^{2+}) (mg/L)**	0.0953	#0.30	0.0	0.0076	31.7667	0.24143
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	0.1720	†*#3.00	0.0	0.00076	5.7333	0.00436
21	**Sodium (Na) (mg/L)**	17.1167	#200.00	0.0	0.0000114	8.55835	0.0000976
22	**Potassium (K) (mg/L)**	10.0400	[a] 10.00	0.0	0.000228	100.4000	0.0229
					∑W = 1.0768		**∑WQ = 1.057726**

WQI_{S10} = 0.9823

APPENDIX 1.2K: QW values for all the parameters in Borehole 11 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	6.0667	†*#8.50	7.0	0.000268	-62.20	-0.0167
2	**Electrical Conductivity (µS/cm)**	276.6667	#1000	0.0	0.0000028	27.6667	0.0000775
3	**Temperature (° C)**	31.4000	#Ambient	0.0	0.000112	125.600	0.0141
4	**TDS (mg/L)**	183.3333	†#500.00	0.0	0.00000456	36.6667	0.000167
5	**TSS (mg/L)**	130.000		0.0	-		
6	**TS (mg/L)**	313.3333	†500.00	0.0	0.00000456	62.6667	0.000286
7	**Total Acidity (mg/L)**	10.1667	[a] 0.30	0.0	0.0076	12.7084	0.09658
8	**Total Alkalinity (mg/L)**	20.1667	80.00	0.0	0.0000285	25.2084	0.000718
9	**Nitrate, NO_3^- (mg/L)**	13.4333	†#50.00	0.0	0.0000456	26.8667	0.00123
10	**Phosphate, PO_4^{3-} (mg/L)**	9.5000	†10.00	0.0	0.000228	95.0000	0.02166
11	**Sulphate, SO_4^{2-} (mg/L)**	29.1667	†*#200.00	0.0	0.0000114	14.58335	0.0001663
12	**BOD (mg/L)**	4.4133	†*3.00	0.0	0.00076	138.1100	0.104964
13	**COD (mg/L)**	5.2600	†*294.00	0.0	0.00000776	1.78912	0.00001388
14	**Turbidity (NTU)**	4.8667	†#5	0.0	0.000456	97.334	0.44384
15	**Hardness (mg/L)**	113.3333	#150	0.0	0.0000152	75.5556	0.00115
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	13.0000	#1.00	0.0	0.00228	1300.000	2.9640
18	**Iron (Fe^{2+}) (mg/L)**	0.0483	#0.30	0.0	0.0076	16.100	0.00836
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.9307	†*#3.00	0.0	0.00076	97.6900	0.0742444
21	**Sodium (Na) (mg/L)**	14.1033	#200.00	0.0	0.0000114	7.05165	0.0000804
22	**Potassium (K) (mg/L)**	11.1867	[a] 10.00	0.0	0.000228	111.8670	0.2551
					∑W = 1.0768		**∑WQ = 3.970037**

WQI_{S11} = 3.6867

APPENDIX 1.2L: QW values for all the parameters in Borehole 12 during rainy season.

S/no	Parameter	Mean (Observed Values)	Standard permissible level(S)	Ideal Value (V)	Unit Weight (W)	Q rating	QW
1	**pH**	6.4333	†*#8.50	7.0	0.000268	-37.78	0.0101
2	**Electrical Conductivity (µS/cm)**	308.3333	#1000	0.0	0.0000028	30.83333	0.0000863
3	**Temperature (°C)**	30.4000	#Ambient	0.0	0.000112	121.600	0.01362
4	**TDS (mg/L)**	135.0000	†#500.00	0.0	0.00000456	27.0000	0.000123
5	**TSS (mg/L)**	273.3333		0.0	-		
6	**TS (mg/L)**	408.3333	†500.00	0.0	0.00000456	81.6667	0.0003724
7	**Total Acidity (mg/L)**	0.6633	[a] 0.30	0.0	0.0076	221.1000	1.68036
8	**Total Alkalinity (mg/L)**	25.0000	80.00	0.0	0.0000285	31.2500	0.000891
9	**Nitrate, NO_3^- (mg/L)**	70.0000	†#50.00	0.0	0.0000456	140.0000	0.006384
10	**Phosphate, PO_4^{3-} (mg/L)**	2.3000	†10.00	0.0	0.000228	23.0000	0.005244
11	**Sulphate, SO_4^{2-} (mg/L)**	29.6667	†*#200.00	0.0	0.0000114	14.83335	0.0001691
12	**BOD (mg/L)**	3.7267	†*3.00	0.0	0.00076	124.2233	0.09441
13	**COD (mg/L)**	4.5667	†*294.00	0.0	0.00000776	1.553299	0.000121
14	**Turbidity (NTU)**	55.6667	†#5	0.0	0.000456	1113.334	0.5076803
15	**Hardness (mg/L)**	103.3333	#150	0.0	0.0000152	68.8887	0.00105
16	**Cadmium (Cd) (mg/L)**	0.0000	†#0.003	0.0	0.76	0.0000	0.0000
17	**Copper(Cu^{2+}) (mg/L)**	0.0800	#1.00	0.0	0.00228	8.0000	0.01824
18	**Iron (Fe^{2+}) (mg/L)**	0.0660	#0.30	0.0	0.0076	22.0000	0.1672
19	**Lead (Pb) (mg/L)**	0.0000	†#0.01	0.0	0.228	0.0000	0.0000
20	**Zinc (Zn) (mg/L)**	2.8580	†*#3.00	0.0	0.00076	95.2667	0.0724
21	**Sodium (Na) (mg/L)**	19.0433	#200.00	0.0	0.0000114	9.52165	0.000109
22	**Potassium (K) (mg/L)**	14.0000	[a] 10.00	0.0	0.000228	1400.000	0.31920
					∑W = 1.0768		**∑WQ = 2.89776**

WQI_{S12}=2.69

APPENDIX 2: Instrumental Settings for Heavy Metal Analysis and concentration of metals added to the spiked water samples:

APPENDIX 2A: Instrumental Settings for Heavy Metal Analysis

Type: Flame AAS.
Background Correction: On.
Flame Type: Air/Acetylene.
Analyte Matrix: Metal-Aqueous.
Elements: Cd, Cu, Fe, Pb; Zn.

