EVALUATING BOREHOLE WATER QUALITY IN OGBOJOBU A RURAL COMMUNITY IN BENIN CITY, NIGERIA.

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BENIN CITY

FEBRUARY, 2025

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A PROJECT WRITTEN AND SUBMITTED TO THE DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE WARD OF DEGREE OF BACHELOR OF SCIENCE (ANIMAL AND ENVIRONMENTAL BIOLOGY) OF THE UNIVERSITY OF BENIN BENIN CITY

JANUARY, 2025

CERTIFICATION

We certify that this work was carried out by **Zaib Aimanosi BELLO** with matriculation number; **LSC2006636** the Department of Animal and Environmental Biology, University of Benin, Benin City.

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DEDICATION

This is dedicated to ALMIGHTY ALLAH, My parents MR and MRS BELLO, and my siblings.

ACKNOWLEDEGMENT

This study would not have been possible without the support and contributions of numerous individuals. I would like to express my deepest gratitude to those who have supported me throughout my undergraduate journey.

I want to take a moment to acknowledge the incredible people in my life, to my Parents, MR and MRS BELLO and my Siblings your presence, support, and unwavering belief in me have made all the difference, thank you. And to Stephanie Iwinosa IYASE, Glory Oghenekome OGHENEKARO, Blessed and Victor OKUNSEBOR, and Sandra Adanna OKPARA your encouragement and guidance have meant the world to me and I am forever grateful. To my family members, whose encouragement and support financially and helped me greatly many thanks. Special thanks to my course mates, friends and roommates.

I also want to acknowledge Dr C.O Asemota Thank You So Much Sir for your Support.

I am overwhelmed with gratitude for the love, support and encouragement I have received from my loved ones. You have shaped me into the person I am today, and I am forever thankful.

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ABSTRACT

This study evaluated the quality of borehole water in rural communities of Benin City, Nigeria, with a focus on protecting vulnerable populations such as children and infants. Water samples were collected from five borehole locations in the Ogbojobu community and analyzed for both biological and physicochemical parameters. Total coliform counts ranged from non-detectable (0 CFU/100 mL) to 1.0 CFU/100 mL, while fecal coliforms were undetectable across all sites, suggesting minimal microbial contamination. Physicochemical analysis revealed that the pH values of the water were slightly acidic, ranging from 5.60 ± 0.00 to 6.63 ± 0.058, which is at or below the WHO permissible range of 6.5–8.5 for drinking water. Other parameters, including conductivity (14.0–60.0 µS/cm), total dissolved solids (8.0–30.0 mg/L), turbidity (0.0–2.0 NTU), hardness, alkalinity, chloride, phosphate, nitrate, calcium, magnesium, iron, zinc, manganese, and copper, were measured with significant variations observed between borehole sites ($p < 0.05$). Notably, lead and cadmium were not detected in any sample. Given that safe drinking water is critical to the health of vulnerable groups, recent studies have emphasized the disproportionate risks heavy metal exposure poses for children and infants. These findings highlight the need for continued monitoring and targeted public health interventions in rural Nigerian communities to safeguard child and infant health from potential chronic exposure to harmful contaminants

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Water, a vital solvent rich in minerals, is indispensable for the sustenance of terrestrial and aquatic ecosystems on Earth. Water is the most important nutrient, essential to the survival of all humanity because it is involved in every bodily function, and makes up about 75% of total body weight (Mack and Nadel 2011; Offei-Ansah, 2012; Shryer, 2007). It is needed to replenish the fluids lost through normal physiological activities such as respiration, perspiration, urination (Murray *et al*., 2003). The lack of this essential mineral can lead to serious implications such as hypertension, high cholesterol, and heart disease. Recent studies have also linked the lack of water to headaches, arthritis, and heartburn (Batmangheligj and page, 2012). Therefore, it is recommended that one should drink at least 64 ounces per day (Bellisle *et al*., 2010). However, despite the need to ensure sufficient water quality, one of the biggest development challenge is ensuring sufficient water quality (Gundry *et al*., 2003).

1.2 JUSTIFICATION OF STUDY

Borehole water varies in purity depending on the geological conditions of the soil through which the ground water flows and some anthropogenic activities. Unsatisfactory water supplies and unwholesome sanitary conditions can result in poor human health. According to World Health Organisation guidelines for drinking water, underground water supplies are usually considered safe provided they are properly located, constructed and operated to WHO regulatory standards. It has been confirmed in the country that water related diarrhoea is the most prevalent disease among the population after malaria, prompting the need for safe drinking water. Until very recently, groundwater has been thought of as being a standard of water purity itself, and to a certain extent, that is indeed true. Consequently, the most fundamental need is provision of water that is suitable for drinking, food preparation and personal hygiene, and that poses no risk in any way to human health. Ground water or borehole water is an important water source in both urban and rural areas of Nigeria. A source of water is considered bacteriological potable if it does not contain any microorganism that may be pathogenic to man. Government and non-governmental agencies, corporate organizations and individuals are involved in sinking of boreholes to provide water for families, staffs, companies and communities. Boreholes and wells are polluted either industrially, domestically or agriculturally. Industrial pollution may involve seepages of used water containing chemicals such as metals and radioactive compounds while domestic pollution may involve seepage from broken septic tanks, pit latrines and privies. The possibility that some situation may be applicable to cities such as Benin City prompted the work, hence, analysis of water for physico-chemical and bacteriological quality.

1.3 AIM AND OBJECTIVES

This study aims to ascertain/access the quality of ground water (borehole) in Ugbojobu, Ovia North East Local Government Area, Edo State.

The specific objectives is: To determine the physicochemical and bacteriological properties of water samples from borehole in Ugbojobu, Ovia North East Local Government Area, Edo State.

CHAPTER TWO

LITERATURE REVIEW

In the last half a century, global population has increased to over 6.5 billion with its attendant increase in industrialization and economic development. All this time, the availability of water has not changed quantitatively, while the demand for potable drinking water has increased drastically. It is estimated that the number of people without access to safe drinking water is as high as 1.5billion with all the consequences for water borne diseases (Topfer, 2007).

The largest amount of water on earth is either ice or saltwater. Less than 4% of the water on earth is available as fresh water and a large part of this is groundwater. Groundwater plays a crucial role as a reservoir of freshwater which is required for potable water as well as irrigation for agriculture (Omoigberale *et al*., 2009).

Apart from the essential role played by water in supporting human life, it also has, if polluted a great potential for transmitting a wide variety of diseases. According to Akpan et al. (1996), in most developing countries like Nigeria where dangerous and highly toxic industrial and domestic wastes are disposed of by dumping them on the Earth; into rivers and streams with total disregard for aquatic lives and rural dwellers, water becomes an important medium for the transmission of enteric diseases in most countries.

Traditionally many societies have depended on surface water; however with increasing challenges of contaminated surface water resulting in disease such as bilharzia, sleeping sickness, river blindness and guinea worm, many societies have adopted digging of boreholes (Carpenter *et al*., 1998; Chigor *et al*., 2012). Digging of borehole is encouraged by local, national and international organisations as alternative to polluted surface drinking water sources. A lot of funds is been allocated into building boreholes even though sometimes the purity of the drinking water from the boreholes is questionable (Ncube and Schutte, 2005). The quality of borehole water depends upon several factors including local geology, hydrology and geochemical characteristics of the aquifers (Bhattacharya *et al*., 1997). Apart from these factors, the activities of microorganisms, temperature and pressure are also responsible for the chemical characteristic of groundwater (Fournier and Truedell, 1973). Therefore, borehole water often contains dissolved mineral ions whose type an concentration can affect their quality. If certain mineral constituent are present in excessive amounts, some type of treatment may be necessary before the water can be used for the intended purpose.

Groundwater resources represent one of the most important treasures of our planet; fresh water that is located below the ground surface and stored in underground saturated geological formations. As water is the main and necessary element of life, aquifers significantly affect the ecological balance of the planet and are directly related to the status of the ecosystems and

the human health.

Management and provision of good quality drinking water contributes to reducing diseases and water borne infections in developing countries (WHO, 2012). Replenishable clean water sources in Nigeria are estimated at 319 billion cubic metres, with groundwater estimated at 52 billion cubic metres (Mgbemena and Okwunodulu, 2015). Despite various strategies provided by the government to improve access to potable clean water in Nigeria, approximately 58% of urban and 39% of rural settings have access to clean and potable drinking water due to the rapidly growing population (Moyo, 2013; Iyasele and Idiata, 2012). Borehole water therefore, remains an unavoidable source of potable water in Nigeria. However, contamination of ground water remains a global public health threat and related health consequences as well as chemical intoxication cannot be underestimated (Akpoveta *et al*., 2011; Tamungang *et al*., 2016). In fact, faecal contamination, domestic waste water, livestock manure, refuse dumps, and chemical pollution have been reported as sources of borehole and underground water contamination (Ugbaja and Otokunefor, 2015; Collins and Merapelo, 2011; Isa, 2013). Contaminated potable drinking water has severe health implications on humans, including diseases of the gastrointestinal tract and bacteraemia (Ikeme *et al*., 2014). Moreover, clean potable drinking water contaminated with toxic chemicals can cause acute and chronic health effects (Takeuchi *et al*., 2005; Seth *et al*., 2014).

Poisonous chemicals are known to percolate the layers of the Earth and terminate in ground water thereby constituting public health hazards. The groundwater reserve is maintained by a hydrostatic balance within the soil pores, below the water table which is naturally recharged by rain water, streams or rivers. The groundwater also discharges from streams or from drilled wells e.g. boreholes. Over-pumping or over abstraction of groundwater from boreholes (where there is a declining groundwater level) may lead to infiltration of septic tank effluent (Mbugua, 2016).

Generally, groundwater is characterized by low contents of organic substances, appreciable concentration of mineral salts and sometimes dissolved gases (Nikoladze et al., 1989). Hanidu and Alli (1977) reported that in Nigeria, there is an adequate surface and groundwater resource to meet current water demand. However, access to potable water supply to all, the temporal and spatial distribution of the water has made it scarce in some locations, resulting in water scarcity. Studies on the quality of groundwater have been carried out in some parts of Nigeria by Nkono and Asubiojo (1998) in south western Nigeria, Adeyeye and Abulude (2004) in Ile-Ife, Oyo state, and Olobaniyi and Owoyemi (2004) in Delta state. Other studies include Olobaniyi and Efe (2007), Alexander (2008) and Yeri et al. (2008). Benin City obtains over 90% of its water for drinking and domestic usage from groundwater sources specifically via boreholes. These boreholes also serve agricultural and industrial purposes. Most of the studies in Benin City have focused on physicochemical parameters of Ikpoba River (Edokpayi 1988; Ogbeibu & Edutie, 2002; Ogbeibu & Osokpor, 2002; Ogbeibu & Anozia, 2007), except Tawari-Fufeyin et al (1999) who reported on characterization of drinking water sources in rural communities in Benin City.

2.1 BOREHOLE WATER/GROUND WATER

Groundwater is the water beneath the earth surface, where all the voids in the rocks and soil are filled. It is a source of water for wells, boreholes and springs. Groundwater is the water that flows or eeps downward and saturate soil or rock supplying springs and well. A borehole is a hydraulicstructure which when properly designed and contructed,permits the economic withdrawal of water from an aquifer. It is a narrow well drilled with machine. Borehole wateris the water obtained from borehole drilled into aquifer or ground water zone, wich is usually a fully saturated subterranean zone, some distance below the water table. Ground water is already used extensively in Nigeria through wells and boreholes. Unfortunately borehole water like water from other sources is never entirely pure. Water plays a key role in the prevention of diseases, Drinking eight glasses of water daily can decrease the risk of colon cancerby 45% and bladder cancer by 50% as well as reducing the risk of other cancers.

The water reserve beneath the land surface (groundwater) is found below the water table in soils and geologic formations that are fully saturated; the pores spaces within the rock or soil matrix are filled or saturated with water. Ground water occurrence is widespread in many environments and a very important supply for many purposes including domestic use and agriculture (irrigation). Tolman 1964, has indicated the importance of ground water as follows that, very large amount of all the water in the world is saline; ground water comprises about two-thirds of the earth's fresh water, and that; ground water comprises 90 to 95% of the usable water (excluding glaciers and ice cap). The principle water bearing strata is termed as aquifers. An aquifer is defined as a geologic formation from which water in usable quantities can be obtained from springs or borehole wells.

There are three classification systems for types of wells; the following may be used as a basis for the classification of wells (Harlan et al., 1989): Methods of construction – dug or drilled; purpose of use – water supply well, test well, observation well, monitoring well, special purpose well, injection well, or disposal well; formation in which the well is completed – bedrock (consolidated), or unconsolidated (alluvial/poorly unconsolidated) well.

Groundwater, which is in aquifers below the surface of the Earth, is one of the Nation's most important natural resources. Groundwater is the source of about 37 percent of the water that county and city water departments supply to households and businesses (public supply). It provides drinking water for more than 90 percent of the rural population who do not get their water delivered to them from a county/city water department or private water company.

In this study, we are only focusing on the drilled wells for purposes of water supply.

2.2 PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS

In chemical analysis, substances that make water un-palatable at concentrations higher than the existing standards for proper health or that affect the look, smell and taste and that are of health concern, are investigated. These investigations help to establish health-based summary statements and guideline values. These summary statements and guideline values for each substance, upon adoption by water authorities, aid in the provision and usage of water which is satisfactory aesthetically and has uniform quality (WHO, 2007).

Bacteriological analysis investigates microbiologically, both quantitatively and qualitatively, microbial contaminants in the water. The importance of bacteriological analysis of drinking water helps to determine the presence of potential water-borne pathogens. It suffices here to say the bacteriological analysis of water provides the most sensitive quality parameter.

2.3 WATER QUALITY INDICATOR

Water quality is described by the concentration of different chemicals contained in it. Assessing water quality generally involves comparing measured chemicals concentrations with natural, background, or baseline concentrations and with guidelines established to protect human health or ecological communities (RAMP, 2005; 2008).

2.3.1 pH

pH (pondus Hydrogenium), is the degree of the basicity or acidity of a water solution or simply as the measure of hydrogen ion concentration of a water solution $[H]^{+}$. pH has no unit of measurement, since it is a dimensionless quantity, by virtue of its logarithmic nature. It is a parameter that determines the quality of all water, which also affects most physical, biological and chemical processes in water supply treatment (WHO, 2007). Water in its pure state, for example has a pH of 7 (neutral); the exact value depends on temperature. For most natural waters, the pH ranges from 6 to 8.5, values below 7 (acidic water) in waters that are high in organic content and values above 7 (alkaline waters) in eutrophic waters, ground water brines and salt lakes (USEPA, 2006). However, for clean water, the pH may be due to, among other reasons, the types of rocks and vegetation within the watershed (WHO, 2007).

It is also a factor of great significance, since some methods or processes of water treatment, geared towards improving water quality can only take place when water has a certain pH, e.g, the reactions of chlorine takes place only when the pH is between a value of 6.5 and 8. Major reasons for variations of pH in water are; industrial and domestic effluent and acid rain from atmospheric depositions. Respiration and photosynthesis of algae in eutrophic waters can also cause fluctuations of pH in water (WHO, 2007). pH is a very technical parameter for the quality of water, even though it does not affect water consumption, it should be monitored at all stages of water treatment to ensure satisfactory water clarification and disinfection. Low pH values (less than 4), indicates that the water is corrosive and that it will tend to dissolve heavy metals such as lead and chromium and other substances that it interacts with. These heavy metals and other dissolved substances tend to become toxic when dissolved in water.

pH values that are greater than 8.5 (high pH), mean that the water is alkaline, and that it will tend to form scale on heating (APHA, 1994). pH adjustment in water is achieved through the use of; calcium carbonate, carbon dioxide, hydrochloric acid, lime (quicklime and hydrated lime), sodium carbonate, sodium hydroxide and sulphuric acid (APHA, 1994).

The minimum and maximum allowable range of pH for portability as issued by the WHO 2003, Safe Drinking Water Act and the European Community is 6.5 – 8.5. The Kenyan standard (KS 05–459, 1996), however, has adopted a minimum value of 4 for carbonated waters.

2.3.2 Total alkalinity

The acid neutralizing ability of a water solution, to the equivalence point of carbonate or bicarbonate is referred to as Alkalinity. The acid neutralizing capacity of a solution, alone, is not alkalinity (Wayman and Robertson, 1956). Only three types of alkalinity can be determined from water analysis namely; hydroxide (OH^-), carbonate (CO_3^-) and bicarbonate (HCO_3^-) alkalinity. These subdivisions are useful in the softening process and in the boiler water analysis. Waters that has a low level alkalinity does not have a stable pH, since they have a low buffering capacity. Volume of an acid that dissociates 100%, required to be added to lower the pH of a sample to 8.3

which gives the free alkalinity (Caustic and sodium carbonate alkalinity), and to a pH of between 8.3 and 4 gives the total alkalinity (APHA, 1994). Most of the natural alkalinity in water is due to hydrogen carbonate (HCO_3^-) as a product from its reaction with limestone or chalk. The measurement is expressed in terms of calcium carbonate ($CaCO_3$). Alkalinity in drinking waer emanates from bicarbonates, carbonates, and hydroxide ions components in treated or untreated (raw) water supplies. The major components are bicarbonates due to weak carbonic acid reacting with basic materials of soil; borates, silicates, and phosphates may be minor components. Alkalinity of raw water may also come from salts formed from organic acids, such as humic acids (Ademoriti, 1996). There are no recommended guideline values for alkalinity in drinking water. However, looking at it from a probability viewpoint; alkalinity is not a significant parameter. Concentrations that vary from 5 to 125mg/l $CaCO_3$ equivalent are expected, and the extremes of these values are tolerated in water supplies (Ademoriti, 1996).

2.3.3 Chlorides

Chlorides are soluble in water are unaffected by biological processes, hence, reducible by dilution. They are compounds of chlorine which occur as chloride ions (Cl^-) in solution. The concentrations of chloride ions depends on the composition of the geologic make up in any given area. The presence of chlorides is common in most natural waters (Ademoriti, 1996). Small quantities of chlorides of calcium and magnesium are found in many waters. This characteristics adds palatability to the water thus is desirable for consumption. Chloride concentration in natural waters is usually below 10 mg/l in areas with high humidity and in isolated fresh water bodies. Tidal streams contain increasing amounts of chlorides (as much as 19,000 mg/l) as the bay or ocean is approached.

