

Physico-Chemical Characteristics of Ground Water of Woji, Port Harcourt Rivers State, Nigeria

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ABSTRACT: *Safe drinking water is essential to humans and other life forms. Majority of the population and industries obtain water from boreholes. The scope of this research study covers the assessment of ground water using water quality index (WQI), checking its compliance with WHO's specifications and suggesting effective controls to mitigate outliers. Ground water samples were collected from various points in Woji and subjected to physical, chemical and microbial analysis to determine the pollution / contamination status. The WHO standard for water colour is 15 (colourless) however, points 5 and 7 have metallic taste. This deviation in taste and colour can originate from chemical contaminants like iron. This corresponds with the iron value deviation observed from WHO value of 0.3mg/l of these two points, 5(0.38mg/l) and 7(0.45mg/l), this can result from rusty pipes or some aesthetic features.*

KEYWORDS: physico-chemical characteristics, ground water, Woji, Port Harcourt Rivers State, Nigeria

INTRODUCTION

Groundwater is one of our most important sources of water in both rural and urban areas in Nigeria. Governmental and non-governmental agencies, corporate organizations and individuals are involved in sinking of boreholes to provide water without properly ensuring the portability. Unfortunately, groundwater is susceptible to pollutants. In rural areas, careless disposal of industrial effluents and other wastes may contribute greatly to poor quality of the water (Chindah and others (2004); Emongor and Others (2005); Furtado and others, (1998) and Ugochukwu, 2004) It is important to note that once ground water is contaminated, restoring its quality nearly impossible therefore it becomes imperative to protect it or put adequate controls in place where it has already been contaminated, Yisa and others (2013).

Safe drinking water is essential to humans and other life forms even though it provides no calories or organic nutrients. Access to safe drinking water has improved over the last

decades in almost every part of the world, but approximately one billion people still lack access to safe water and over 2.5 billion lack access to adequate sanitation, Wiki (2013). Consumption of water contaminated by disease causing agents (Pathogens) or toxic chemicals can cause health problems like diarrhea, cholera, typhoid, dysentery, cancer and skin diseases, Howard and others (2003). Unsafe water can also have socio-economic effects thus, emphasizing the need to ascertain the quality of water. World Health Organization (WHO) has stipulated specifications for portable water as a way of prodding borehole sinkers to ensure the quality of their water.

Statement of Problem

- Drinking contaminated groundwater can have serious health effects. Diseases such as hepatitis and dysentery may be caused by contamination from septic tank waste.
- Poisoning may be caused by toxins that have leached into well water supplies. Wildlife can also be harmed by contaminated groundwater.
- Consumption of contaminated water can cause long term effects such as certain types of cancer, socio-economic challenges like epidemics and Lost Time Injuries (LTI).
- Restoring the quality of contaminated ground water is nearly impossible.
- The need for potable drinking water cannot be overemphasized.

Study Objectives

This study is aimed at evaluating the water quality of selected points in Woji, Port Harcourt, checking its compliance with World Health Organization (WHO) specifications to ascertain its suitability for drinking and domestic purposes and determining the Water Quality Index. It describes the distribution of physicochemical parameters in order to bring the groundwater quality problem to the attention of the population. It also identifies the major pollutants in groundwater and the major sources of ions in water.

Significance of the Study

This work will be beneficial in the following ways:

- It gives information on the groundwater quality of the study area available which will aid planning developmental projects like water treatment plants.
- Contribute to already existing literature on Ground water quality assessment.
- Enlightens and sensitizes the public on the Water quality index of the study areas.
- Serves as a basis for more water quality assessment on the study areas

Scope of Study

The scope of this research study covers the assessment of ground water using Water Quality Index (WQI), checking its compliance with WHO's specifications and suggesting effective controls to mitigate outliers.

Limitation of Study

The major limitations of the research were:

- Funding for the needed laboratory and software analysis.
- Difficulty in accessing the study areas due to human attitude and security awareness.
- Appropriate sampling of borehole water considering the fact that air bubbles should be minimized.
- Challenge of moving laboratory equipment to the study areas for the measurement of In-situ parameters.

LITERATURE REVIEW

Water is the most essential element to life on earth. Water covers 71% of the Earth's surface. It is vital for all known forms of life. On Earth, 96.5% of the planet's water is found in seas and oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air), and precipitation. The two sources of water are Surface and ground water. Water can be used for direct and indirect purposes. Direct purposes include bathing, drinking, and cooking, while examples of indirect purposes are the use of water in processing wood to make paper and in producing steel for automobiles. The bulk of the world's water use is for agriculture, industry, and electricity.

There has been an increase in the demand of fresh water due to the rapid growth of population as well as the accelerated pace of industrialization in the last few decades. This demand has led to the use of ground water not only for its wide spread occurrence and availability but also for its constituent good quality which makes it ideal supply of drinking water.

Groundwater

Ground water is one of the most important water sources on earth. It comprises of all water stagnating or moving below the earth's surface or even emerging at the earth's surface (spring).

The hydrological cycle, which is the groundwater – surface water interaction is governed by the evaporation of water and its condensation and return to the earth as precipitation (rain, fog, dew, snow and ice). By the accumulation of water from precipitation to surface water, with partial infiltration and as a result of direct percolation through the earth's layers, new ground water is formed, Schneider and others (1988).

Groundwater Contamination

Water is said to be polluted or contaminated when its quality is degraded as a result of man's activities to an extent that it becomes less suitable for its intended use, Chapman

(1992). The foreign substances that impair or degrade the water quality are referred to as pollutants and may be of organic, inorganic, biological or physical origin. The deleterious effect of pollutions include harm to human health, hindrance to aquatic activities and the inability of the water to support agriculture, industrial and other related economic activities.