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Element	Wavelength (nm)	Slit width (nm)	Lamp Type	Lamp Current
Cd	228.8	0.7	Hollow Cathode Lamp (HCL)	4
Cu	324.7	0.7	HCL	4
Fe	248.3	0.7	HCL	15
Pb	283.3	0.7	HCL	10
Zn	213.9	0.7	HCL	15

APPENDIX 2B: Concentration of Heavy Metals added to the Spiked Water Samples for Recovery Analysis:

	0.524 ppm
Cd	
Cu	0.514 ppm
Fe	0.513 ppm
Pb	0.502 ppm
Zn	0.529 ppm

APPENDIX 2C: Instrumental information on Sodium and Potassium Analysis.

Method: Flame emission photometry.

ELEMENT	EMISSION WAVELENGTH (nm)	FAME COLOUR
Potassium	766	Violet
Sodium	589	Yellow

Temperature Range: 1500°C – 2000°C

Warm up: 15 – 20 minutes.

Fuel: Propane.

Electric air (moisture and oil-free) at 14 psi.

Operating environment: 15 - 35°C.

APPENDIX 3: DESCRIPTIVE STATISTIC FOR PARAMETERS DUE TO GENERAL DEGREE OF POLLUTION.

APPENDIX 3A: COMPARING DRY SEASON BOD, COD, TEMPERATURE (ANOVA).

Descriptive

PARAMETER SAMPLE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
BOD (mg/L)	12	5.1553	.82151	.23715	4.6333	5.6772	3.19	5.97
COD (mg/L)	12	7.5408	1.08523	.31328	6.8513	8.2304	6.18	9.59
TEMPERATURE	12	30.4389	.74575	.21528	29.9651	30.9127	29.03	31.77
Total	36	14.3783	11.59259	1.93210	10.4560	18.3007	3.19	31.77

ANOVA

PARAMETER SAMPLE

PARAMETER VALUE	Equal variances assumed	36.413	.000	4.017	22	.001	4.43471
	Equal variances not assumed			4.017	11.068	.002	4.43471

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
PARAMETER VALUE	Equal variances assumed	1.10389	2.14537	6.72404
	Equal variances not assumed	1.10389	2.00687	6.86255

APPENDIX 4: DESCRIPTIVE STATISTIC FOR PARAMETERS DUE TO VARIATION IN SOIL TYPE AND GEOLOGICAL DIFFERENCES.

APPENDIX 4A: RAINY SEASON ANOVA FOR PARAMETERS DUE TO VARIATION IN SOIL TYPE AND GEOLOGICAL DIFFERENCES

Descriptive

PARAMETER VALUE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
RAINY SEASON MEAN PH	12	5.4028	.85381	.24647	4.8603	5.9453	4.13	7.10
RAINY SEASON MEAN E. C. (µS/cm)	12	189.5833	107.70829	31.09271	121.1488	258.0179	20.00	340.00
RAINY SEASON MEAN TDS (mg/L)	12	127.3611	81.12672	23.41927	75.8156	178.9066	3.33	250.00
RAINY SEASON MEAN TSS (mg/L)	12	186.6667	60.03366	17.33023	148.5231	224.8102	103.33	273.33
RAINY SEASON MEAN TS (mg/L)	12	311.8055	120.68712	34.83937	235.1246	388.4865	73.33	503.33
RAINY SEASON MEAN TURBIDITY (mg/L)	12	10.7989	14.37338	4.14924	1.6665	19.9313	3.83	55.67
RAINY SEASON MEAN TOTAL ACIDITY (mg/L)	12	2.7395	4.22197	1.21878	.0569	5.4220	.10	10.43
RAINY SEASON MEAN TOTAL ACIDITY (mg/L)	12	29.0667	10.56062	3.04859	22.3568	35.7766	15.43	52.03
RAINY SEASON MEAN TOTAL HARDNESS (mg/L)	12	111.6861	8.83946	2.55173	106.0698	117.3024	100.00	126.67
RAINY SEASON MEAN SO4- (mg/L)	12	31.5192	16.84319	4.86221	20.8175	42.2208	20.53	82.63
Total	120	100.6630	115.07889	10.50522	79.8616	121.4643	.10	503.33

ANOVA

PARAMETER VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1168379.048	9	129819.894	35.039	.000
Within Groups	407556.013	110	3705.055		
Total	1575935.061	119			