Chloride is introduced in water through the leaching process of chlorides from sedimentary rocks (e.g. rock salt deposits) and soils (Ademoriti, 1996). Higher concentrations of chloride can be found near salt water intrusions, wet coastal areas, irrigation drains, in sewage and other waste outlets. Chlorides in large amounts (above 100mg/l) affect the taste, making it salty and unfit for humans and animals. Corrosion of metallic piping and plumbing fittings is made more severe by excessive chloride concentrations, depending on the alkalinity of the water, which contributes to the total metal ions content of water in the supply (WHO, 2004).

High level of chloride are catastrophic to individuals who are affected by heart and kidney diseases (Ademoriti, 1996). The removal of chloride in water is not done by conventional treatment. Levels of chlorides in water, however, can be lowered by the process of dechloridation which is achieved by the use of agents like activated carbon, aluminium ammonium sulphate, ion-exchange resins, sodium bi-sulphite (sodium pyrosulphate), sodium sulphite and sulphur dioxide. Pollution control and dilution can also be used to reduce chloride concentration. The actual removal of chloride, however, can be accomplished through a demineralization process, which includes reverse osmosis or electrodialysis (Ademoriti, 1996). The WHO (1963) listed 200mg/l as a guideline value for chloride as a maximum acceptable value, and 600mg/l as a maximum allowable value. On the other hand the European Community used 250mg/l as a guideline value and 200 mg/L as a level over which effects may be registered. A secondary drinking water standard for chloride was issued by the USEPA (2008), at 250 mg/l as a guideline, listed by WHO (2004) of a guideline value of 250 mg/l (Ademoriti, 1996). The 250 mg/l as the standard for chloride in drinking water has been adopted by Kenya standard (KS 05-459-1, 1996).

Domestic effluents has a higher concentration of chlorides than in natural water, and therefore acts as a suitable pollution tracer for borehole contamination. The methods used was a rapid determination by titration with $AgNO_3$ solution, using K_2CrO_4 as an indicator. The end-point was indicated by the appearance of a permanent reddish tinge (Mohr's method).

2.3.4 Electrical Conductivity

The measure of the ability of a water solution to conduct an electrical current is referred to as its electrical conductivity, which is expressed as millisiemens per centimeter (mS/cm). The total amount of solids dissolved in water (TDS) in parts per million (ppm) or mg/l, can also be estimated by the electrical conductivity. Its value has a direct relationship to the temperature of water, in that; when temperature of water is raised by 1℃, the value of electrical conductivity of water goes up by 2-3%. It also has a direct relationship to solute concentration and therefore to the total dissolved solids (TDS). Dissolved salts dissociates to anions and cations, which conduct electricity. During field work, the conductivity of water is preferred, since it is more difficult to measure the TDS. Liquid water, that is chemically pure, has a very low electrical conductance. The presence of dissociated ions in solution, however, render the solution conductive. The most important factors in determining how well a given solution will conduct an electrical current are; variations in dissolved mineral salts (dissolved solids, the number and kinds of ions present, the extent of dissociation of the dissolved minerals into ions, their relative charge of ions, temperature of the solution and mobility of the ions) (Des, 2010). Water in most freshwater bodies, has a conductivity values that range from 10 to 1000 µS/cm. higher values, greater than 1000 µS/cm, can be observed in waters which are loaded with huge volumes of surface run-off or those that are polluted (Des, 2010).

Electrical conductivity arises from dissolved mineral matter in water. Free carbon dioxide and ammonia also impart conductivity in water, though their effects is negligible, except in waters of very low salinity. Because water conductivity has a direct relationship with TDS and temperature; water with very high conductivity may possess repugnant tastes and thus less attractive to consumers. No known method has been proposed for the management of the levels of conductivity in water, and no guideline values has been proposed for conductivity in drinking waters.

2.3.5 Nitrates and Nitrites

Natural unpolluted water, practically, does not contain Nitrites. Nitrites are the first product of oxidation of free ammonia by biochemical activity. The nitrite concentration present is due to the organic matter in the soils. Concentrations that are higher than the very low value of 0.001 mg/l are of sanitary significance (Kaplan, 1987). Nitrates represents the mineralization of nitrogen from organic matter and can also occur in a well oxygenated environment. In excessive levels nitrate may cause serious illness and occasionally, death in infants (Kaplan, 1987).

Nitrates generally occur in trace amounts in freshwater bodies on land, however, the concentration could be much higher in some ground water (APHA, 1994). Nitrates are reduced to NH_3 by Devarda's alloy (containing 50% Cu, 45% Al, 5% Zn) in strongly alkaline solutions; the NH_3 is distilled into excess standard acid and finally estimated titrimetrically.

Nitrites are an intermediate product, both in the oxidation of NH_3 to NO_2 and in the reduction of NH_3 which occurs in natural waters, water distribution systems and waste-water treatment plants. A method based on the diazotization reaction was used and a reddish-purple azo-dye color was formed at pH 2.0 – 2.5 by the bonding of diazotized-sulphanilamide with N-(1 – naphtyl)ethylenediamine dihydrochloride.

2.3.6 Ammonia

Ammonia is generally present in surface water, ground water and domestic sewage (APHA, 1994). It is produced largely by the hydrolysis of urea and deamination of organic nitrogen-containing compounds (Des, 2010). Water samples are analyzed using the Nester's method (Kazi et al., 2009). A method based on the reaction of HgI_4^{2-} (tetraiodomercury (II) anion) and NH_3 in alkaline solution.

2.3.7 Sulphate

Sulphate occurs in natural waters from a few to several thousand milligrams per litre in natural water and waste waters. Excess Na_2SO_4 should be absent in drinking water as they cause cathartic action (APHA, 1994).

2.3.8 Phosphate

Phosphate occurs in waste waters and natural waters as inorganic and organically bound phosphate since they are mainly used for laundry purposes. Primarily, they are naturally produced in biochemical processes and are also constituents of domestic sewage (APHA, 1994). The phosphate concentration in water, comprises; ortho-phosphates and condensed phosphates, both soluble and insoluble organic species. A digestion method is necessary to oxidise organic-bound phosphate by rupturing both the condensed-phosphate and condensed-ortho-phosphate bonds and releasing phosphate as soluble PO_{34}.HNO_3 - H_2SO_4, digestion shall be used for these samples. In dilute ortho-phosphate solution, ammonium molybdate reacts in acidic medium to form molybdophosphoric acid which is measured at 460 nm (APHA, 1994).

2.3.9 Phenols

Phenol analysis is important because of the objectionable taste from chlorinated phenols even at very low concentrations. It can also be an indication of contamination of boreghole water. It is common at high concentration in waste waters. In this methods, phenols and other phenolic compounds are first sepoarated from the sample by distillation (APHA, 1994). Reaction of phenol and 4-aminoantipyrine at pH 10 using $K_3Fe(CN)_6$ as a catalyst, develops a red coloured species which is extractible into $CHCl_3$. The absorbance is measured at 460 nm.

2.3.10 Sodium

Sodium salts are highly soluble and naturally occur in ground water from sodium bearing rock minerals. At levels of above 200 mg/l litre, sodium salt can be tasted by most people (Alhajjar et al., 1990).

2.3.11 Chemical oxygen demand (COD)

This parameter gives a measure of oxygen equivalent to the organic matter content of the water that can be oxidized by a strong chemical oxidant and thus is an index of organic pollution (APHA, 1994).

2.3.12 Color and Odour

These two parameter are physical characteristics in drinking water affect the smell and appearance are of more importance to esthetics than for health of the consumer (Alhajjar et al., 1990). Colour in water may be as a result of algae or decaying leaves. They may also be due to the effect of organic matter or gases in solution. For example, borehole water could have a pungent smell caused by hydrogen sulphide gas. Chemical impurities associated with the aesthetic quality of drinking water include iron, magnesium, copper, zinc etc.

Metal ions in solution cause a metallic taste and would likely stain laundry and plumbing fixtures (Sosbey, 2002). Excessive chlorides give the water an objectionable salty taste. Pure water is colourless. Presence of colour in water is due to minerals and organic matter from the environment. Colour is classified as either apparent colour (colour contributed by suspended matter in water) or true colour (after filtration). True colour is the most difficult to remove by conventional treatment methods. Colour is a physical parameter that is not necessarily related to toxicity or pathogenic contamination of water. Nevertheless the colour affects its preference for industrial and domestic use. It causes psychological rejection and fear to consumers (Sosbey, 2002). The Kenya Standards (KS) and WHO guidelines specify 15 Total Colur Units (TCU) as the acceptable level of colour in water (Sosbey, 2002). The WHO guidelines are based on acceptance of the fact that at 15 TCU no colour is detected visually.

Water with a bad taste and odour is not attractive to consumers as the consumers normally associate the water with contamination. Tastes and odours can also be cue to algae growth which secretes a substance that is oily and that may result to taste and odour, phenols and chlorophenols, or salts and metals from the soil. Some odours are indicative of increased biological activity in water. Water that is alkaline, tastes bitter. If it has a taste but not accompanied by smell, the cause is usually inorganic contamination. When it has both, then it could be due to organic materials. Gases and liquids from decaying matter can cause odour and taste in water (Sosbey, 2002). When some specific substances combine, for example, organics and chorine, they have an effect on taste and odour (WHO, 2003a). Taste and odour can be neutralized by oxidizing substances responsible for causing the problem. For this, oxidants like chlorine and potassium permanganate can be used or using activated carbon prior to filtration to remove odour and taste and later regenerated to maintain its effectiveness (WHO, 2003a). The KS and WHO guidelines specify that the physical properties of drinking water be acceptable by consumers.

2.3.13 Turbidity

Turbidity is defined as the dispersion and interference of light passage that is caused by the organic matter like silt, clay and other finely divided organic or inorganic particles suspended in water (WHO, 2007). The surface characteristics and size of the suspended matter has an influence on the scattering and absorption of light. It is caused by colloids in suspension, which are mainly clay particles, microorganisms and vegetation. Colloidal matter harbors microorganisms and chemicals that affect the quality of water and hinder disinfection during treatment (Sosbey, 2002). The degree of turbidity of water is often taken to an approximate measure of the extent of pollution. However, it is not the only measure when determining presence or absence of pollution. This is because water may be clear but is contaminated by acids, toxic metals or other substances that do not cause turbidity. Following rainfall, variation in colour of water may indicate contamination due to surface runoff and may lead to the need of treatment prior to use especially for public supplies (Sosbey, 2002). The KS and WHO guidelines value for turbidity is 5 NTU and above this value, water can be objected for aesthetic value. A value of turbidity that is higher than 5 NTU may be repulsive to consumers.

2.3.14 Coliform and Total Bacteria

A group of bacteria called coliform are a microbiological measure that is most important in drinking water quality (WHO, 2003a). Coliform, if found present in water, act as a sign for contamination by microbial pollutants and as measure of the biological quality, easily. The coliform count thus reflects the chance of pathogens being present; the lower the coliform count, the less likely it is that pathogens are in the water. Biological contaminants constitute water quality parameters, since their presence or absence maybe an indication of the attributes of the water source. Pathogens are of primary importance to water specialists, they include bacteria, viruses, protozoa and parasitic worms. They infest their host for a part of their life cycle and also thrive in water systems (Spellman, 2003). Autotrophic bacteria require carbon dioxide to multiply by binary fission while heterotrophic bacteria require organic compounds.

Total coliform bacteria include a wide range of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hours at 35-37°C. *Escherichia coli* is a subset of the coliform group that can ferment lactose at higher tempertures. As part of lactose fermentation, total coliforms produce the enzyme β -galactosidase. Traditionally, coliform bacteria were regarded as belonging to the genera *Escherichia*, *Citrobacter*, *Klebsiella* and *Enterobacter*, but the group is more heterogeneous and includes a wider range of genera, such as Serratia and Hafnia. The total coliform group includes both faecal and environmental species.

Photosynthetic bacteria get their energy from sunlight, whereas chemosynthetic bacteria from chemical reactions. They are very adaptive and can be found in almost any environment (Spellman, 2003). Faecal waste is the main source of bacterial contamination in water, especially through waste discharge from septic tanks and sewage treatment facilities. Bacteria from these sources can enter well that are either open at the land surface or do not have watertight casings or caps (Sililo et al., 2001).

Total coliforms are a large group of different types of bacteria that share several characteristics. They are commonly found in the environment, such as in soil, and in the intestines of animals, including humans. The main sources of total coliforms in water are contamination from human and animal waste. Total coliforms are used as an indicator of the cleanliness of a water source. Although total coliform bacteria themselves do not necessarily cause harmful illness, their presence indicates that water will likely contain other more harmful pathogens. In drinking water, total coliform testing can be used to monitor the effectiveness of the disinfection processes. Coliforms present in drinking water indicate there could be pathogens present in the water that cause serious diseases.

Total coliforms can enter the water through environmental contamination such as waste from mammals or birds, agricultural runoff, and untreated human sewage. The World Health Organisation state that total coliform bacteria must not be detectable in any 100mL sample of water. Similarly, the Drinking Water Inspectorate state total coliform bacteria should not be detectable in any 100mL sample of water takrn at consumers taps.

2.3.15 Faecal coliform

A faecal coliform is a rod-shaped, gram-negative, non-sporulating bacteria that is facultatively anaerobic. The majority of coliform bacteria are found in the intestines of warm-blooded animals. Faecal coliforms are oxidase-negative, may develop in the presence of bile salts or other comparable surface agents, and can break down lactose into acid and gas in less than 48 hours at a temperature of 44.5°C (Doyle *et al*., 2006). The phrase “thermotolerant coliform” is used over “faecal coliform” since it is more accurate (Bartram and Ballance, 2006).

Coliform bacteria comprise both genera with faecal origins (such as *Escherichia*) and genera without faecal origin (e.g., *Enterobacter, Klebsiella, Citrobacter*). The test is designed to be a faecal contamination indicator, more especially for E. *coli,* a bacterium that serves as a marker for other pathogens that may be present in faeces. Faecal coliforms in water may not always indicate the presence of faeces and may not even be physically hazardous (Doyle *et al*., 2006).

2.3.16 Escherichia coli

Escherichia coli are faecal coliforms and are a subset of the total coliform family. Escherichia coli (E. coli) is a species of thermotolerant coliform distinguished by producing indole from tryptophan, and it also possess β -galactosidase and β -glucuronidase enzymes. The distinction in the laboratory is their ability to produce the enzyme glucuronidase and their ability to grow at elevated temperature (44.5°C). under the total coliform rule, specimen that test positive for total coliform are supposed to be further tested for confirmation of faecal coliform or E. coli. E. coli and faecal coliform do not distinguish between human and animal contamination. However, they are better indicators for the presence of recent faecal contamination than total coliform. Their densities are much lower than those for total coliform, and thus are not used as an indicator for treatment effectiveness and post-treatment contamination. E. *coli* confirmation test gives better sign to show faecal pollution than test for faecal coliform group (Sililo *et al*., 2001).

Nevertheless, some findings show that E. coli can also be found, multiply and persist in the environment especially in tropical soils, climates and waters rich with organic matter (Jimenez *et al*., 1989; JMP, 2012). The majority of E. coli strains are non-pathogenic, even though some serotypes, like E. *coli* 0157:H7, can cause serious illnesses (Wilson *et al*., 2011). The use of E. coli as an indicator organism of water quality dates back to the late of 18th century. However, the procedures were not suitable for periodic detection of E. coli. Due to these surrogates for E. coli like coliforms were used to dtect faecal contamination (Edberg *et al*., 2000). Multiple tube fermentation and membrane filter methods are most commonly used techniques detect indicator organisms of faecal contamination in water. After the enzymes β -glucuronidase and β -galactosidase were identified the sensitivity of multiple tube fermentation and membrane filter techniques increased (Annie, 2002).

The detection of E. coli shows recent faecal contamination of water sources as the bacteria is sensitive to environmental factors due to this, the indicator bacteria is widely used to monitor the quality of water. The detection of E.coli in water samples does not prove that pathogenic organisms are present, instead it shows a risk of faecal contamination, and therefore the possible presence of pathogenic microorganisms of faecal origin (Brüssow *et al*., 2004). As a result the detection and enumeration E. coli is broadly used to monitor water samples for faecal contamination (Atlas *et al*., 1993).

These are important water quality parameters since they play a key role in water borne diseases (Kaplan, 1987). E. coli and faecal coliform count are performed by incubating the water samples at specified temperature and culture medium for 48hrs and the colony that shall have grown on the plate/Petri dish, counted.

2.4 VARIATIONS IN BOREHOLE WATER QUALITY

The quality of a water resource depends on the management of anthropogenic discharges as well as the natural physiochemical characteristics of the catchment area. In the analytical study of borehole water quality in both sedimentary terrain and basement by Fasunwon et al., (2010), it was discovered that the composition of the terrains has an influence on the water quality. It was observed that the pH ranged from 5.30 to 7.60. iron, nitrite, nitrate and manganese contents had maximum values of 2.70, 2.00, 7.30 and 0.10 mg/l respectively. Total alkalinity ranged from 21.00 to 275 mg/l, salinity ranged from 15.00 to 566 mg/l, chloride ranged from 5.50 to 70.00 mg/l, but sulphate was absent in all the water samples. The results obtained showed how elemental compositions vary with lithogy. Obiri-Danso et al., (2002) also carried out studies on borehole water quality and observed that higher bacterial counts were recorded during the wet (rainy) season compared to the dry (harmattan) season. Faecal coliforms count in three borehole samples ranged between 3×101 and 3.5×107 cfu/100ml. manganese and iron levels were within the WHO standards for all the nine sites, but lead (Pb) levels excepts for one site were all higher than the WHO standards for drinking water. According to the author, a brief sanitation survey at each site suggested that wells and boreholes were frequently cited near latrines, refuse tips and other social amenities, and in the vicinity of domestic or grazing animals.

2.5 QUALITY OF WATER AND HEALTH

Water plays essential roles in supporting human life. It also has, if contaminated great potential for transmitting a wide variety of diseases and illness. In the developed world, water related diseases are rare, due essentially to the presence of efficient water supply and waste water disposal systems. However, in the developing world perhaps a lot of people are without safe water supply and adequate sanitation (Tebbut, 1983). As a result, the toll of water related diseases in these areas is frightening in its extent. In the developed world, there is a concern about the possible long term health hazards which may arise from the presence of trace concentration of impurities in drinking water, particularly attention being paid to potentially carcinogenic compounds. There are also several contaminants which may be naturally occurring or man-made, having known effects on the health of consumers. It is therefore important that the relationship between water quality and health be fully appreciated by the engineers and scientists, concerned with water quality control (Tebbut, 1983). The significance of water route in spread of diseases varies both with the diseases and the local circumstance (Adesiyn et al., 1983). Wolf (2001) added that harmful chemicals such as pesticides from agriculture and heavy metals like Lead and Mercury from industries can build up in the food chain where they can reach toxic levels in fish and other sea animals. The effects of water pollution by chemicals include cancer, arthritis, skin irritation and eruption, heart diseases, central nervous system problems, skin rashes, kidney problems and bronchitis (Ukpong and Okon, 2013). The principal microbial water borne diseases are typhoid and paratyphoid fevers (salmonellosis), cholera, bacillary dysentery (shigellosis), infectious hepatitis, dracontiasis and schistosomiasis (Udoessien, 2003). Others are food poisoning, amoebic dysentery, giardiasis, gastro enteritis, hepatitis A and poliomyelitis.