APPENDIX 4B: DRY SEASON ANOVA FOR PARAMETERS DUE TO VARIATION IN SOIL TYPE AND GEOLOGICAL DIFFERENCES

Descriptive

PARAMETER VALUE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
DRY SEASON MEAN PH	12	6.1320	1.02936	.29715	5.4779	6.7860	4.90	7.50
DRY SEASON MEAN E.C.(µS/cm)	12	133.8889	120.28445	34.72313	57.4638	210.3140	16.67	410.00
DRY SEASON MEAN TDS (mg/L)	12	62.5000	64.96503	18.75379	21.2232	103.7768	.00	210.00
DRY SEASON MEAN TSS (mg/L)	12	164.1667	67.61634	19.51916	121.2053	207.1280	70.00	270.00
DRY SEASON MEAN TS (mg/L)	12	226.6667	103.07397	29.75489	161.1766	292.1567	70.00	390.00
DRY SEASON MEAN TURBIDITY (mg/L)	12	9.7425	12.85664	3.71139	1.5738	17.9112	3.45	50.00
DRY SEASON MEAN ACIDITY (mg/L)	12	.3467	.31115	.08982	.1490	.5444	.07	1.23
DRY SEASON MEAN ALKALINITY (mg/L)	12	36.4847	7.39815	2.13566	31.7842	41.1853	28.03	52.10
DRY SEASON MEAN TOTAL HARDNESS (mg/L)	12	118.9314	15.26938	4.40789	109.2297	128.6331	100.03	140.11
DRY SEASON MEAN SO4- (mg/L)	12	21.7750	1.26694	.36573	20.9700	22.5800	20.11	24.18
Total	120	78.0634	93.54840	8.53976	61.1539	94.9730	.00	410.00

ANOVA

PARAMETER VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	663654.486	9	73739.387	21.473	.000
Within Groups	377750.534	110	3434.096		
Total	1041405.020	119			

APPENDIX 4C: ANOVA OF PARAMETERS DUE TO VARIATION IN SOIL TYPE AND GEOLOGICAL DIFFERENCES FOR RAINY SEASON AND DRY SEASON.

Descriptives

PARAMETER VALUE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
RAINY SEASON MEAN PH	12	5.4028	.85381	.24647	4.8603	5.9453	4.13	7.10
RAINY SEASON MEAN E. C. (µS/cm)	12	189.5833	107.70829	31.09271	121.1488	258.0179	20.00	340.00
RAINY SEASON MEAN TDS (mg/L)	12	127.3611	81.12672	23.41927	75.8156	178.9066	3.33	250.00
RAINY SEASON MEAN TSS (mg/L)	12	186.6667	60.03366	17.33023	148.5231	224.8102	103.33	273.33
RAINY SEASON MEAN TS (mg/L)	12	311.8055	120.68712	34.83937	235.1246	388.4865	73.33	503.33
RAINY SEASON MEAN TURBIDITY (mg/L)	12	10.7989	14.37338	4.14924	1.6665	19.9313	3.83	55.67
RAINY SEASON MEAN TOTAL ACIDITY (mg/L)	12	2.7395	4.22197	1.21878	.0569	5.4220	.10	10.43
RAINY SEASON MEAN TOTAL ACIDITY (mg/L)	12	29.0667	10.56062	3.04859	22.3568	35.7766	15.43	52.03
RAINY SEASON MEAN TOTAL HARDNESS (mg/L)	12	111.6861	8.83946	2.55173	106.0698	117.3024	100.00	126.67
RAINY SEASON MEAN SO_4^{2-} (mg/L)	12	31.5192	16.84319	4.86221	20.8175	42.2208	20.53	82.63
DRY SEASON MEAN pH	12	6.1320	1.02936	.29715	5.4779	6.7860	4.90	7.50

Descriptive

PARAMETER VALUE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
DRY SEASON MEAN E.C. (µS/cm)	12	133.8889	120.28445	34.72313	57.4638	210.3140	16.67	410.00
DRY SEASON MEAN TDS (mg/L)	12	62.5000	64.96503	18.75379	21.2232	103.7768	.00	210.00
DRY SEASON MEAN TSS (mg/L)	12	164.1667	67.61634	19.51916	121.2053	207.1280	70.00	270.00
DRY SEASON MEAN TS (mg/L)	12	226.6667	103.07397	29.75489	161.1766	292.1567	70.00	390.00
DRY SEASON MEAN TURBIDITY (mg/L)	12	9.7425	12.85664	3.71139	1.5738	17.9112	3.45	50.00
DRY SEASON MEAN TOTAL ACIDITY (mg/L)	12	.3467	.31115	.08982	.1490	.5444	.07	1.23
DRY SEASON MEAN TOTAL ALKALINITY (mg/L)	12	36.4847	7.39815	2.13566	31.7842	41.1853	28.03	52.10
DRY SEASON MEAN TOTAL HARDNESS (mg/L)	12	118.9314	15.26938	4.40789	109.2297	128.6331	100.03	140.11
DRY SEASON MEAN SO4- (mg/L)	12	21.7750	1.26694	.36573	20.9700	22.5800	20.11	24.18
Total	240	89.3632	105.25888	6.79443	75.9786	102.7478	.00	503.33

ANOVA

PARAMETER VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1862677.842	19	98035.676	27.464	.000
Within Groups	785306.546	220	3569.575		
Total	2647984.388	239			

APPENDIX 5: DESCRIPTIVE STATISTIC FOR METALS AND POSSIBLE INPUTS FROM WATER SOURCES (ESPECIALLY WASTE WATER PERCOLATION).

APPENDIX 5A: ANOVA FOR METALS DURING RAINY SEASON

Descriptive

HEAVY METALS

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Cd	12	.0000	.00000	.00000	.0000	.0000	.00	.00
Cu	12	11.0800	11.51539	3.32421	3.7635	18.3965	.03	27.56
Fe	12	1.4989	3.44752	.99521	-.6915	3.6894	.00	12.29
Pb	12	.0000	.00000	.00000	.0000	.0000	.00	.00
Zn	12	1.4367	1.42171	.41041	.5334	2.3400	.03	3.39
K	12	10.1717	4.25028	1.22695	7.4712	12.8722	1.32	15.10
Na	12	11.9708	6.19289	1.78773	8.0361	15.9056	2.14	21.21
Total	84	5.1654	7.34439	.80134	3.5716	6.7593	.00	27.56

ANOVA

HEAVY METALS

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2244.821	6	374.137	12.906	.000
Within Groups	2232.203	77	28.990		
Total	4477.023	83			

APPENDIX 5B: ANOVA FOR METALS DURING DRY SEASON.

Descriptive

PARAMETER VALUES

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Cd	12	.0000	.00000	.00000	.0000	.0000	.00	.00
Cu	12	8.9608	9.37113	2.70521	3.0067	14.9150	.00	22.57
Fe	12	1.2438	2.97800	.85967	-.6483	3.1360	.00	10.58
Pb	12	.0000	.00000	.00000	.0000	.0000	.00	.00
Zn	12	1.3167	1.25143	.36126	.5215	2.1118	.00	3.00
K	12	6.4083	3.71107	1.07129	4.0504	8.7662	.00	12.01
Na	12	11.8100	6.60831	1.90765	7.6113	16.0087	2.03	22.42
Total	84	4.2485	6.36811	.69482	2.8666	5.6305	.00	22.57

ANOVA

PARAMETER VALUES

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1653.245	6	275.541	12.388	.000
Within Groups	1712.638	77	22.242		
Total	3365.883	83			

APPENDIX 5C: ANOVA FOR METALS DURING RAINY SEASON AND DRY SEASON.

Descriptive

PARAMETER VALUE

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
RAINY SEASON Cd	12	.0000	.00000	.00000	.0000	.0000	.00	.00
RAINY SEASON Cu	12	11.0800	11.51539	3.32421	3.7635	18.3965	.03	27.56
RAINY SEASON Fe	12	1.4989	3.44752	.99521	-.6915	3.6894	.00	12.29
RAINY SEASON Pb	12	.0000	.00000	.00000	.0000	.0000	.00	.00
RAINY SEASON Zn	12	1.4367	1.42171	.41041	.5334	2.3400	.03	3.39
RAINY SEASON K	12	10.1717	4.25028	1.22695	7.4712	12.8722	1.32	15.10
RAINY SEASON Na	12	11.9708	6.19289	1.78773	8.0361	15.9056	2.14	21.21
DRY SEASON Cd	12	.0000	.00000	.00000	.0000	.0000	.00	.00
DRY SEASON Cu	12	8.9608	9.37113	2.70521	3.0067	14.9150	.00	22.57
DRY SEASON Fe	12	1.2438	2.97800	.85967	-.6483	3.1360	.00	10.58
DRY SEASON Pb	12	.0000	.00000	.00000	.0000	.0000	.00	.00
DRY SEASON Zn	12	1.3167	1.25143	.36126	.5215	2.1118	.00	3.00
DRY SEASON K	12	6.4083	3.71107	1.07129	4.0504	8.7662	.00	12.01
DRY SEASON Na	12	11.8100	6.60831	1.90765	7.6113	16.0087	2.03	22.42
Total	168	4.7070	6.86840	.52991	3.6608	5.7532	.00	27.56

ANOVA

PARAMETER VALUE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3933.377	13	302.567	11.812	.000
Within Groups	3944.841	154	25.616		
Total	7878.218	167			

APPENDIX 6: Correlation all Parameters during rainy season.

Correlations

		MEAN pH	MEAN E.C.(uS/cm)	MEAN TEMPERATURE (^{0}C)	MEAN TDS (mg/L)	MEAN TSS (mg/L)	MEAN TS (mg/L)
MEAN pH	Pearson Correlation	1	.320	-.169	.364	.111	.317
	Sig. (2-tailed)		.310	.600	.244	.732	.315
	N	12	12	12	12	12	12
MEAN E.C.(uS/cm)	Pearson Correlation	.320	1	.343	.744**	.386	.741**
	Sig. (2-tailed)	.310		.275	.005	.215	.006
	N	12	12	12	12	12	12
MEAN TEMPERATURE (0C)	Pearson Correlation	-.169	.343	1	.340	-.083	.198
	Sig. (2-tailed)	.600	.275		.279	.797	.537
	N	12	12	12	12	12	12
MEAN TDS (mg/L)	Pearson Correlation	.364	.744**	.340	1	.300	.863**
	Sig. (2-tailed)	.244	.005	.279		.343	.000
	N	12	12	12	12	12	12
MEAN TSS (mg/L)	Pearson Correlation	.111	.386	-.083	.300	1	.734**
	Sig. (2-tailed)	.732	.215	.797	.343		.007
	N	12	12	12	12	12	12
MEAN TS (mg/L)	Pearson Correlation	.317	.741**	.198	.863**	.734**	1
	Sig. (2-tailed)	.315	.006	.537	.000	.007	
	N	12	12	12	12	12	12
MEAN TURBIDITY (mg/L)	Pearson Correlation	.437	.407	-.026	.124	.583*	.384
	Sig. (2-tailed)	.155	.189	.936	.700	.047	.218
	N	12	12	12	12	12	12
MEAN TOTAL ACIDITY (mg/L)	Pearson Correlation	-.084	.289	.188	.440	.257	.436