2.6 WATER QUALITY STANDARDS

The incidents of water borne disease and epidermis nationwide arising from drinking water of doubtful quality have become of great concern. The primary purpose of the guideline for drinking water quality is the protection of public health (WHO, 2006). As described by Horsefall and Spiff (1998), water quality standard is a measure, principle or rule established by authority set to protect the water resource for uses such as drinking water supply, recreational uses and aesthetics, agriculture (irrigation and livestock watering), protection of aquatic life and industrial water supplies. In order to maintain water quality, guidelines for drinking water was set up by the World Health Organisation. A guideline value represents the levels (a concentration or number) of a constituent that ensures aesthetically pleasing water and does not result in any significant risk to the health of the consumer (WHO, 1984; 1985).

2.7 RELEVANT WATER QUALITY ASPECTS

In principle, water quality aspects can be categorized as chemical, physical and microbiological issues. Quality changes associated with chemical reactions include the loss of disinfectant residual, disinfection by-product formation, development of taste and odour, increase in pH, corrosion, build-up of iron and manganese, the occurrence of hydrogen sulphide, and leachate from internal coating (Kirmeyer et al., 1999). Microbiology problems occur in cases where microorganisms are introduced into storage facilities, grow and proliferate (Kirmeyer et al., 1999). As identified by Smith et al., (1990), microbial growth is supported by increases in water temperature, the availability of nutrients and minerals, the occurrence of corrosion products, a lack of disinfection residual and stagnation periods (low or no flow) (Grayman and Clark, 1993). The impacts of physical processes on water quality are related to the accumulation of sediments, contaminant entries and temperature effects like thermal stratification. Moreover, changes in temperature can cause chemical or microbiological problems in turn (USEPA, 2002).

The decay of the disinfection agent and the formation of by-product are the most common chemical problems that can cause microbiological processes which may result in water quality deterioration (Clark et al., 1996). Factor such as the concentration of organic material, the presence and state of biofilms, nitrification processes, conditions regarding ultraviolet radiation and temperature can affect disinfectant consumption (Hannoun et al., 2003). Regarding domestic storage tanks, wall effects are of special importance due to the bigger surface-to-volume ratio when compared with central storage reservoirs (Grayman et al., 2004). The loss of disinfectant residual is often intensified by oversized storage volumes, poor water mixing rates, inappropriate maintenance (cleaning) and structural defects (lack of sealing), which can cause contamination (Miyagi et al., 2017) (Matsinhe et al., 2014) (Schafer and Mihelcic, 2012) (Basile et al., 2008) (Mahmood et al., 2005).

The formation of disinfection by-products (DBPs) results from chemical reactions of the disinfectant with organic substance. Different kinds of by-products formed can be attributed to the type of disinfectant used. The DBP formation depends on the contact time, disinfectant residual, temperature, pH, precursor concentration and bromide ion concentration (Kirmeyer et al., 1999).

The presence of disinfectant residuals and their by-products, biological activity, emissions from materials in contact with water and external contamination may contribute to the development of taste and odour (Burlingame and Anselme, 1995). In a study by Rigal (1992), impairments of the taste of drinking water in contact with thermoplastic materials were described and attributed to the release of phthalates, aldehydes, ketones, alkanes and fatty carboxylic acids from the materials investigated.

Changes in pH are of special importance regarding corrosion control passivating layers require stable pH conditions. Otherwise, corrosion can occur and particles as well as other corrosion by-products can be released into the water. As a result, additional chemical and microbiological processes may take place and the corrosion itself can be accelerated. There is also the possibility of microbial induced corrosion by iron-oxidising and Sulphur-reducing bacteria, which often coexist and establish a biofilm on exposed metal surfaces (Little, 1990). In contrast, biofilms on storage tanks walls can represent a kind of barrier to corrosion processes (O'Conner et al., 1975; Abernathy and Camper 1998).

Especially during stagnation periods, compounds can be released from tank materials to the drinking water, depending on the chemical composition, the rate of migration and water temperature (Kirmeyer et al., 1999). If the leachates contain organic compounds, bacterial growth can be supported. Otherwise, changes in pH and ion composition can result. A study indicating the bacterial growth-promoting effect of nutrients leached from coatings on storage facilities was formed by Ellgas and Lee (1980). Van der Kooij (1993) and Schoenen and Wehse (1988) also attributed the observed bacterial growth to the released of growth-promoting substances from materials being in contact with drinking water.

Since the loss of disinfectant residual and increases in temperature are typical of domestic drinking water storage tanks, the propensity for regrowth and biofilms is increased. This is further supported by the high surface-area-to-volume ratio and by stagnation and long residence times, respectively. The water age can be higher due to oversizing of tanks and short circuit flows between the inlet and outlet. Poor mixing (including thermal stratification, swirls, zones without flow - dead zones) can exacerbate water quality problems by creating zones within the storage tanks where the water age significantly exceeds the average water age throughout facility (Grayman et al., 1999; USEPA 2002). Long residence times and higher temperatures of up to 22 ℃ are optimal for microbiological growth (Kerneis et al., 1995; Uhl et al., 2002; Uhl and Schaule 2004). An increase in heterotrophic plates counts, as a consequence of an increased temperature and the concentration of biodegradable organic matter that resulted in decrease in free chlorine residual, was shown by Ndiongue et al., (2005). The impact of nutrients available for bacterial growth and of the level of disinfectant residual on bacterial biomass and production was investigated by Prevost et al., (1998), who showed that bacterial growth was slower at low nutrient levels.

In systems where free ammonia is present, nitrification can occur. The nitrification process can cause a degradation of chloramine residuals, a consumption of dissolved oxygen, a slight decrease in pH and increases in the heterotrophic bacterial populations as well as in the concentrations of nitrite, nitrate and organic nitrogen. Sufficiently high flow rates and mixing are suitable measures to avoid stagnation and long retention times and thus nitrification.

In water distribution systems, poor mixing promotes sediment accumulation, leading to increased disinfectant demand, microbial growth, DBP formation and increased turbidity within the bulk water (USEPA, 2002). These effects are not just reductions in quality by themselves, but they can also cause further quality problems. For example, Egorov et al., (2003) assumed a relation between turbidity and gastrointestinal illness due to the consumption of non-boiled tap water. Quality problem especially arise at low concentrations of the disinfectant. Beuhler et al., (1994) reported on elevated levels of coliforms associated with accumulated sediment.

If there is a temperature difference between the water entering the tank or reservoir and the water inside, stratified layers will form (USEPA, 2002). This should be prevented by an optimized mode of reservoir operation, or techniques should be applied to promote mixing, respectively. Using hydraulic simulations that consider mixing in drinking water storage tanks (Hannoun et al., 2003) and the thermal stratification (Gualtieri et al., 2004), conclusions can be drawn on measures to minimize adverse effects on water quality. A simple method in design to prevent or minimize stagnation and poor mixing is to promote better mixing inside the tanks (USEPA, 2002).

The entry of contaminants can directly affect water quality. In cases of uncovered storage facilities or due to missing caps and closures, it will be possible for worms or insects to enter storage tanks. Microorganisms can be introduced in storage systems from windblown dust, debris and rainwater. Moreover, leakages present a potential risk of contamination from animal excrement, as reported by Geldreich (1996), who could trace back a *Salmonella* contamination to birds defiling a storage facility.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area:

The study was carried out at five borehole points, collecting two samples from each point at UGBOJOBU Community close to NIFOR (Nigerian Institute For Oil palm Research), Ovia North East Local Government Area, Benin City, Edo State, Nigeria.

3.2 Sampling stations:

Station 1: Is located at NIFOR gate, Ugbojobu community Ovia North East Local Government Area, Edo State. The water from this borehole is used for drinking, washing, bathing and other domestic activities.

Station 2:Is located by a cementary at Ugbojobu community Edo State. The water from this borehole is used for molding blocks, washing,and other domestic activities. The distance of the borehole from septic tank is 42 foot which is approximately 13 meters.

Station 3: Is located by a Jehovah witness church, Ugbojobu community, Edo State. The water from this borehole is used for drinking, washing, bathing and other domestic activities. The distance of the borehole from septic tank is 11 foot which is approximately 3 meters.

Station 4: Is located at Market place, Ugbojobu community, Edo State.The water from this borehole is used for drinking, washing, bathing and other domestic activities.

Station 5: Is located at Azua street, Ugbojobu community, Edo State. The water from this borehole is used for drinking, Farming activities, Molding of blocks, bathing and other domestic activities. The distance of the borehole from septic tank is 120 foot which is approximately 37 meters.

3.3 Sampling Procedures:

For each sampling sites, two different samples were collected, one sample for the analysis of physical and chemical characteristics while the other sample for microbiological characteristics. The water from the boreholes was allowed to flow for ten seconds before collection but for the microbiological sample bottles extra care was taken so as not to alter and introduced another microorganism into the bottle.

3.4 Laboratory Analysis

Laboratory analysis was performed immediately on the samples on arrival at the laboratory in accordance with the American Public Health Association (APHA, 2017) methods. The water samples from each sites were collected from the borehole, the pumping machine was put on in other to enable water pump from the borehole engine and allowed to flow for ten seconds before collection. Samples for physicochemical analysis were collected in 2-litre plastic containers previously washed, rinsed and dried in the laboratory. All samples were transported in a plastic bag to the laboratory for analysis. Samples were collected twice in the month of October.

3.5 Bacteriological and physicochemical analyses

The Bacteriological analyses were carried out in accordance with Bergey's Manual of Determinative Bacteriology (Buchanan et al., 1974; Gerhardt et al., 1994). The bacteriological parameters investigated includes, the estimation of the coliform organisms. The physicochemical parameters studies were pH, water temperature, turbidity, colour, salinity, total dissolved solids, dissolved solids, dissolved oxygen, biological oxygen demand, nitrate, phosphate, calcium, magnesium, potassium and anions.

3.5.1 Determination of pH

A pH-meter, with an accuracy that gave a reading within +/- 0.1 pH unit, and a glass electrode that produces a potential varying linearly with pH of solution in which it is immersed. 50ml of sample was drawn into a 50ml beaker and placed in a water bath at 25℃. The instrument was calibrated with two standard buffer solutions of pH 10 and 4.0 before measurement. The stable reading displayed was recorded.

3.5.2 Turbidity (NTU)

This was determined using the HACH colorimeter DR 920-model by absorptometric method in the laboratory. The instrument is turned on and it is calibrated using distilled water, a cell sample is filled with 10ml of sample and placed in the cell holder and concentration displayed digitally.

3.5.3 Determination of Colour

The color of water is an important indicator of water quality that can be measured by several methods. The primary source of color in water bodies is dissolved organic matter from decaying natural vegetation, plant, animal, and microbial material. This dissolved organic matter causes water to appear colored by absorbing and reflecting certain wavelengths of visible light. Just as colored solutions appear to have a distinct hue due to the specific wavelengths they absorb, water rich in dissolved organic substances reflects some visible wavelengths more than others, resulting in an observable coloration.

The reference method involves visually comparing a water sample to a scale of standard color solutions. This allows the water's color to be quantified in Hazen color units on the platinum-cobalt scale. Other common methods include spectrophotometry, which measures light absorption at specific wavelengths, providing more consistency than visual assessments. No matter the technique, the underlying principle is that color indicates substances dissolved in the water. A change in water color over time or between locations flags a change in organic material concentrations, mineral content, pollution levels, or other factors. Careful color analysis combined with other tests can diagnose issues with water composition and treatment needs.

3.5.4 Determination of Salinity

Salinity, the measure of dissolved salts in water, indicates important properties of aqueous environments. It is vital to measure for ecology studies and water quality monitoring. The most universal unit is parts per thousand (ppt), denoting the mass ratio of salt to water. Ocean salinity ranges from 3-3.5% salt, translated to 30-35 ppt.

Instruments determine salinity based on how salt concentration alters water's electrical properties. Salinity meters pass current between electrodes, comparing the resistance to standard seawater samples. Conductivity sensors also calculate ppt by detecting minute conductivity changes. Another method, chlorinity, chemically analyzes dissolved chloride content which proportions to salinity. Each technique exploits the fact that dissociated salt ions increase water body conductivity. Therefore, measuring electrical traits proxies salinity. Rapid, precise salty meters have enabled oceanographers to map regional and global trends, while portable meters help monitor bay and estuary habitats. Understanding a water mass's salt content gives clues to its origin, mixing, and other chemical-physical descriptors imperative in ocean sciences.

3.5.5 Determination of Total Dissolved Solids (TSS)

Total dissolved solids (TDS) measure all inorganic and organic molecules dissolved in water. TDS indicates water purity and monitors filtration efficacy. Freshwater TDS ranges from 50-250 ppm, while seawater far exceeds 10,000 ppm. Accurately quantifying TDS as parts per million (ppm) relies on gravimetric or evaporative techniques using analytical balances. This directly weighs leftover solids after complete water evaporation. Simpler conductivity meters estimate TDS by applying the linear relationship between dissolved ions and electrical conductivity. However, various dissolved substances conduct differently, introducing uncertainty. Still, portable TDS pens allow rapid in-field approximation. Overall, tracking TDS reveals not just the quantity of dissolved substances, but also changing contamination and treatment system performance when TDS fluctuation indicates changing dissolved loads. Comparing TDS levels to water chemistry profiles and intended water use best determines if observed levels are acceptable or concerning.

3.5.6 Determination of Dissolved Solids

Total dissolved solids (TDS) encompasses all inorganic and organic molecules dispersed in water, rather than suspended as particles. As an indicator of water purity, monitoring TDS guides water treatment efficacy and detects pollution influx. TDS is expressed as parts per million (ppm) concentration. Seawater typifies high TDS waters, with salinity imparting around 35,000 ppm. Freshwaters range from 50-250 ppm. To quantify TDS levels, gravimetric analysis is considered the most accurate laboratory approach. A known water volume is completely evaporated, precisely weighing the dried residual solid matter. This directly determines the dissolved load. More practical TDS meters estimate values by measuring electrical conductivity, which correlates to ionic content. However, the conductivity-TDS conversion varies across substances. Despite this uncertainty, portable TDS pens permit rapid in-field approximating. For strict accuracy, evaporative and conductivity techniques can be combined to profile the dissolved component makeup. Comparing readings against reference baselines indicates changing pollution and treatment requirements.

3.5.7 Determination of Nitrate

500ml of sample was taken in NH3 distillation apparatus; 50ml of 10% (w/v) NaOH was added and evaporated to about 200ml then cooled. 3g of Devarda's alloy, then 30ml 0f 10% NaOH was added and immediately connected to the flask with a vertical condenser whose outlet drips into a receiver containing 200ml of 0.2N H_2SO_4. The mixture was distilled for 1hour then the receiver was disconnected from the distillation apparatus and the volume of the distillate made up to 250ml. 10ml aliquot was drawn, accurately, using a bulb pipette, into a 50ml volumetric flask then neutralized to pH 4.5 using 0.2N H_2SO_4. 2ml of Nestler's reagent was then added and the distillate directly back titrated with standard alkali (0.2N NaOH) using Methyl red as indicator. 1ml H_2SO_4 = 0.0621g NO_3. The volume of the titre was then recorded as nitrate (NO_3, ppm).

3.5.8 Determination of Phosphates

100ml of sample in a beaker was reacted to digest in a mixture of 1ml conc. H_2SO_4 and 5ml conc. HNO_3, then evaporated to dryness. The process was repeated (digestion and evaporation). The residue was leached with 5ml of 5N HNO_3 and transferred to a 50ml volumetric flask. 5ml of 10% ammonium molybdate was added, followed by 5ml of 25% ammonium vanadate (in 6N HCl) and diluted to the mark and left to stand for 10minutes (APHA, 1994). Then the absorbance of the resulting yellow coloured liquid was measured at 460nm. A blank was taken through the same steps as the sample, and analysed. A calibration curve was prepared using a series of standard solutions of phosphate, (220g KH_2PO_4/I). 1ml = 50µg$PO^3{}_4$

3.5.9 Dissolved oxygen (DO) (mgL-1) (WINKLER'S METHOD)

In the laboratory 2ml of concentrated tetraoxosulphate (vi) acid was added to the fixed sample and was allowed to stand. The addition of concentrated tetraoxosulphate (vi) acid help to dissolve the brown precipitate to give a golden yellow coloration which shows that the iodine in

Winkler's solution B has been liberated in an amount equivalent to that of the dissolved oxygen originally present in the water sample. Exactly, 200ml of the golden yellow solution was measured into a conical flask and two drops of starch indicator was added, this turn the solution to dark blue. This was then titrated against sodium thiosulphate ($Na_2S_20_3$) from the burette until the solution changed from dark blue to colorless, the volume of the titrant used was then recorded this is equivalent to the concentration of the DO in mg/l (Ademoroti, 1996).

3.5.10 Biological Oxygen Demand (BOD) (mg/L)

The water samples were incubated at 20℃ for five days in an incubator in the laboratory. The sample was fixed using Winkler's A and B solution on day 5 as earlier described (Ademoroti, 1996).

BOD mg/l = Doo – DO5

Where Doo = Dissolved oxygen at day one

DO5 = Dissolved oxygen at the end of 5 days

3.5.11 Determination of *Escherichia coliform* (E. coli)

The culture medium for incubating *Escherichia coliform* was made from a mixture of 10g Peptone, 10g Lactose, 2g KH_2PO_4, 15g Agar, 4g Eosin Y and 0.065g Methylene blue in 1 litre distilled water (pH 7.1 after sterilization). 0.1ml of water sample was incubated in the culture media on a membrane at 37±1℃ for 48hours and the number of coliform colonies were counted and expressed as colony counts per 100ml of water sample.

CHAPTER FOUR

RESULTS

4.1 INTRODUCTION

The Summary of the results from the Analysis of the water samples obtained from the five different borehole location in Ogbojobu community is shown in Table 4.1.

4.2 Biological Parameters

The values of the total Coliform counts from the five boreholes ranged from a non-detectable value (0 CFU\100ml) to 1.0 CFU/100ml. While samples from boreholes 1 and 5 is observed to have cases of total Coliform count with the value of 1.0 CFU/100ml, samples from boreholes 2, 3, and 4 has 0.0 CFU values (Figure 4.1). In all the Samples from the 5 boreholes, fecal coliform count was 0 CFU\100ml.