Correlations

		MEAN TURBIDITY (mg/L)	MEAN TOTAL ACIDITY (mg/L)	MEAN TOTAL ALKALINITY (mg/L)	MEAN TOTAL HARDNESS (mg/L)	MEAN NO_3- (mg/L)
MEAN pH	Pearson Correlation	.437	-.084	-.417	-.031	.301
	Sig. (2-tailed)	.155	.795	.177	.925	.342
	N	12	12	12	12	12
MEAN E.C. (uS/cm)	Pearson Correlation	.407	.289	-.416	-.481**	.453
	Sig. (2-tailed)	.189	.363	.179	.113	.139
	N	12	12	12	12	12
MEAN TEMPERATURE (^{0}C)	Pearson Correlation	-.026	.188	-.226	.123	.090
	Sig. (2-tailed)	.936	.558	.479	.703	.782
	N	12	12	12	12	12
MEAN TDS (mg/L)	Pearson Correlation	.124	.440**	-.618	-.181	.126
	Sig. (2-tailed)	.700	.152	.032	.574	.696
	N	12	12	12	12	12
MEAN TSS (mg/L)	Pearson Correlation	.583	.257	-.364	-.338	.506
	Sig. (2-tailed)	.047	.419	.244	.283	.093
	N	12	12	12	12	12
MEAN TS (mg/L)	Pearson Correlation	.384	.436**	-.652	-.327**	.350**
	Sig. (2-tailed)	.218	.157	.022	.299	.265
	N	12	12	12	12	12
MEAN TURBIDITY (mg/L)	Pearson Correlation	1	-.089	-.198	-.320	.958*
	Sig. (2-tailed)		.783	.537	.311	.000
	N	12	12	12	12	12
MEAN TOTAL ACIDITY (mg/L)	Pearson Correlation	-.089	1	-.527	.060	.066

Correlations

		MEAN SO4- (mg/L)	MEAN PO4- (mg/L	MEAN BOD (mg/L)	MEAN COD (mg/L)	MEAN Cd (mg/L)
MEAN pH	Pearson Correlation	-.093	-.138	-.236	-.207	.
	Sig. (2-tailed)	.774	.669	.460	.518	.
	N	12	12	12	12	12
MEAN E.C.(uS/cm)	Pearson Correlation	.113	.545	-.770	-.784**	.
	Sig. (2-tailed)	.728	.067	.003	.003	.
	N	12	12	12	12	12
MEAN TEMPERATURE (0C)	Pearson Correlation	.156	.336	-.217	-.241	.
	Sig. (2-tailed)	.627	.285	.498	.450	.
	N	12	12	12	12	12
MEAN TDS (mg/L)	Pearson Correlation	.328	.505**	-.836	-.835	.
	Sig. (2-tailed)	.298	.094	.001	.001	.
	N	12	12	12	12	12
MEAN TSS (mg/L)	Pearson Correlation	-.368	.363	-.723	-.723	.
	Sig. (2-tailed)	.239	.246	.008	.008	.
	N	12	12	12	12	12
MEAN TS (mg/L)	Pearson Correlation	.026	.550**	-.981	-.981**	.**
	Sig. (2-tailed)	.936	.064	.000	.000	.
	N	12	12	12	12	12
MEAN TURBIDITY (mg/L)	Pearson Correlation	-.085	-.128	-.377	-.351	.*
	Sig. (2-tailed)	.794	.691	.227	.263	.
	N	12	12	12	12	12
MEAN TOTAL ACIDITY (mg/L)	Pearson Correlation	-.227	.591	-.431	-.439	.

Correlations

		MEAN Cu (mg/L)	MEAN Fe (mg/L)	MEAN Pb (mg/L)	MEAN Zn (mg/L)	MEAN k (mg/L)
MEAN pH	Pearson Correlation	-.314	-.285	.	.125	.236
	Sig. (2-tailed)	.320	.370	.	.700	.460
	N	12	12	12	12	12
MEAN E.C.(uS/cm)	Pearson Correlation	.119	.460	.	.172**	.858
	Sig. (2-tailed)	.713	.133	.	.593	.000
	N	12	12	12	12	12
MEAN TEMPERATURE (^{0}C)	Pearson Correlation	.442	.354	.	.296	.261
	Sig. (2-tailed)	.150	.259	.	.351	.412
	N	12	12	12	12	12
MEAN TDS (mg/L)	Pearson Correlation	.496	.506**	.	.304	.778
	Sig. (2-tailed)	.101	.093	.	.336	.003
	N	12	12	12	12	12
MEAN TSS (mg/L)	Pearson Correlation	.427	.315	.	.328	.685
	Sig. (2-tailed)	.167	.318	.	.298	.014
	N	12	12	12	12	12
MEAN TS (mg/L)	Pearson Correlation	.564	.508**	.	.388**	.926**
	Sig. (2-tailed)	.056	.092	.	.213	.000
	N	12	12	12	12	12
MEAN TURBIDITY (mg/L)	Pearson Correlation	-.224	-.056	.	.318	.386*
	Sig. (2-tailed)	.484	.863	.	.314	.215
	N	12	12	12	12	12
MEAN TOTAL ACIDITY (mg/L)	Pearson Correlation	.484	.513	.	.187	.322

Correlations

		MEAN Na (mg/L)
MEAN pH	Pearson Correlation	.553
	Sig. (2-tailed)	.062
	N	12
MEAN E.C.(uS/cm)	Pearson Correlation	.522
	Sig. (2-tailed)	.082
	N	12
MEAN TEMPERATURE (^{0}C)	Pearson Correlation	.095
	Sig. (2-tailed)	.770
	N	12
MEAN TDS (mg/L)	Pearson Correlation	.544
	Sig. (2-tailed)	.068
	N	12
MEAN TSS (mg/L)	Pearson Correlation	.600
	Sig. (2-tailed)	.039
	N	12
MEAN TS (mg/L)	Pearson Correlation	.701
	Sig. (2-tailed)	.011
	N	12
MEAN TURBIDITY (mg/L)	Pearson Correlation	.463
	Sig. (2-tailed)	.129
	N	12
MEAN TOTAL ACIDITY (mg/L)	Pearson Correlation	.435

Correlations

		MEAN PH	MEAN E.C.(uS/cm)	MEAN TEMPERATURE (0C)	MEAN TDS (mg/L)	MEAN TSS (mg/L)	MEAN TS (mg/L)
MEAN TOTAL ACIDITY (mg/L)	Sig. (2-tailed)	.795	.363	.558	.152	.419	.157
	N	12	12	12	12	12	12
MEAN TOTAL ALKALINITY (mg/L)	Pearson Correlation	-.417	-.416	-.226	-.618	-.364	-.652
	Sig. (2-tailed)	.177	.179	.479	.032**	.244	.022**
	N	12	12	12	12	12	12
MEAN TOTAL HARDNESS (mg/L)	Pearson Correlation	-.031	-.481	.123	-.181	-.338	-.327
	Sig. (2-tailed)	.925	.113	.703	.574	.283	.299
	N	12	12	12	12	12	12
MEAN NO_3- (mg/L)	Pearson Correlation	.301	.453	.090	.126	.506	.350
	Sig. (2-tailed)	.342	.139**	.782	.696	.093	.265**
	N	12	12	12	12	12	12
MEAN SO_4^{2-} (mg/L)	Pearson Correlation	-.093	.113	.156	.328	-.368	.026
	Sig. (2-tailed)	.774	.728	.627	.298	.239	.936**
	N	12	12	12	12	12	12
MEAN PO_4^{3-} (mg/L	Pearson Correlation	-.138	.545	.336	.505	.363	.550
	Sig. (2-tailed)	.669	.067**	.285	.094**	.246**	.064
	N	12	12	12	12	12	12
MEAN BOD (mg/L)	Pearson Correlation	-.236	-.770	-.217	-.836	-.723	-.981
	Sig. (2-tailed)	.460	.003	.498	.001	.008*	.000
	N	12	12	12	12	12	12
MEAN COD (mg/L)	Pearson Correlation	-.207	-.784	-.241	-.835	-.723	-.981
	Sig. (2-tailed)	.518	.003	.450	.001	.008	.000

Correlations

		MEAN TURBIDITY (mg/L)	MEAN TOTAL ACIDITY (mg/L)	MEAN TOTAL ALKALINITY (mg/L)	MEAN TOTAL HARDNESS (mg/L)	MEAN NO3- (mg/L)
MEAN TOTAL ACIDITY (mg/L)	Sig. (2-tailed)	.783		.078	.854	.839
	N	12	12	12	12	12
	Pearson Correlation	-.198	-.527	1	.213	-.229
MEAN TOTAL ALKALINITY (mg/L)	Sig. (2-tailed)	.537	.078		.507**	.474
	N	12	12	12	12	12
	Pearson Correlation	-.320	.060	.213	1	-.357
MEAN TOTAL HARDNESS (mg/L)	Sig. (2-tailed)	.311	.854	.507		.254
	N	12	12	12	12	12
	Pearson Correlation	.958	.066	-.229	-.357	1
MEAN NO_3- (mg/L)	Sig. (2-tailed)	.000	.839**	.474	.254	
	N	12	12	12	12	12
	Pearson Correlation	-.085	-.227	.108	-.333	-.048
MEAN SO_4^{2-} (mg/L)	Sig. (2-tailed)	.794	.479	.738	.290	.882
	N	12	12	12	12	12
	Pearson Correlation	-.128	.591	-.427	-.545	-.038
MEAN PO_4^{3-} (mg/L	Sig. (2-tailed)	.691	.043**	.166	.067**	.907**
	N	12	12	12	12	12
	Pearson Correlation	-.377	-.431	.663	.333	-.360
MEAN BOD (mg/L)	Sig. (2-tailed)	.227	.161	.019	.291	.251*
	N	12	12	12	12	12
	Pearson Correlation	-.351	-.439	.608	.324	-.345
MEAN COD (mg/L)	Sig. (2-tailed)	.263	.153	.036	.304	.271

Correlations

		MEAN SO4- (mg/L)	MEAN PO4- (mg/L	MEAN BOD (mg/L)	MEAN COD (mg/L)	MEAN Cd (mg/L)
MEAN TOTAL ACIDITY (mg/L)	Sig. (2-tailed)	.479	.043	.161	.153	.
	N	12	12	12	12	12
	Pearson Correlation	.108	-.427	.663	.608	.
MEAN TOTAL ALKALINITY (mg/L)	Sig. (2-tailed)	.738	.166	.019	.036**	.
	N	12	12	12	12	12
	Pearson Correlation	-.333	-.545	.333	.324	.
MEAN TOTAL HARDNESS (mg/L)	Sig. (2-tailed)	.290	.067	.291	.304	.
	N	12	12	12	12	12
	Pearson Correlation	-.048	-.038	-.360	-.345	.
MEAN NO_3^- (mg/L)	Sig. (2-tailed)	.882	.907**	.251	.271	.
	N	12	12	12	12	12
	Pearson Correlation	1	.082	.010	.019	.
MEAN SO_4^{2-} (mg/L)	Sig. (2-tailed)		.801	.976	.953	.
	N	12	12	12	12	12
	Pearson Correlation	.082	1	-.531	-.549	.
MEAN PO_4^{3-} (mg/L	Sig. (2-tailed)	.801		.075	.065**	.**
	N	12	12	12	12	12
	Pearson Correlation	.010	-.531	1	.990	.
MEAN BOD (mg/L)	Sig. (2-tailed)	.976	.075		.000	.*
	N	12	12	12	12	12
	Pearson Correlation	.019	-.549	.990	1	.
MEAN COD (mg/L)	Sig. (2-tailed)	.953	.065	.000		.