4.3 Physicochemical Parameters

4.3.1 pH

The pH values from all the boreholes were slightly acidic, with mean values and standard deviation ranging from 5.60±0.00 to 6.63±0.058. The variations in pH as shown in Figure 4.1 shows that the minimum value of 5.60 was recorded in the samples from boreholes 1 and 5, while, the highest value of 6.70 was recorded in a sample from borehole 3, all were however either below or within the WHO permissible value (6.5 – 8.5) for drinking water. Analysis of

Variance (ANOVA) showed that samples from boreholes 3 and 4 though were significantly different ($p < 0.05$) from each other, were also significantly higher ($p < 0.05$) than those from samples from boreholes 1, 2 and 5 that were not significantly different ($p > 0.05$) (Table 4.1).

Table 4. 1**: Summary of the Physico - Chemical Parameters of Borehole water samples**

PARAMETERS	UNIT	SAMPLE1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	*p*-Value	WHO
		Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)	Mean±SD (Min-Max)		
Ph	-	5.67±0.058^{c} (5.6-5.7)	5.93±0.058^{c} (5.9-6.0)	6.63±0.058^{a} (6.6-6.7)	6.10±0.265^{b} (5.8-6.3)	5.60±0.0^{c} (5.7-5.6)	P<0.05	6.5-8.5
Colour	Pt.Co	0.67±0.577^{b} (0.0-1.0)	1.0±1.0^{b} (0-2)	0.0±0.0^{b} (0.0-0.0)	0.0±0.0^{b} (0.0-0.0)	5.0±1.0^{a} (4.0-6.0)	P<0.05	15
Conductivity	µS/cm	18.67±2.31^{bc} (16.0-20.0)	18.67±1.155^{bc} (18.0-20.0)	58.67±2.309^{a} (56.0-60.0)	14.0±0.0^{c} (14.0-14.0)	21.33±2.309^{b} (20.0-24.0)	P<0.05	1000
TDS	*mg/l*	9.33±1.155^{bc} (8.0-10.0)	9.33±0.577^{bc} (9.0-10.0)	29.33±1.155^{a} (28.0-30.0)	7.0±0.0^{c} (7.0-7.0)	10.67±1.155^{b} (10.0-12.0)	P<0.05	500
Turbidity	NTU	0.0±0.0^{b} (0.0-0.0)	0.0±0.0^{b} (0.0-0.0)	0.0±0.0^{b} (0.0-0.0)	0.0±0.0^{b} (0.0-0.0)	1.67±0.577^{a} (1.0-2.0)	P<0.05	10
Suspended solid	*mg/l*	0.33±0.577 (0.0-1.0)	0.33±0.577 (0.0-1.0)	0.33±0.577 (0.0-1.0)	0.33±0.577 (0.0-1.0)	1.33±0.577 (1.0-2.0)	P>0.05	5
Hardness	*mg/l*	11.33±2.309^{c} (10.0-14.0)	16±0.0^{b} (16.0-16.0)	42.0±0.0^{a} (42.0-42.0)	12.67±2.309^{bc} (10.0-14.0)	14.0±0.0^{bc} (14.0-14.0)	P<0.05	500
Alkalinity	*mg/l*	4.0±0.0^{c} (4.0-4.0)	14.67±1.155^{b} (14.0-16.0)	31.33±1.155^{a} (30.0-32.0)	5.33±1.155^{c} (4.0-6.0)	4.67±1.155^{c} (4.0-6.0)	P<0.05	200
Chloride	*mg/l*	11.77±4.076^{ab} (7.06-14.12)	14.12±0.0^{a} (14.12-14.12)	7.06±0.0^{b} (7.06-7.06)	16.46±4.053^{a} (14.12-21.14)	14.12±0.0^{a} (14.12-14.12)	P<0.05	200
Phosphate	*mg/l*	0.14±0.003^{c} (0.133-0.138)	0.15±0.003^{b} (0.145-0.15)	0.20±0.003^{a} (0.193-0.199)	0.11±0.004^{d} (0.110-0.118)	0.14±0.001^{c} (0.135-0.137)	P<0.05	0.05
Nitrate	*mg/l*	0.10±0.003^{b} (0.094-0.099)	0.06±0.002^{c} (0.061-0.065)	0.04±0.002^{d} (0.041-0.045)	0.04±0.001^{d} (0.040-0.041)	0.25±0.002^{a} (0.251-0.255)	P<0.05	200
Calcium	*mg/l*	2.94±0.924^{b} (2.41-4.01)	4.01±0.0^{b} (4.01-4.01)	9.62±0.0^{a} (9.62-9.62)	4.01±1.386^{b} (2.41-4.81)	4.81±0.0^{b} (4.81-4.81)	P<0.05	200
Magnesium	*mg/l*	1.62±1.126^{b} (0.97-2.92)	0.49±0.0^{b} (0.49-0.49)	4.38±0.0^{a} (4.38-4.38)	0.65±0.277^{b} (0.49-0.97)	0.49±0.0^{b} (0.49-0.49)	P<0.05	150
Iron	*mg/l*	0.12±0.004^{d} (0.111-0.118)	0.10±0.002^{e} (0.093-0.097)	0.22±0.006^{a} (0.211-0.221)	0.13±0.002^{c} (0.124-0.128)	0.175±0.002^{b} (0.173-0.177)	P<0.05	0.1
Zinc	*mg/l*	0.14±0.003^{c} (0.14-0.146)	0.19±0.005^{b} (0.185-0.195)	0.36±0.009^{a} (0.35-0.367)	0.154±0.004^{c} (0.150-0.158)	0.18±0.003^{b} (0.180-0.186)	P<0.05	0.01
Lead	*mg/l*	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	P>0.05	5
Manganese	*mg/l*	0.07±0.005^{a} (0.065-0.075)	0.03±0.002^{d} (0.025-0.029)	0.04±0.001^{b} (0.043-0.045)	0.04±0.001^{c} (0.035-0.037)	0.03±0.002^{cd} (0.031-0.035)	P<0.05	0.05

Copper	*mg/l*	0.10±0.003[b] (0.094-0.099)	0.05±0.003[d] (0.049-0.055)	0.12±0.002[a] (0.115-0.119)	0.07±0.003[c] (0.066-0.071)	0.07±0.004[c] (0.072-0.079)	P<0.05	1
Cadmium	*mg/l*	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	P>0.05	0.003
Total Coliform	*Cfu/ 100 ml*	0.67±0.577 (0.0-1.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.33±0.577 (0.0-1.0)	P>0.05	0
E. Coli	*Cfu/ 100 ml*	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	0.0±0.0 (0.0-0.0)	P>0.05	0

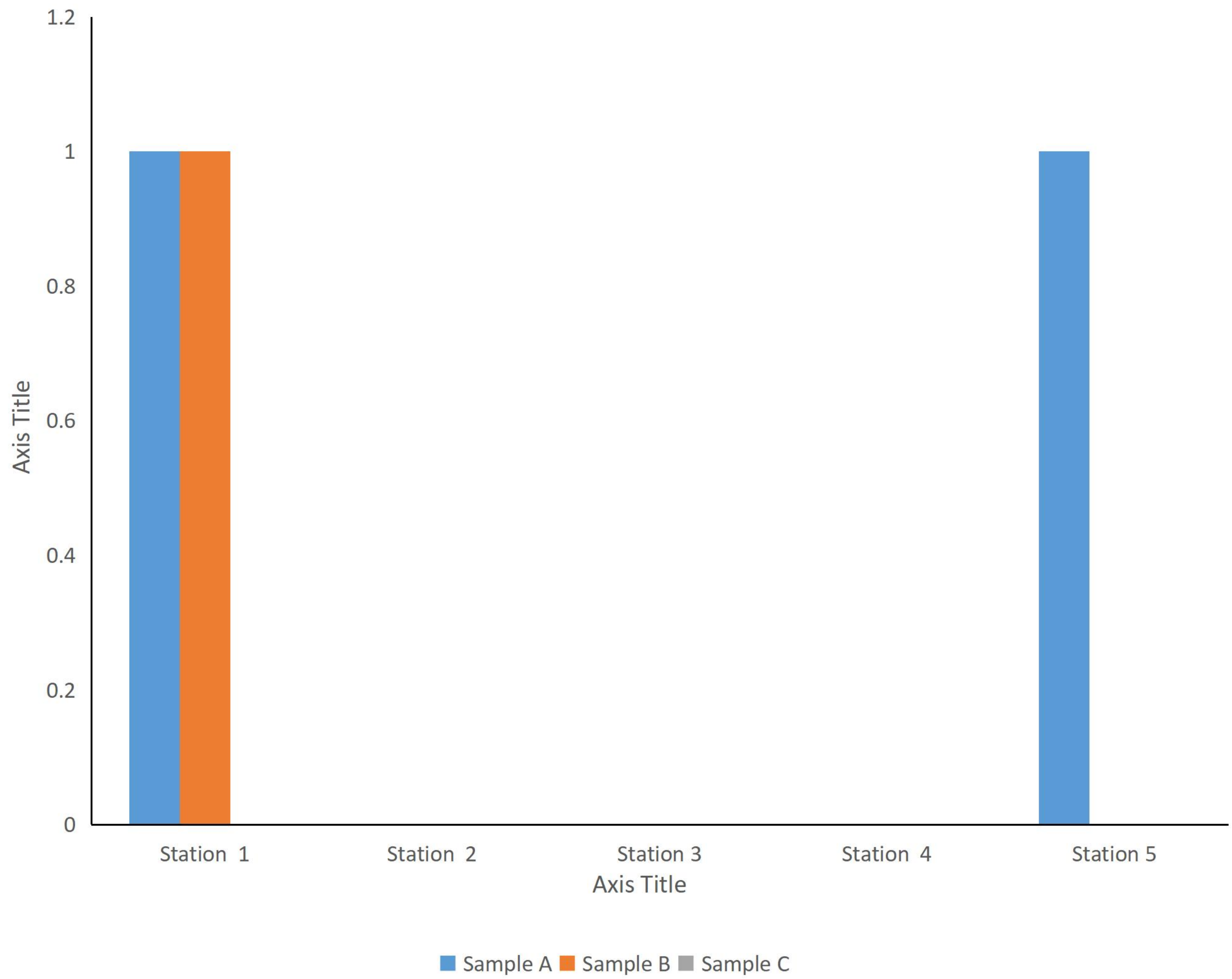

Figure 4.1**: Spatial variation of** Total Coliform in the borehole water samples.

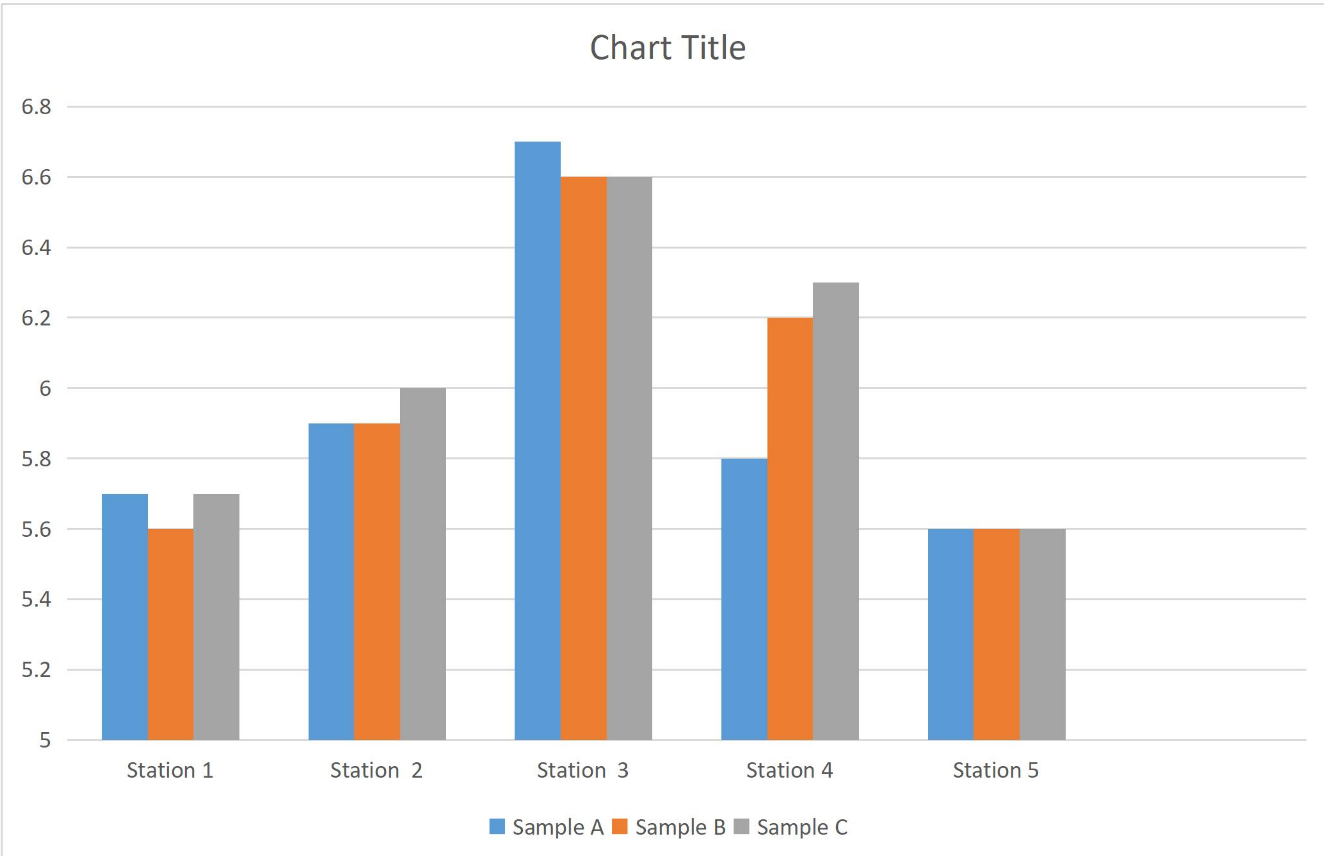

Figure 4. 2: Spatial variation of **pH of Borehole water samples**

4.3.2 Color

The value for Color was highest in both station 2 and 5 with the value of 0-2 and 4.0-6.0 respectively. While the lowest is seen in station 3 with the value 0.0 and station 4 with thw value 0.0 across the five sampling stations.

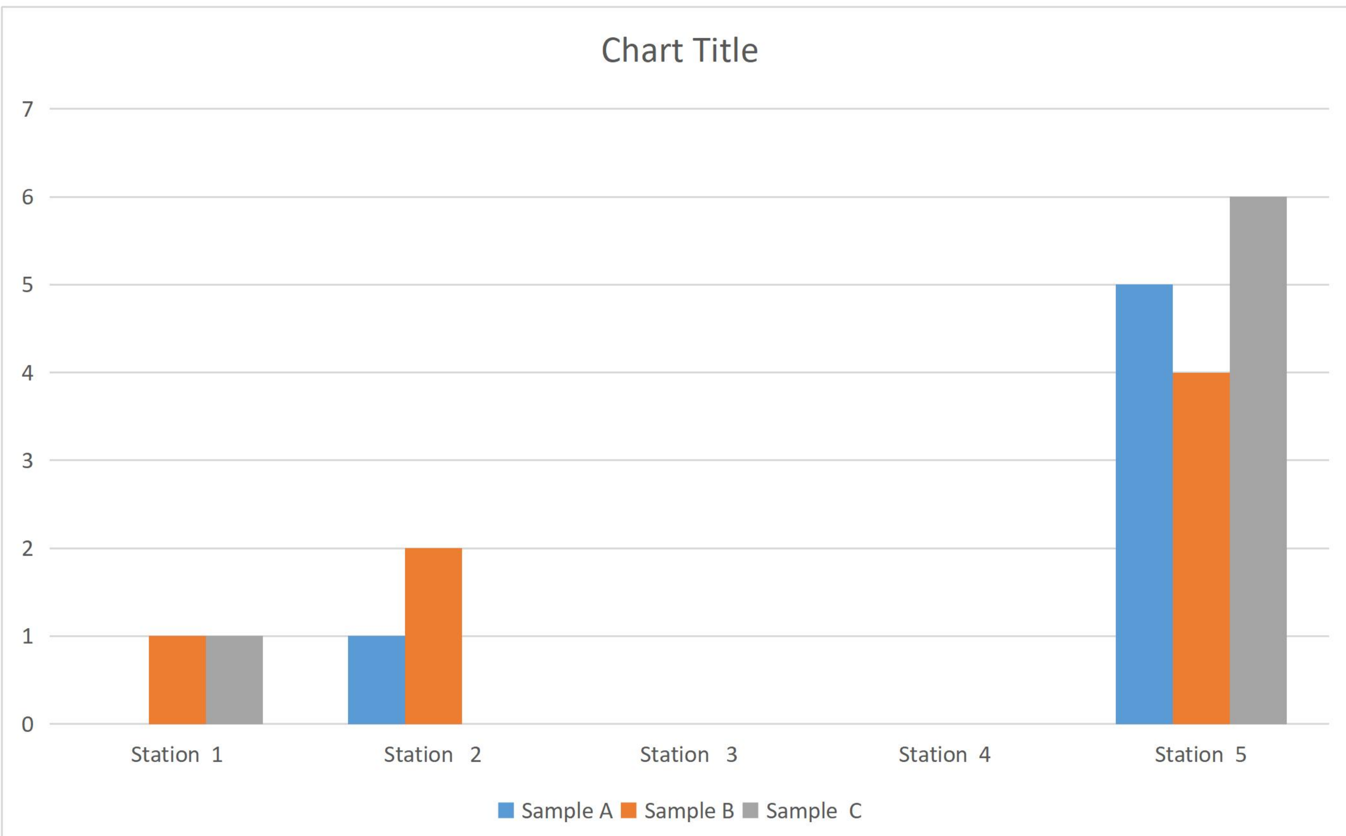

Figure 4.3**:** Spatial variation of Color of Borehole water samples on a Bar chat.

4.3.3 Conductivity

The electrical conductivity of the values of the samples ranges from 14.0-60.0mg/l. Sample station 4 is seen to have the lowest value of 14.0-14.0 and station 3 is the highest with the value of 56.0-60.0.

4.3.4 **Total Dissolved Solid**

The total dissolved solids values ranged from8.0mg/l to 30.0mg/l across the five stations. Station 3 had the highest value of 28.0-30.0mg/l while station 4 had the lowest value of 7.0-7.0.