Correlations

		MEAN Cu (mg/L)	MEAN Fe (mg/L)	MEAN Pb (mg/L)	MEAN Zn (mg/L)	MEAN k (mg/L)
MEAN TOTAL ACIDITY (mg/L)	Sig. (2-tailed)	.110	.088	.	.560	.308
	N	12	12	12	12	12
	Pearson Correlation	-.357	-.379	.	-.300	-.477
MEAN TOTAL ALKALINITY (mg/L)	Sig. (2-tailed)	.255	.224	.	.343**	.117
	N	12	12	12	12	12
	Pearson Correlation	-.027	.035	.	-.426	-.485
MEAN TOTAL HARDNESS (mg/L)	Sig. (2-tailed)	.934	.915	.	.168	.110
	N	12	12	12	12	12
	Pearson Correlation	-.197	-.003	.	.361	.389
MEAN NO_3^- (mg/L)	Sig. (2-tailed)	.539	.994**	.	.249	.211
	N	12	12	12	12	12
	Pearson Correlation	.120	-.094	.	.368	.045
MEAN SO_4^{2-} (mg/L)	Sig. (2-tailed)	.709	.771	.	.240	.890
	N	12	12	12	12	12
	Pearson Correlation	.632	.434	.	.442	.610
MEAN PO_4^{3-} (mg/L	Sig. (2-tailed)	.027	.158**	.	.150**	.035**
	N	12	12	12	12	12
	Pearson Correlation	-.514	-.615	.	-.271	-.913
MEAN BOD (mg/L)	Sig. (2-tailed)	.088	.033	.	.394	.000*
	N	12	12	12	12	12
	Pearson Correlation	-.541	-.582	.	-.295	-.948
MEAN COD (mg/L)	Sig. (2-tailed)	.069	.047	.	.352	.000

Correlations

		MEAN Na (mg/L)
MEAN TOTAL ACIDITY (mg/L)	Sig. (2-tailed)	.158
	N	12
	Pearson Correlation	-.771
MEAN TOTAL ALKALINITY (mg/L)	Sig. (2-tailed)	.003
	N	12
	Pearson Correlation	-.100
MEAN TOTAL HARDNESS (mg/L)	Sig. (2-tailed)	.757
	N	12
	Pearson Correlation	.434
MEAN NO_3^- (mg/L)	Sig. (2-tailed)	.159
	N	12
	Pearson Correlation	-.413
MEAN SO_4^{2-} (mg/L)	Sig. (2-tailed)	.182
	N	12
	Pearson Correlation	.258
MEAN PO_4^{3-} (mg/L	Sig. (2-tailed)	.418
	N	12
	Pearson Correlation	-.697
MEAN BOD (mg/L)	Sig. (2-tailed)	.012
	N	12
	Pearson Correlation	-.680
MEAN COD (mg/L)	Sig. (2-tailed)	.015

Correlations

		MEAN PH	MEAN E.C.(uS/cm)	MEAN TEMPERATURE (0C)	MEAN TDS (mg/L)	MEAN TSS (mg/L)	MEAN TS (mg/L)
MEAN COD (mg/L)	N	12	12	12	12	12	12
	Pearson Correlation	.	.	.	.	.	.
MEAN Cd (mg/L)	Sig. (2-tailed)	.	.	.	.	.	.
	N	12	12	12	12**	12	12**
	Pearson Correlation	-.314	.119	.442	.496	.427	.564
MEAN Cu (mg/L)	Sig. (2-tailed)	.320	.713	.150	.101	.167	.056
	N	12	12	12	12	12	12
	Pearson Correlation	-.285	.460	.354	.506	.315	.508
MEAN Fe (mg/L)	Sig. (2-tailed)	.370	.133	.259	.093	.318	.092
	N	12	12**	12	12	12	12**
	Pearson Correlation	.	.	.	.	.	.
MEAN Pb (mg/L)	Sig. (2-tailed)	.	.	.	.	.	.
	N	12	12	12	12	12	12**
	Pearson Correlation	.125	.172	.296	.304	.328	.388
MEAN Zn (mg/L)	Sig. (2-tailed)	.700	.593	.351	.336	.298	.213
	N	12	12**	12	12**	12**	12
	Pearson Correlation	.236	.858	.261	.778	.685	.926
MEAN k (mg/L)	Sig. (2-tailed)	.460	.000	.412	.003	.014	.000
	N	12	12	12	12	12*	12
	Pearson Correlation	.553	.522	.095	.544	.600	.701
MEAN Na (mg/L)	Sig. (2-tailed)	.062	.082	.770	.068	.039	.011
	N	12	12	12	12	12	12

Correlations

		MEAN TURBIDITY (mg/L)	MEAN TOTAL ACIDITY (mg/L)	MEAN TOTAL ALKALINITY (mg/L)	MEAN TOTAL HARDNESS (mg/L)	MEAN NO3- (mg/L)
MEAN COD (mg/L)	N	12	12	12	12	12
	Pearson Correlation	.	.	.	.	.
MEAN Cd (mg/L)	Sig. (2-tailed)	.	.	.	.	.
	N	12	12	12	12**	12
	Pearson Correlation	-.224	.484	-.357	-.027	-.197
MEAN Cu (mg/L)	Sig. (2-tailed)	.484	.110	.255	.934	.539
	N	12	12	12	12	12
	Pearson Correlation	-.056	.513	-.379	.035	-.003
MEAN Fe (mg/L)	Sig. (2-tailed)	.863	.088	.224	.915	.994
	N	12	12**	12	12	12
	Pearson Correlation	.	.	.	.	.
MEAN Pb (mg/L)	Sig. (2-tailed)	.	.	.	.	.
	N	12	12	12	12	12
	Pearson Correlation	.318	.187	-.300	-.426	.361
MEAN Zn (mg/L)	Sig. (2-tailed)	.314	.560	.343	.168	.249
	N	12	12**	12	12**	12**
	Pearson Correlation	.386	.322	-.477	-.485	.389
MEAN k (mg/L)	Sig. (2-tailed)	.215	.308	.117	.110	.211
	N	12	12	12	12	12*
	Pearson Correlation	.463	.435	-.771	-.100	.434
MEAN Na (mg/L)	Sig. (2-tailed)	.129	.158	.003	.757	.159
	N	12	12	12	12	12

Correlations

		MEAN $SO4^{2-}$ (mg/L)	MEAN PO_4^{3-} (mg/L	MEAN BOD (mg/L)	MEAN COD (mg/L)	MEAN Cd (mg/L)
MEAN COD (mg/L)	N	12	12	12	12	12
	Pearson Correlation	.	.	.	.	.
MEAN Cd (mg/L)	Sig. (2-tailed)	.	.	.	.	
	N	12	12	12	12**	12
	Pearson Correlation	.120	.632	-.514	-.541	.
MEAN Cu (mg/L)	Sig. (2-tailed)	.709	.027	.088	.069	.
	N	12	12	12	12	12
	Pearson Correlation	-.094	.434	-.615	-.582	.
MEAN Fe (mg/L)	Sig. (2-tailed)	.771	.158	.033	.047	.
	N	12	12**	12	12	12
	Pearson Correlation	.	.	.	.	.
MEAN Pb (mg/L)	Sig. (2-tailed)	.	.	.	.	.
	N	12	12	12	12	12
	Pearson Correlation	.368	.442	-.271	-.295	.
MEAN Zn (mg/L)	Sig. (2-tailed)	.240	.150	.394	.352	.
	N	12	12**	12	12**	12**
	Pearson Correlation	.045	.610	-.913	-.948	.
MEAN k (mg/L)	Sig. (2-tailed)	.890	.035	.000	.000	.
	N	12	12	12	12	12*
	Pearson Correlation	-.413	.258	-.697	-.680	.
MEAN Na (mg/L)	Sig. (2-tailed)	.182	.418	.012	.015	.
	N	12	12	12	12	12

Correlations

		MEAN Cu (mg/L)	MEAN Fe (mg/L)	MEAN Pb (mg/L)	MEAN Zn (mg/L)	MEAN K (mg/L)
MEAN COD (mg/L)	N	12	12	12	12	12
	Pearson Correlation	.	.	.	.	.
MEAN Cd (mg/L)	Sig. (2-tailed)	.	.	.	.	.
	N	12	12	12	12**	12
	Pearson Correlation	1	.423	.	.522	.468
MEAN Cu (mg/L)	Sig. (2-tailed)		.171	.	.081	.125
	N	12	12	12	12	12
	Pearson Correlation	.423	1	.	-.292	.400
MEAN Fe (mg/L)	Sig. (2-tailed)	.171		.	.358	.197
	N	12	12**	12	12	12
	Pearson Correlation	.	.	.	.	.
MEAN Pb (mg/L)	Sig. (2-tailed)	.	.		.	.
	N	12	12	12	12	12
	Pearson Correlation	.522	-.292	.	1	.405
MEAN Zn (mg/L)	Sig. (2-tailed)	.081	.358	.		.191
	N	12	12**	12	12**	12**
	Pearson Correlation	.468	.400	.	.405	1
MEAN k (mg/L)	Sig. (2-tailed)	.125	.197	.	.191	
	N	12	12	12	12	12*
	Pearson Correlation	.181	.409	.	.073	.584
MEAN Na (mg/L)	Sig. (2-tailed)	.573	.186	.	.822	.046
	N	12	12	12	12	12

Correlations

		MEAN Na (mg/L)
MEAN COD (mg/L)	N	12
	Pearson Correlation	.
MEAN Cd (mg/L)	Sig. (2-tailed)	.
	N	12
	Pearson Correlation	.181
MEAN Cu (mg/L)	Sig. (2-tailed)	.573
	N	12
	Pearson Correlation	.409
MEAN Fe (mg/L)	Sig. (2-tailed)	.186
	N	12
	Pearson Correlation	.
MEAN Pb (mg/L)	Sig. (2-tailed)	.
	N	12
	Pearson Correlation	.073
MEAN Zn (mg/L)	Sig. (2-tailed)	.822
	N	12
	Pearson Correlation	.584
MEAN k (mg/L)	Sig. (2-tailed)	.046
	N	12
	Pearson Correlation	1
MEAN Na (mg/L)	Sig. (2-tailed)	
	N	12

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

APPENDIX 7: COMPARING THE WATER QUAITY INDEX FOR THE TWO SEASONS (RAINY SEASON AND DRY SEASON).

Group Statistics

	PARAMETER CODE	N	Mean	Std. Deviation	Std. Error Mean
PARAMETER VALUE	DRY SEASON WQI	12	5.8713	7.68026	2.21710
	RAINY SEASON WQI	12	11.1294	12.05495	3.47996

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference
PARAMETER VALUE	Equal variances assumed	4.718	.041	-1.274	22	.216	-5.25809
	Equal variances not assumed			-1.274	18.667	.218	-5.25809

Independent Samples Test

		t-test for Equality of Means		
		Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
PARAMETER VALUE	Equal variances assumed	4.12622	-13.81535	3.29916
	Equal variances not assumed	4.12622	-13.90482	3.38863