4.3.5 Turbidity

The Turbidity of the water at all stations were below the recommended range of 10.00mg/l by Federal Ministry of Environment (FMEnv, 2007). The water samples were not Turbid as observed from the values which ranged from 0.00mg/l to 168mg/l across the five stations. Station 1, 2, 3 and 4 had the lowest value for Turbidity across the five sampling site while station 5 showed the highest value of 1.0-2.0.

4.3.6 Suspended Solids

The Suspended Solids values ranged from a non detectable value (0mg/l) to 2.0mg/l across the five sampling stations. Station 5 had the highest value of 1.0-2.0 across the five sampling stations. The values did not exceed the WHO permissible limits.

Bar Graph of ELECTRICAL CONDUCTIVITY (EC)

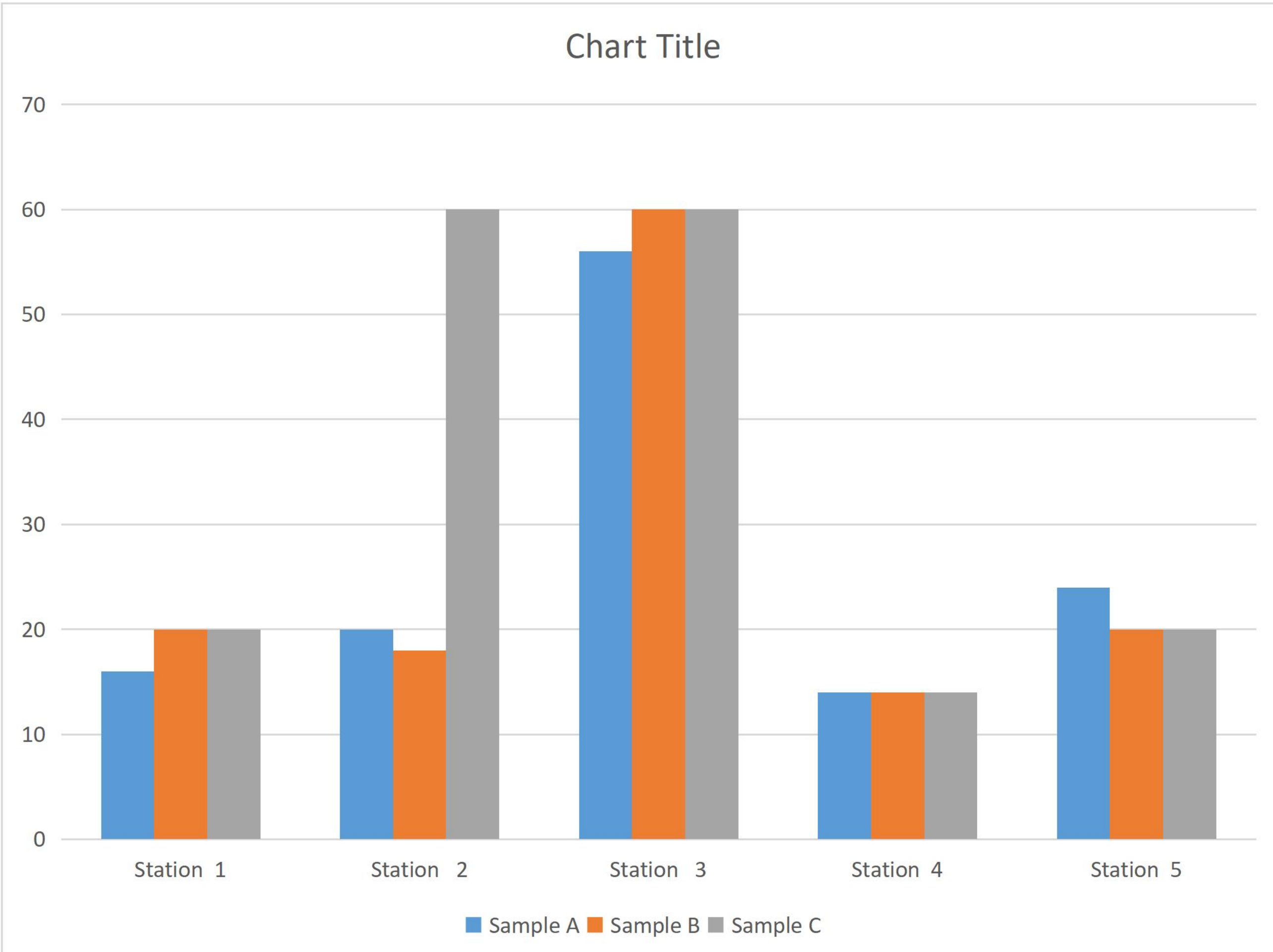

Figure 4.4 **:** Spatial variation of Electrical Conductivity of Borehole water samples.

Bar Graph of TOTAL DISSOLVED SOLID

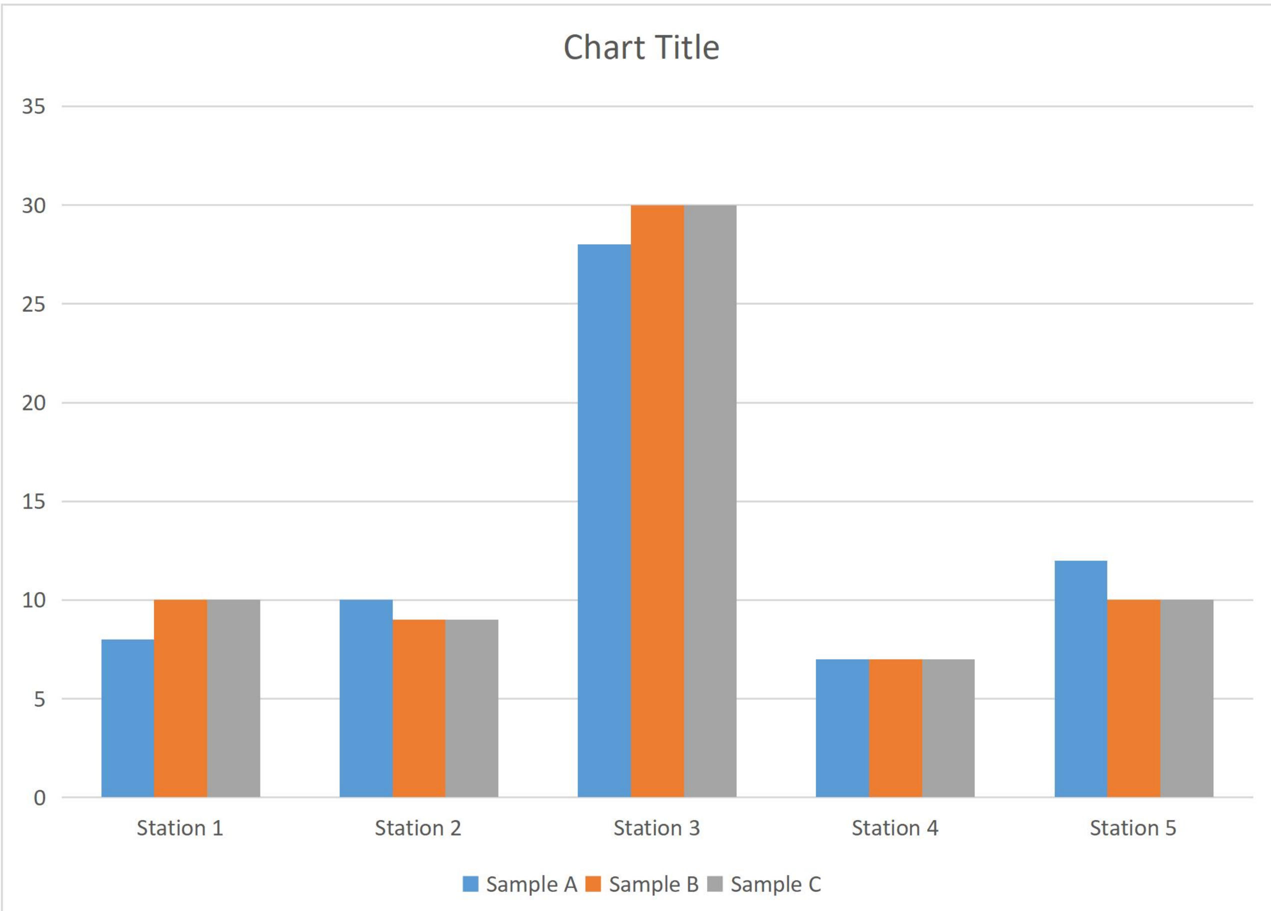

Figure 4.5**:** A Spatial variation of Total Dissolved Solid of Borehole water samples.

Bar Graph of TURBIDITY

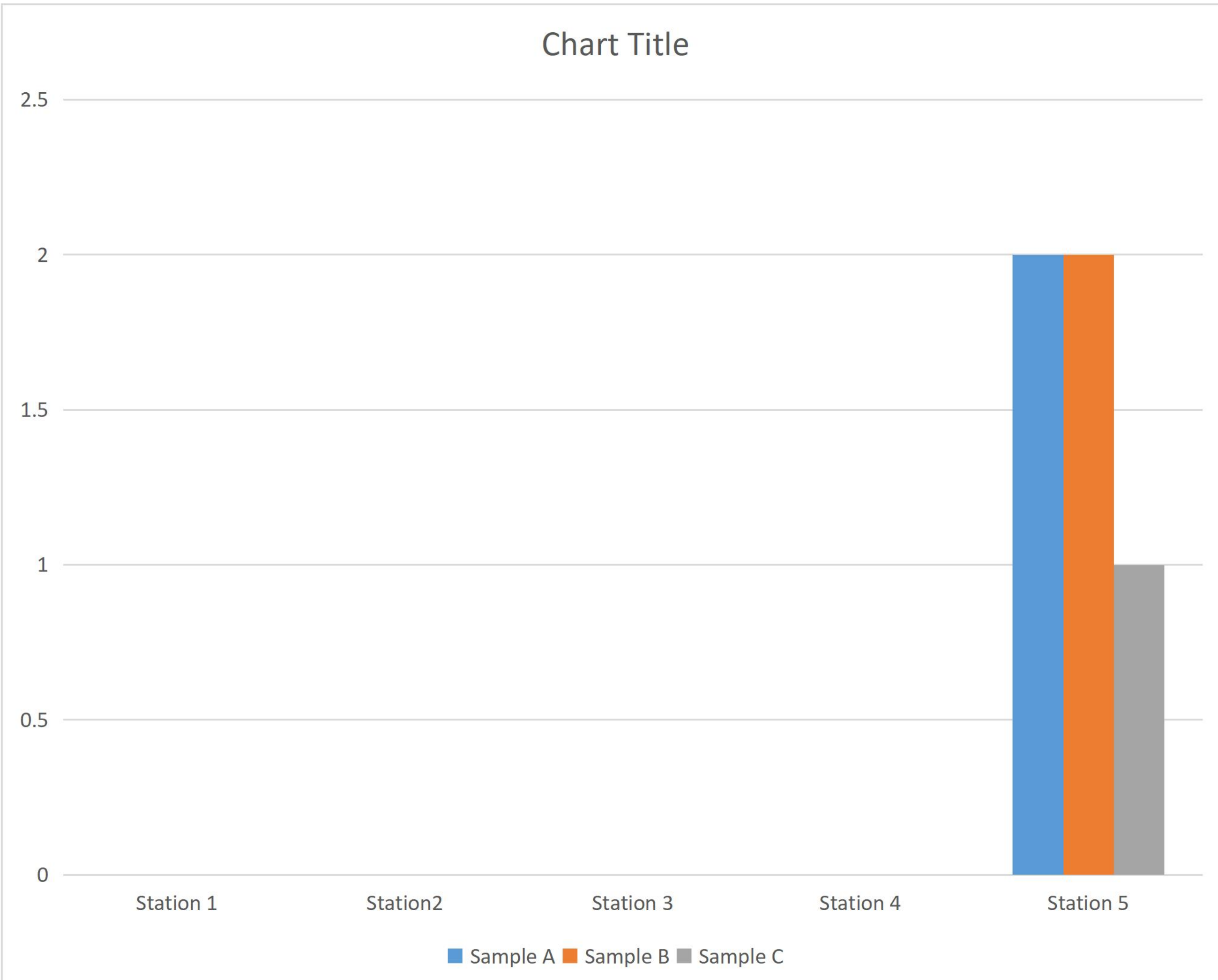

Figure 4.6**:** A Spatial variation of Turbidity of Borehole water samples.

Bar Graph of SUSPENDED SOLID

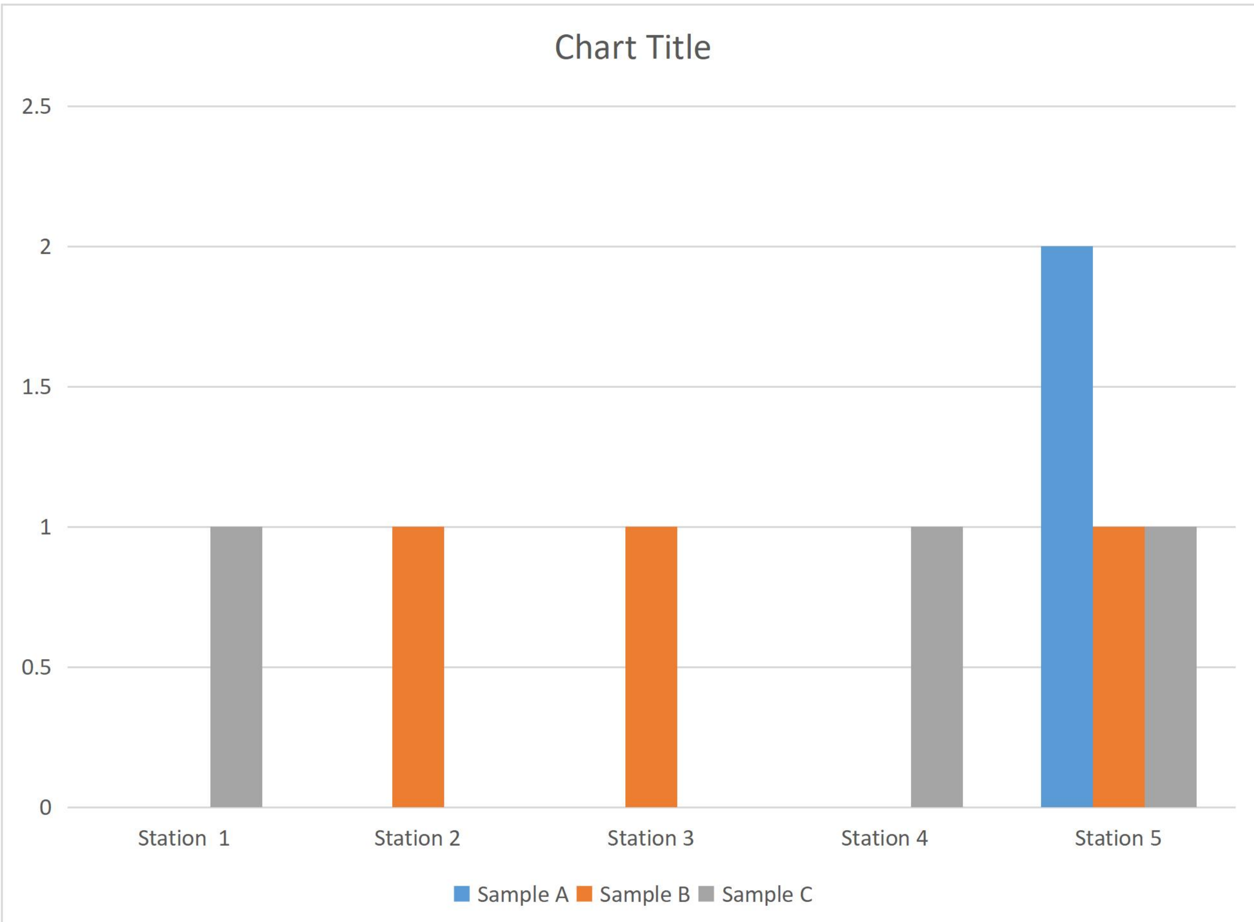

Figure 4.7**:** A Spatial variation of Suspended Solid of Borehole water samples.

4.3.7 Hardness

The Hardness of the water ranged from 10.0-42.0mg/l across the five stations. Across the five sampling stations, the values were lowest in station 1 and 4 with the value of 10.0-14.0 and 10.0-14.0 respectively and highest in station 3 with the value of 42.0-42.0.

4.3.8 Alkalinity

The Alkalinity of the water samples was within the value range of 4.0 to 32.0 across the five stations. The values did not exceed the WHO limit. Across the five sampling stations, station 1 is seen to have the lowest value of 4.0-4.0mg/l while station 3 the highest value of 30.0-32.0mg/l.

4.3.9 Chloride

The chloride value of sample ranges from 7.06-21.4mg/l. Station 3 is seen to have the lowest with the value of 7.06-7.06mg/l and station 4 is the highest with the value of 14.12-21.14mg/l.

4.3.10 Phosphate

The phosphate value ranged between 0.11mg/l to 0.199mg/ across the five stations. Across the five sampling stations, the values were highest in station 3 with the value of 0.193-0.199 and 0.199 and lowest in station 4 with the value 0.110-0.118mg/l.

Bar Graph of HARDNESS

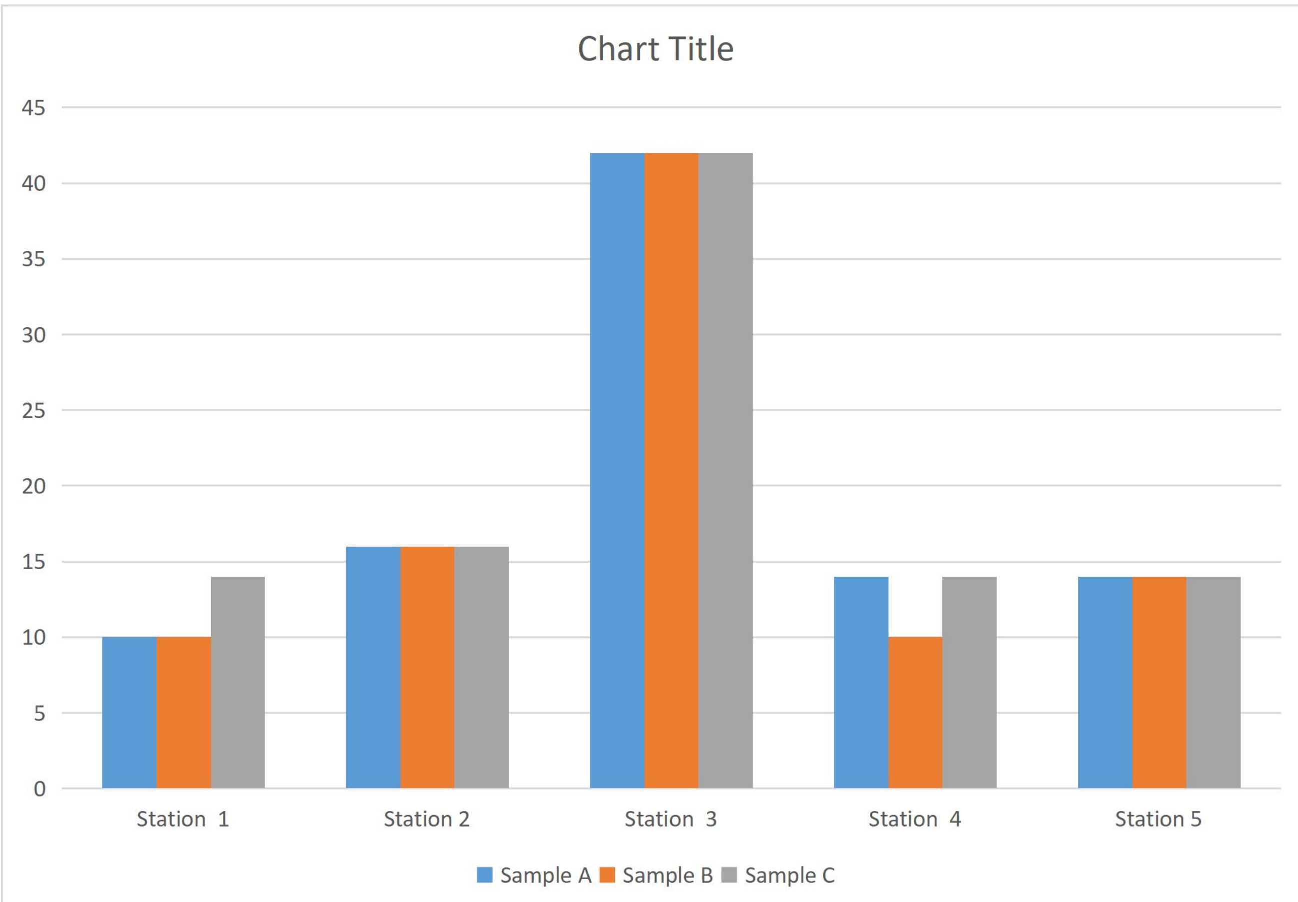

Figure 4.8**:** A Spatial variation of Hardness of Borehole water samples.

Bar Graph of ALKALINITY

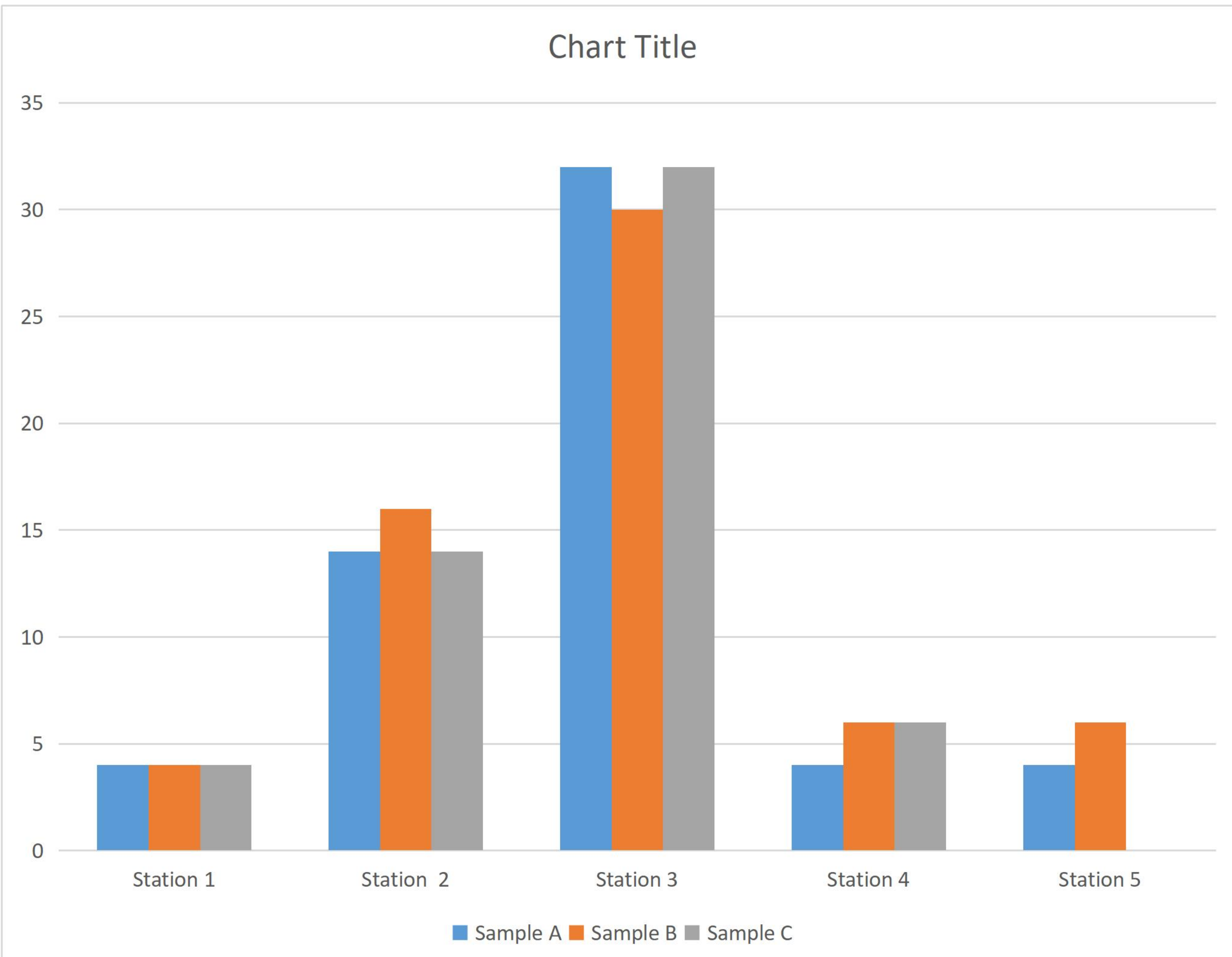

Figure 4.9**:** A Spatial variation of Alkalinity of Borehole water samples

Bar Graph of CHLORIDE

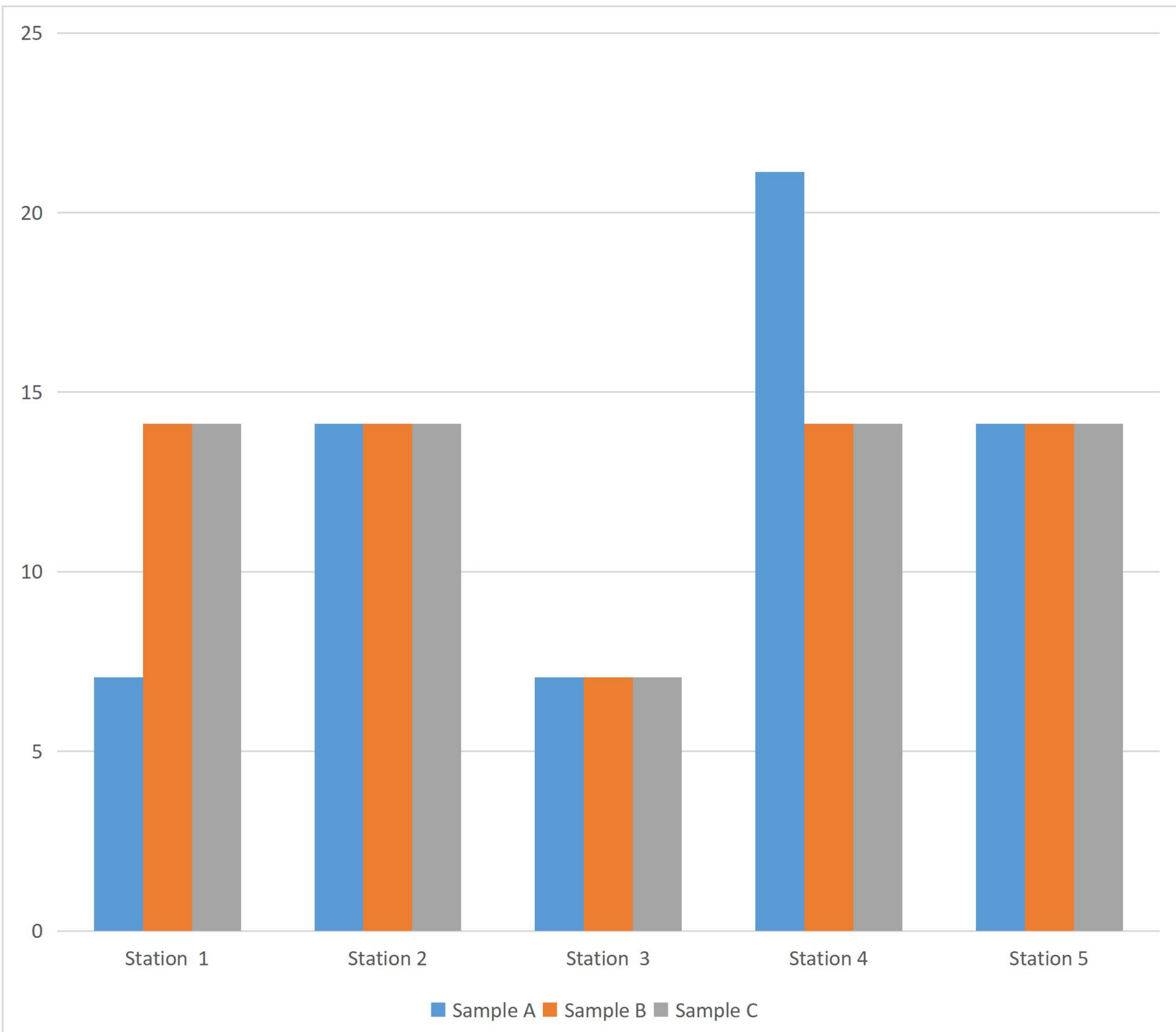

Figure 4.10**:** A Spatial variation of Chloride of Borehole water samples.

Bar Graph of PHOSPHATE

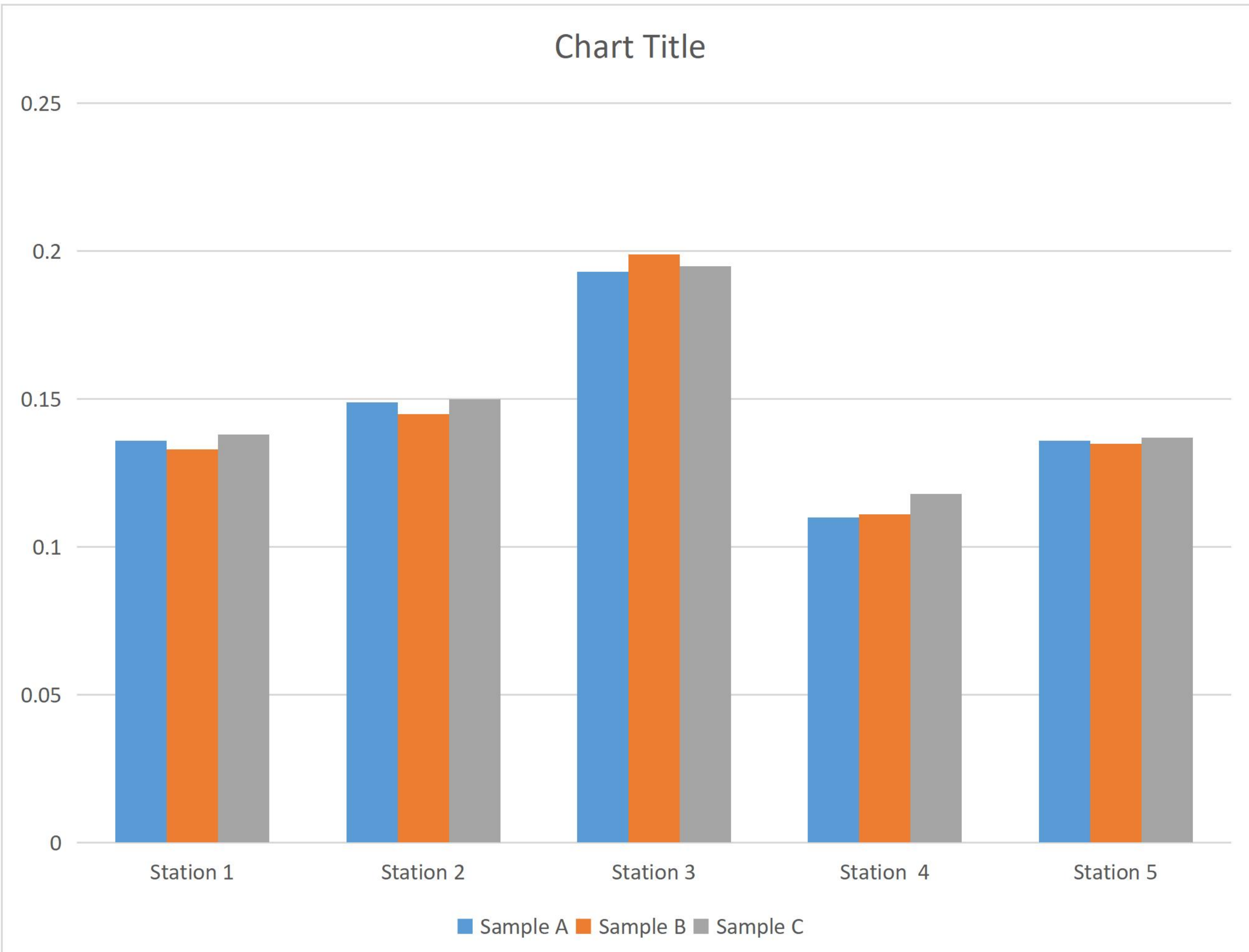

Figure 4.11: A Spatial variation of Phosphate of Borehole water samples.

4.3.11 Nitrate

The Nitrate value from the five stations ranged between 0.040mg/l to0.251mg/l. The values were highest in station 5 with the value 0.251-0.255 and lowest in station 4 with the value of 0.040-0.041.

4.3.12 Calcium

The calcium had values that ranged from 2.41mg/ to 9.62mg/l across the five stations. Station 3,5 and 2 had the highest value of 9.62-9.62, 4.81-4.81 and 4.01mg/l respectively while station 1 had the lowest value of 2.41-4.01mg/l.

4.3.13 Magnesium

The Magnesium values ranged from 0.49mg/l to 4.38mg/l across the five stations. Comparing the values of all the five stations station 2 to have the lowest values of 0.49-0.49mg/l while station 3 have the highest with the value 4.38-4.38.

4.3.14 Copper

The values for copper from the five stations ranged from 0.049mg/ to 0.1115mg/l. Comparing the values across the five sampling stations shows that station 3 had the highest value of 0.115-0.119mg/l while station 2had the lowest value of 0.049-0.055mg/l.

4.3.15 Zinc

The values for zinc from the five stations ranged from 0.14mg/1 to 0.195m/l. Comparing the values across the five sampling stations showed that station 1 had the lowest value of 0.14mg/l-0.146mg/l while station 2 had the highest value of 0.185-0.195mg/l.

Bar Graph of NITRATE

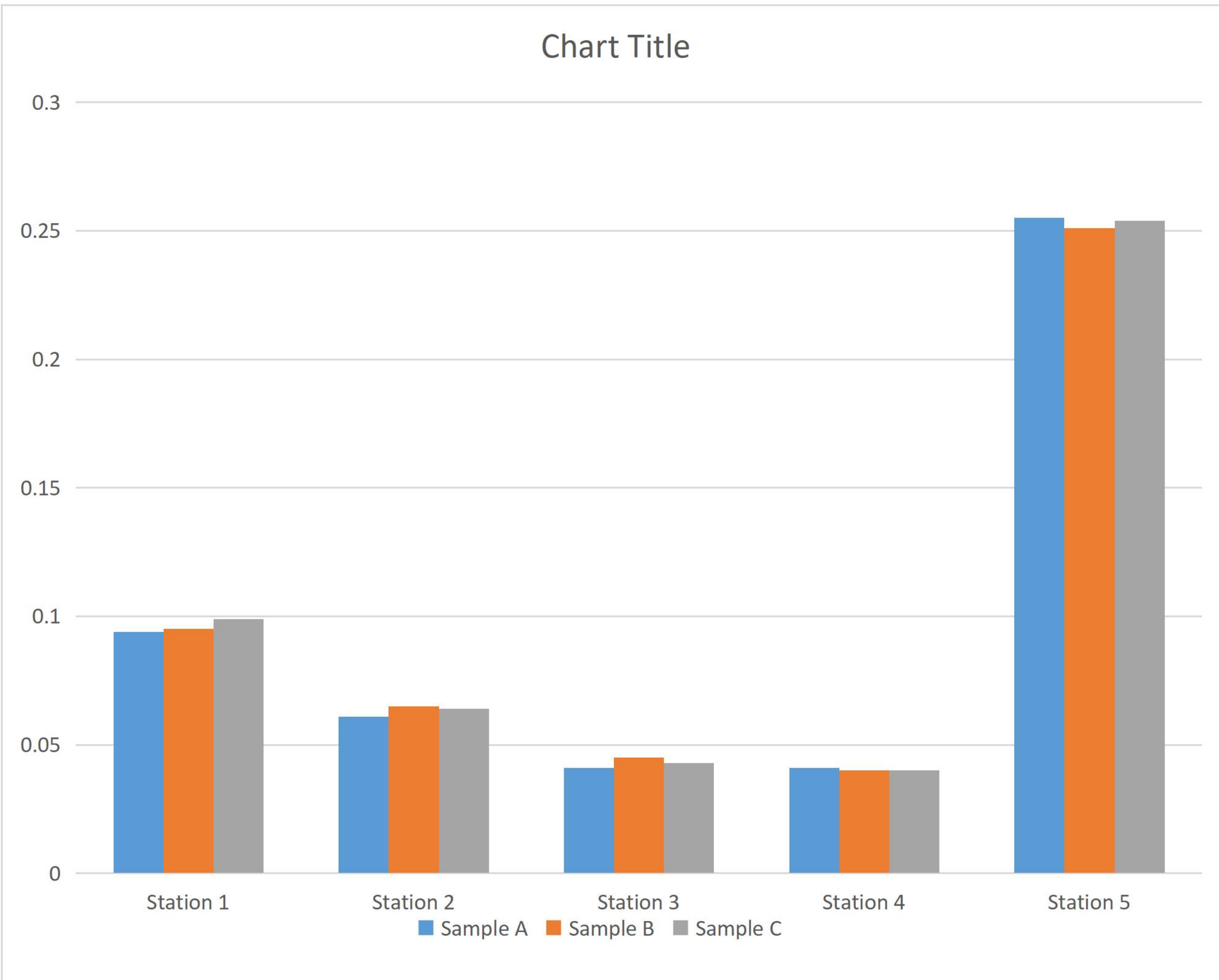

Figure 4.12**:** A Spatial variation of Nitrate of Borehole water samples.

Bar Graph of CALCIUM

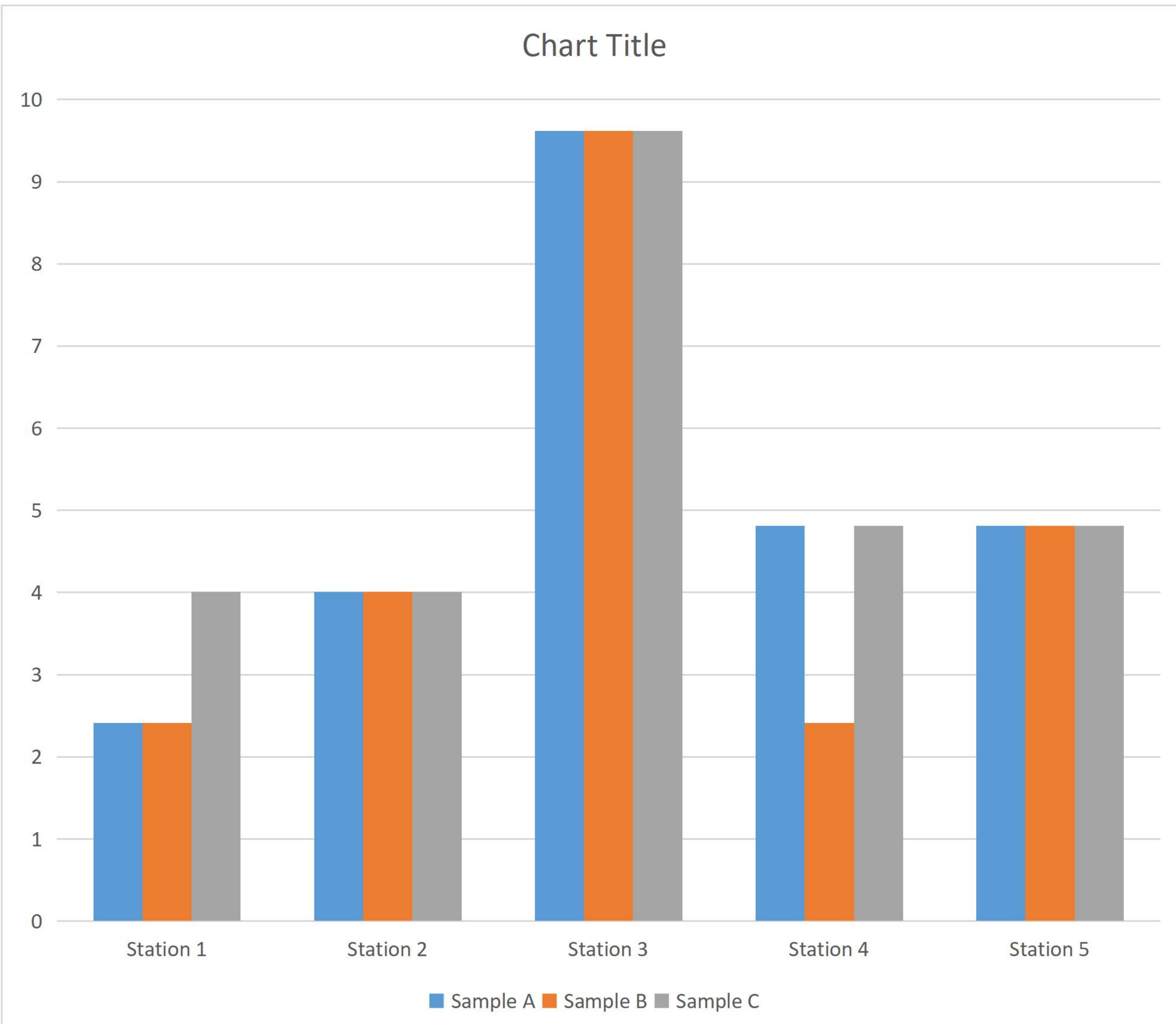

Figure 4.13: A Spatial variation of Calcium of Borehole water samples.

Bar graph of MAGNESIUM

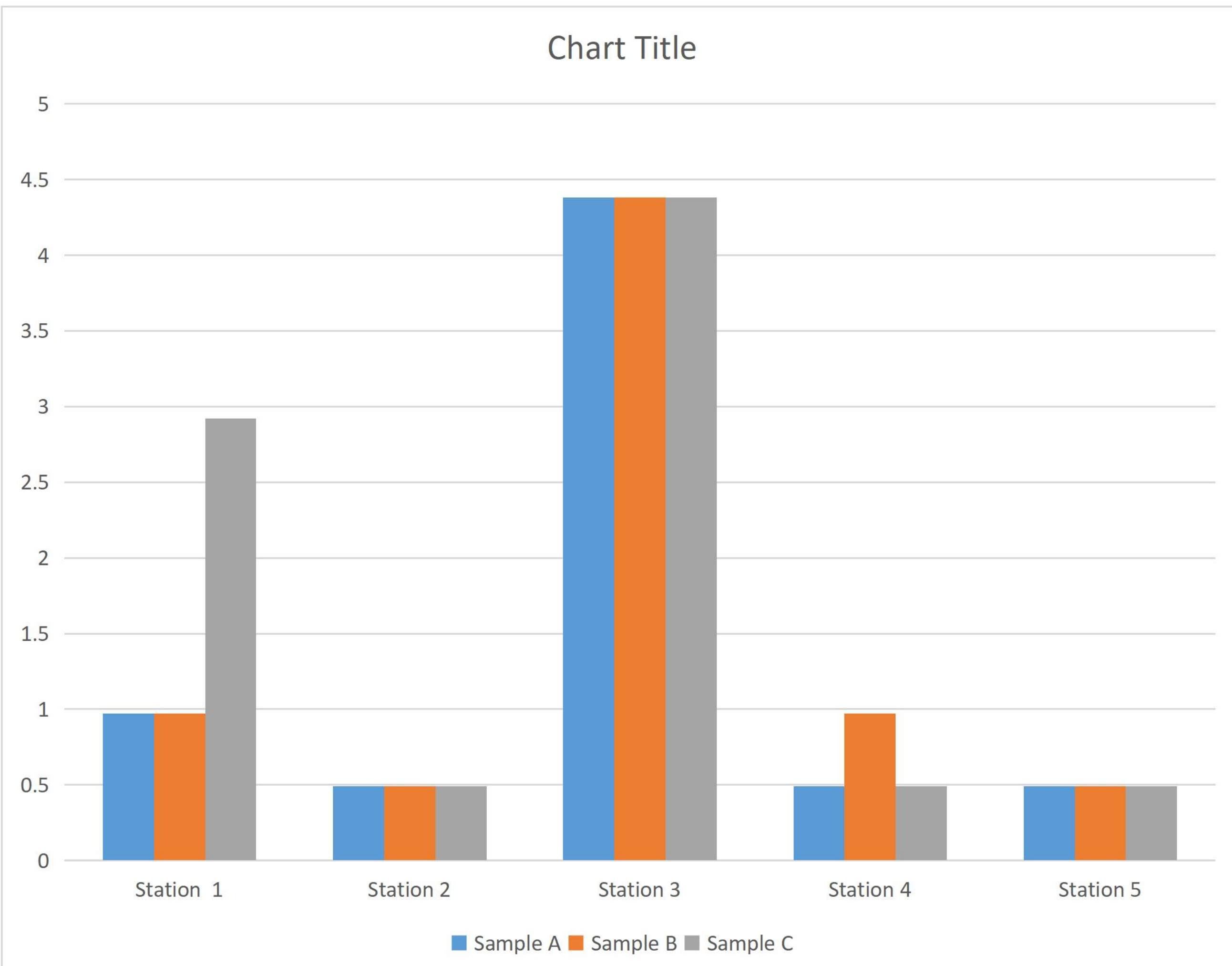

Figure 4.14**:** A Spatial variation of Magnesium of Borehole water samples.

Bar Graph of COPPER

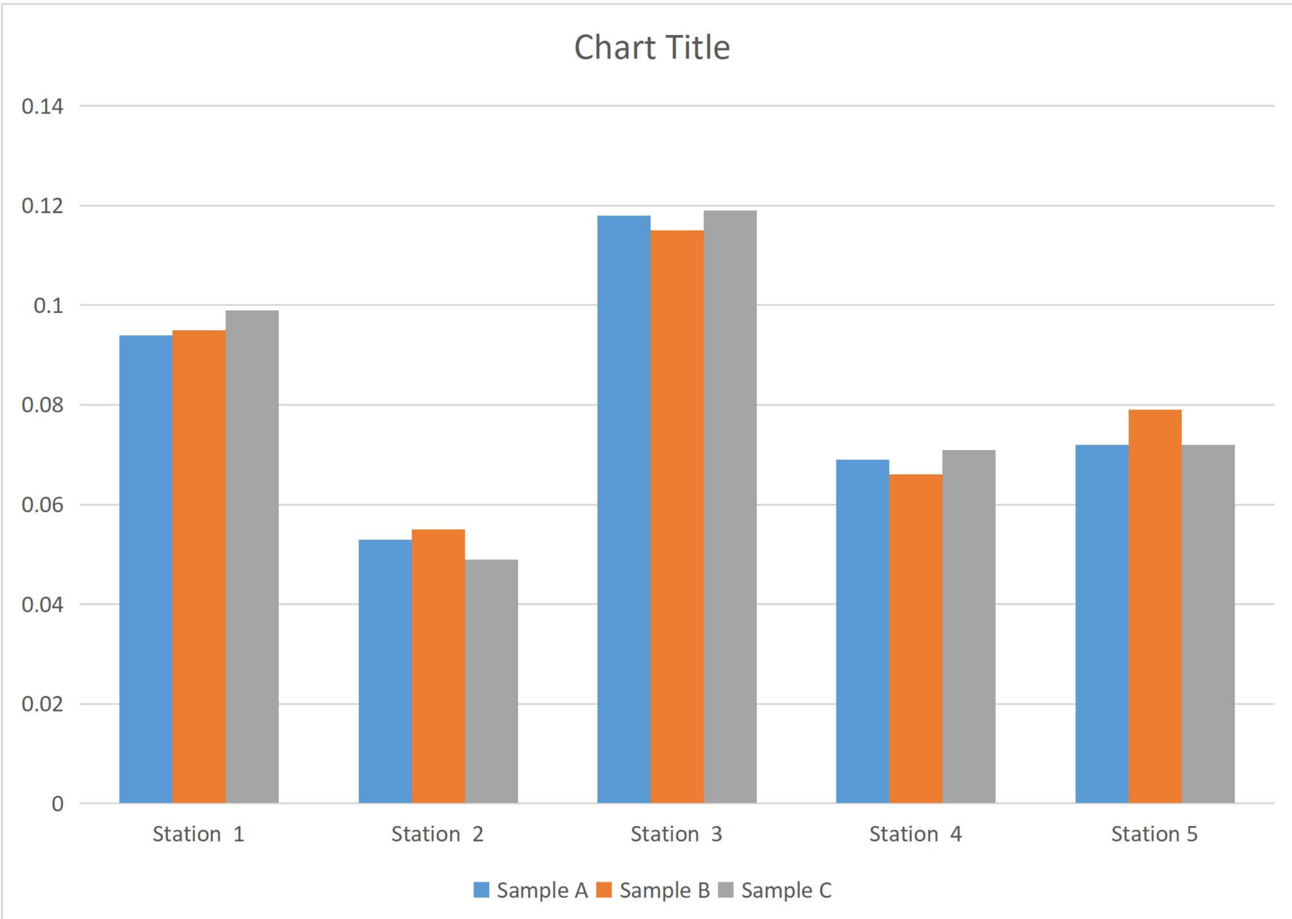

Figure 4.15**:** A Spatial variation of Copper of Borehole water samples.

Bar Graph of ZINC

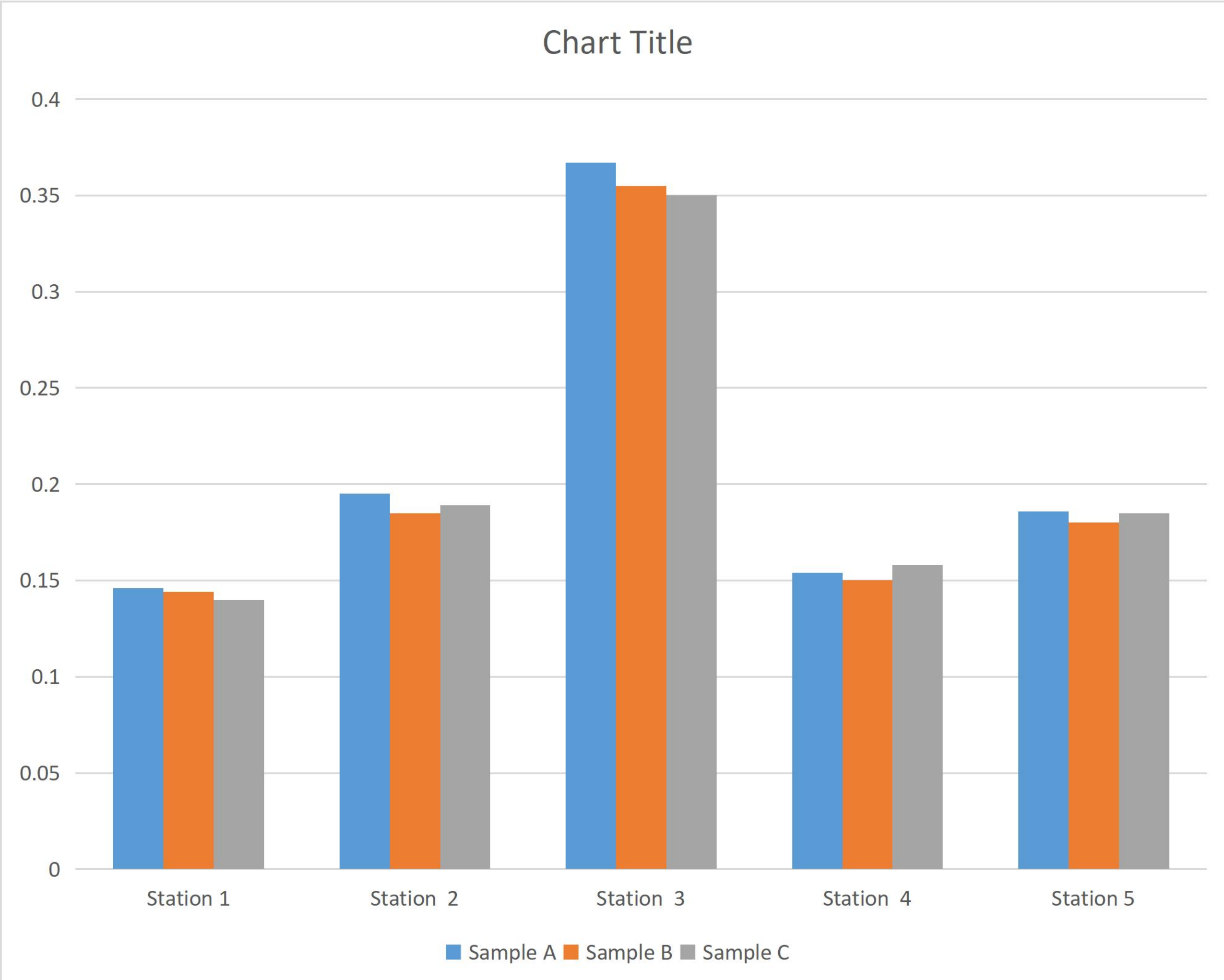

Figure 4.16**:** A Spatial variation of Zinc of Borehole water samples.

4.3.16 Lead

The value of lead was 0.0mg/l through the five stations.

4.3.17 Manganese

The value of manganese ranged from 0.025-0.075mg/l. The sample station 2 was seen to have the least value of 0.025mg/l-0.2mg/l while station 1 has the highest value of 0.065-0.075mg/l.

4.3.18 Cadmium

The value of cadmium was detected to be 0.0mg/l through the five sampling stations.

4.3.19 Iron

The Iron Value ranges from 0.093-0.221mg/l. Sampling Station 2 is seen to have the lowest value of 0.093-0.097mg/l while station 3 is seen to have the highest value of 0.211-0.221mg/l.

Bar Graph of LEAD

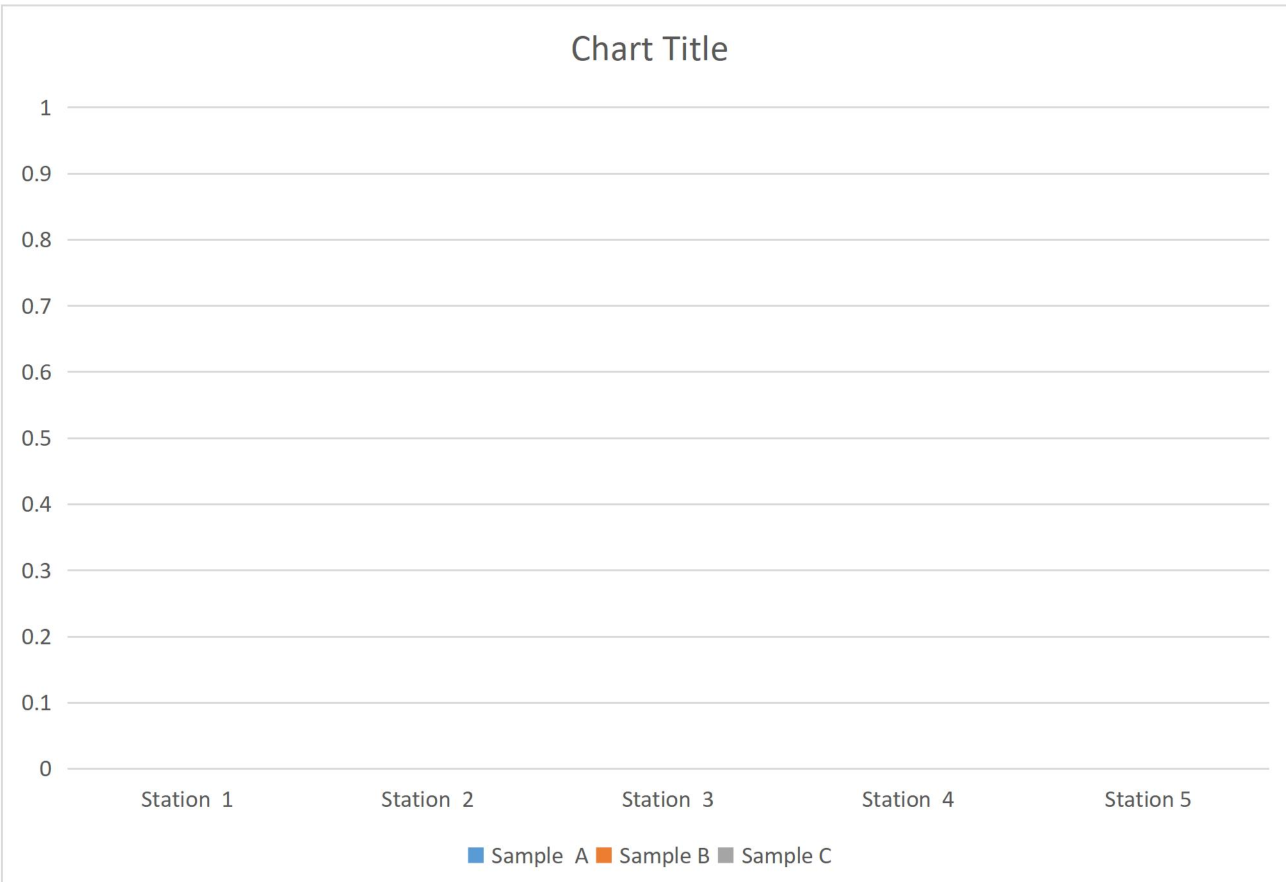

Figure 4.17**:** A Spatial variation of Lead of Borehole water samples.

Bar Graph of MANGANESE

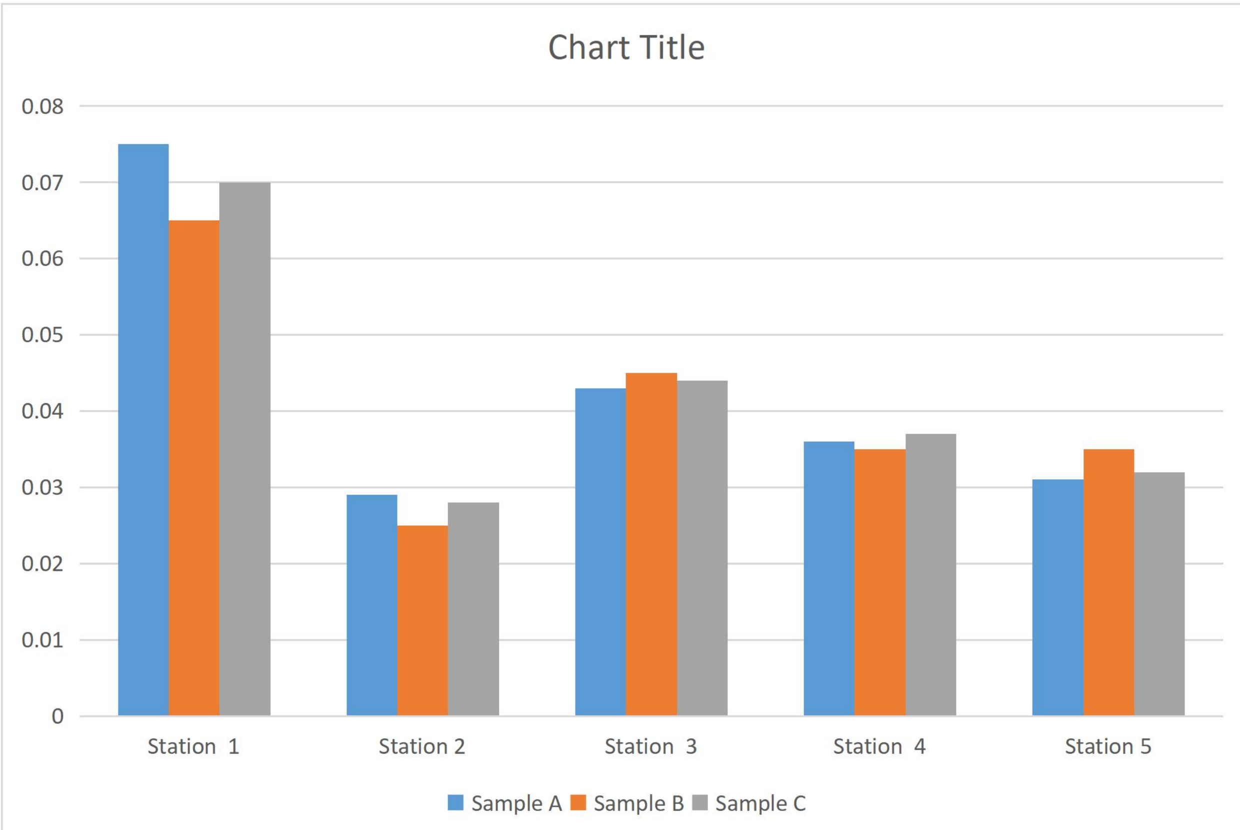

Figure 4.18**:** A Spatial variation of Manganese of Borehole water samples.

Bar Graph of CADMIUM

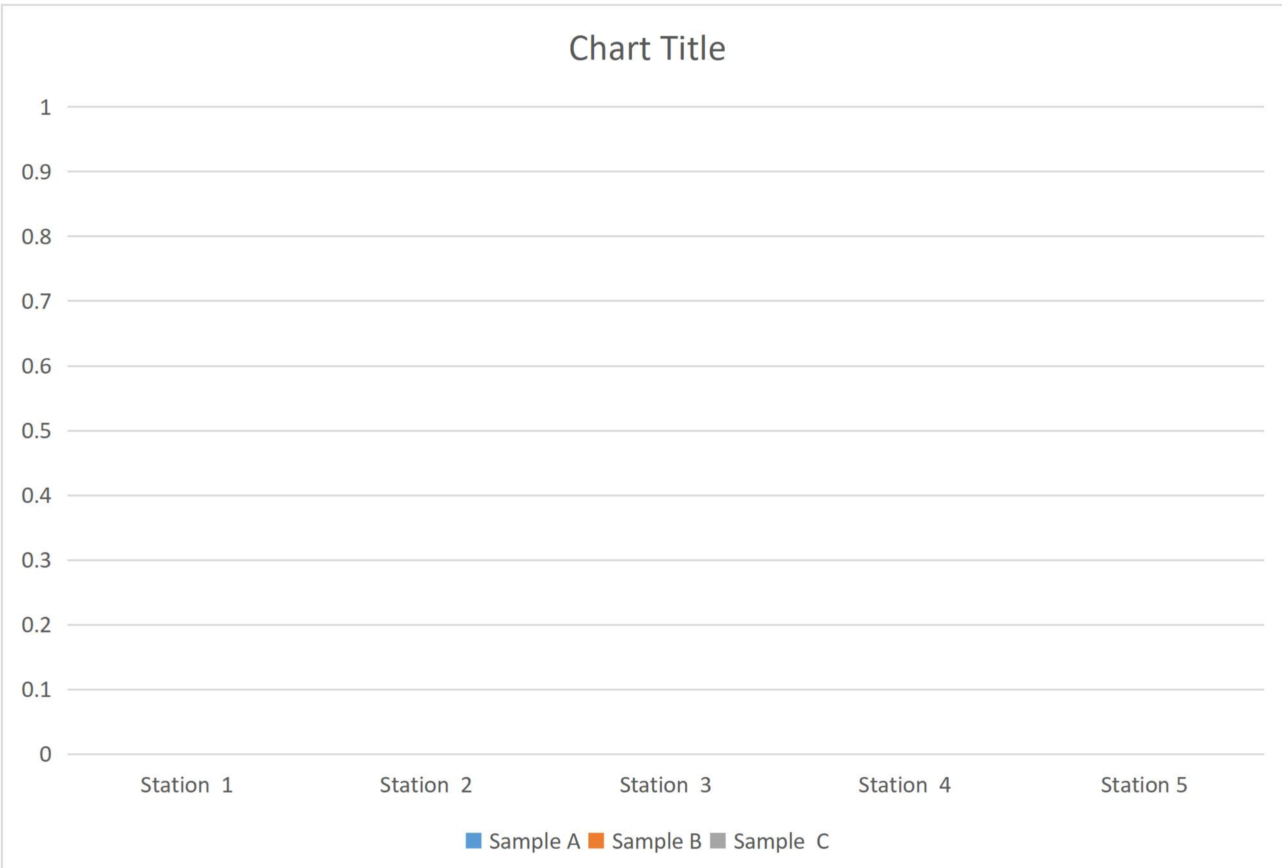

Figure 4.19**:** A Spatial variation of Cadmium of Borehole water samples.

Bar Graph of IRON

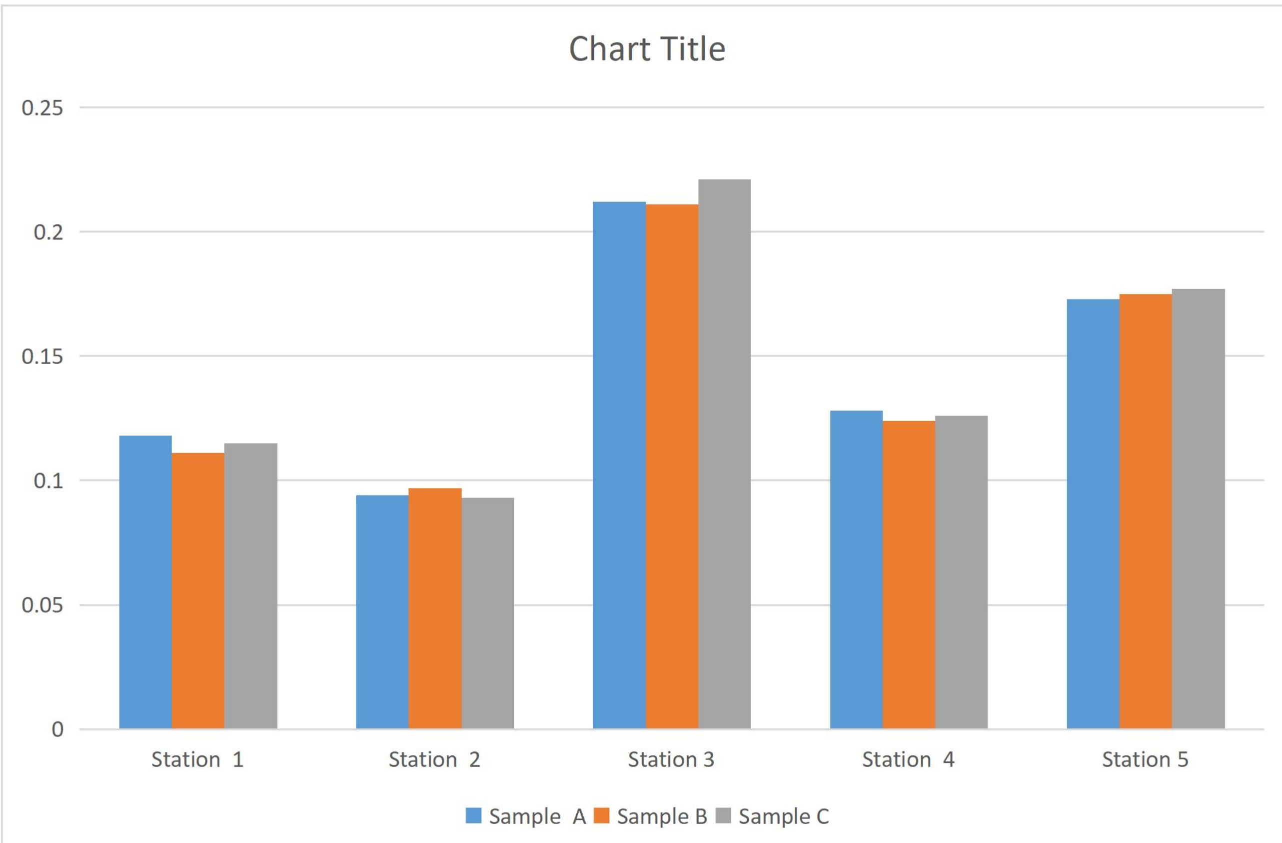

Figure 4.20**:** A Spatial variation of Iron of Borehole water samples.

CHAPTER FIVE

DISCUSSION

The pH values compared to the WHO (2021) permissible limit is below the acceptable range of drinking water, and thus is not safe for drinking. USEPA (2006), reported that a pH range for natural water should be from 6 to 8.5, and pH of 7 to be neutral and that values below 7 (acidic water) in water that are high in organic content and values above 7 (alkaline water) in eutrophic waters, ground water brines and salt lakes.

Alkalinity was observed to be low. APHA, (1994) reported that water that has a low level of alkalinity does not have a stable pH, since they have a low buffering capacity. Ademoroti, (1996) reported that there are no recommended guideline for alkalinity seeing that it is not a significant parameter.

Electrical conductivity is a measure of the total ionic composition of water and therefore its overall richness. The Electrical conductivity from the five stations (ranging from 14.0-60.0) when compared to the permissible limit/guideline by the World Health Organization (WHO 2021) fell below the range specified, thus is safe. Conductivity values encountered here were below the WHO limits Des, (2010) reported that water in fresh water bodies, has a conductivity values that range from 10 to 1000 µS/cm.

Turbidity, Suspended solids and Total Dissolved Solids values when compared is also below the recommended set value by Guideline for Drinking Water Quality (GDWQ). Turbidity, Suspended solids and Total Dissolved solids values were low in all stations (station 1 to 5), all below the World Health Organization (WHO) limits. McClusky (1971) reported that turbidity maximal is created by the mixture of suspended solids from streams and sea, a scenario completely absent in this study. Sosbey, (2002) reported that the colloidal matter harbours microorganisms and chemicals that affects the quality of water and hinder disinfection during treatment.

The samples color had colors. The station with the highest color value was station 2 with the value 0-2 and station 5 with the value 4.0-6.0.

Potassium, Magnesium and Calcium values were below the specified concentration by GDWQ. They all fell within acceptable range concentration to be present in drinking water.

E. coli was found to be present in station 1, and 5 with the value 0.0-1.0 and 0.0-1.0 respectively. The findings by JMP, (2012) and Jimenez et al., (1989) show that E. coli can also be found, multiply and persist in the environment especially in tropical soils, climates and waters rich with organic matter. Brüssow et al., (2004) reported that the detection of E.coli in water samples does not prove that pathogenic organisms are present, instead it shows a risk of fecal contamination, and therefore the possible presence of pathogenic microorganisms of fecal origin. The World Health Organization (WHO 2003) reported that in drinking water, total coliform testing can be used to monitor the effectiveness of the disinfection processes. Coliforms present in drinking water indicate there could be pathogens present in the water that cause serious diseases. The presence of total coliforms in the water is therefore useful for monitoring the microbial quality of drinking water from time to time (Gangil, et al., 2013). To minimize health risk resulting from the consumption of such contaminated ground water, appropriate treatment processes should therefore be utilized for disinfection of ground water for quality and safe food processing and drinking water (Oyedeji, et al., 2010).Chukwu (2008), reported that the unsatisfactory water supplies and unwholesome sanitary conditions can result in poor human health. Aliyu et al., (2006) also gave in his findings that the sanitary quality of drinking water is determined primarily by the kind of microorganisms present rather than the numbers.

CONCLUSION AND RECOMMENDATIONS

The physicochemical analysis showed contamination of some of the water samples by total coliforms, slightly acidic levels in the water samples. This makes the water unsafe for consumption, either for direct drinking. The evaluation of borehole water quality in rural communities of Benin City highlights the importance of regular water quality assessments to ensure safe drinking water. The study revealed that while boreholes serve as a vital source of water for these communities, some samples exhibited contamination from chemical, or physical pollutants. This contamination could be attributed to inadequate sanitation, poor borehole construction, or proximity to waste disposal sites.

To mitigate health risks associated with contaminated borehole water, it is crucial to implement proper water treatment methods, improve sanitation infrastructure, and conduct periodic water testing. Government agencies and local stakeholders should collaborate to enforce water quality standards and promote community awareness about safe water practices. Ensuring access to clean and safe borehole water will significantly improve public health and overall well-being in rural areas of Benin City.

Recommendations

To improve borehole water quality in rural communities of Benin City and ensure safe drinking water, the following recommendations are proposed:

1. **Regular Water Quality Monitoring:** Conduct periodic testing of borehole water to check for microbial, chemical, and physical contaminants. Establish community-based water monitoring programs in collaboration with local health authorities and research institutions.
2. **Proper Borehole Construction and Maintenance:** Ensure boreholes are constructed following standard guidelines, including adequate casing and sealing to prevent surface contamination. Maintaining a safe distance (at least 30 meters) between boreholes and potential contamination sources such as latrines, waste dumps, and agricultural fields. Implement regular maintenance and cleaning of borehole structures to prevent biofilm buildup and contamination.
3. **Improved Sanitation and Waste Management:** Promote the construction of properly designed latrines and septic systems away from groundwater sources. Implement community waste disposal systems to prevent open dumping, which can lead to groundwater contamination. Encourage hygienic practices, such as handwashing and proper waste handling, to reduce the spread of waterborne diseases.
4. **Community Awareness and Education:** Organize community workshops and sensitization programs to educate residents on the importance of water hygiene and safe water handling practices. Teaching simple and affordable household water treatment methods, such as boiling, filtration, and chlorination, to improve drinking water safety.
5. **Introduction of Water Treatment Solutions:** Provide affordable and accessible water treatment technologies, such as point-of-use filters and solar disinfection systems, to

households. Encouraging the use of natural filtration methods, such as sand filters and activated carbon, to remove contaminants from borehole water.

6. **Government and Stakeholder Involvement:** Strengthen policies and regulations governing borehole drilling, water quality standards, and environmental protection. Encourage public-private partnerships to fund the development of sustainable water supply and sanitation projects in rural communities. Establish local water management committees to oversee borehole maintenance and ensure compliance with safety guidelines.
7. **Addressing Climate and Environmental Factors:** Implement flood control measures, such as proper drainage systems, to reduce water contamination during heavy rains. Promote afforestation and soil conservation practices to protect groundwater sources from pollution. By implementing these recommendations, rural communities in Benin City can significantly improve the quality of their borehole water, reduce health risks, and ensure access to clean and safe drinking water for all.

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