The degree of pollution (contamination) will depend on the efficiency of the waste disposal methods, safety of land use patterns, density of disposal systems in an area, composition of waste and soil and a number of other site-specific information. The physical and chemical properties of the contaminant determine its mobility and toxic effect. A contaminant may move through the subsurface as a pure liquid or gas phase, as a dissolved phase, in particulate form or attached to colloids. Soluble compounds may be transported readily within the groundwater, and attain high levels of concentration. Less soluble compounds will occur in low concentrations but may provide a long-term source of contamination. Advective transport of dissolved phase contaminants within the groundwater is seen as the primary mechanism by which subsurface contaminants may impact upon surface water systems.

The sources of contaminated groundwater may be spatially restricted point sources such as an industrial spill or waste dump, or more diffuse sources such as arise from the widespread application of agricultural fertilizers and pesticides. The initial contaminant concentration in the groundwater will depend on the mass and distribution of the contaminant in the source area, the rate of groundwater flow and the physical-chemical-biological processes controlling contaminant dissolution, Fetter (1999).

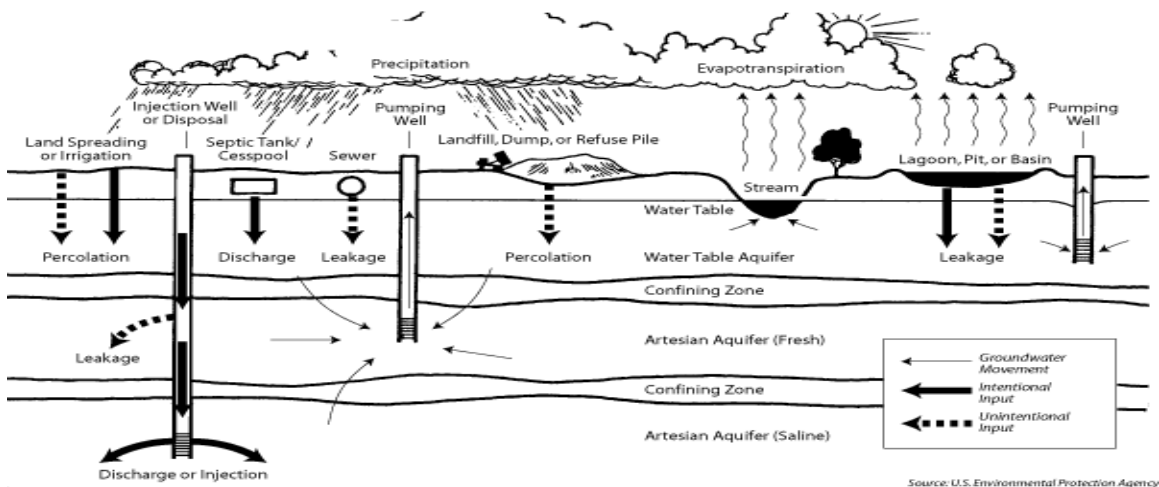


Figure 2. 1. Hydrological Cycle as described by the United States Environmental Protection Agency.

Septic Systems

A noted source of pollution in groundwater supplies is the latrine/septic tank, causing an increase in biochemical oxygen demand BOD, chemical oxygen demand COD, nitrate, inorganic chemicals and pathogens thus leading to outbreak of diseases common in developing nations like Africa, Asia and South America, Chapman (1992). Onsite wastewater disposal systems used by homes, offices or other buildings that are not connected to a city sewer system. Septic systems are designed to slowly drain away human waste underground at a slow, harmless rate.

An improperly designed, located, constructed, or maintained septic system can leak bacteria, viruses, household chemicals, and other contaminants into the groundwater causing serious problems. Sangodoyin (1993) observed that the unsanitary mode of disposal of wastes, such as defecation in streams and the dumping of refuse in pits, rivers and drainage channels as seen in most Nigerian urban settlements, could be expected to affect surface and groundwater quality.

Landfills / Storage Tanks

Landfills are the places that our garbage is taken to be buried. Landfills are supposed to have a protective bottom layer to prevent contaminants from getting into the water. However, if there is no layer or it is cracked, contaminants from the landfill (car battery acid, paint, household cleaners, etc.) can make their way down into the groundwater. Storage tanks may contain gasoline, oil, chemicals, hazardous waste or other types of liquids and they can either be above or below ground. If the contaminants leak out and get into the groundwater, serious contamination can occur.

Industrial Waste

Industrial waste disposal method of discharging effluents unto land, stream and sanitation sewers also have potential of polluting ground water. Other sources of groundwater pollution include tank and pipeline leakage and mining activities. Oil and gas production is often accompanied by substantial discharges of wastewater called brine, which is disposed of using methods such as abandoned pits, evaporation ponds and streams. These methods have the potential of polluting aquifers with brine, leading to an increase in sodium, calcium, ammonia, boron, chlorides, sulfates, trace metals and substantial amounts of total solids, Chapman (1992).

Agricultural Chemicals and Road Salts

The widespread use of agricultural chemicals and road salts is another source of potential groundwater contamination. Road salts are used in the wintertime to put melt ice on roads to keep cars from sliding around. When the ice melts, the salt gets washed off the roads and eventually ends up in the water. Agricultural sources of pollution include irrigation with a lot of return flow back into the ground, Ogedengbe (1980). The possible effect on the ground water include an increase in ground water salinity, due to inadequate drainage

and direct evapotranspiration of irrigation return flow from soils whose salinity has been increased by salts from fertilizers, Todd (1980) and Chapman (1992). Others include animal waste from animal pens and slaughter houses where they are confined for purposes of meat and milk production and may carry through storm run-offs, significant amounts of nitrates, salts, organic loads and bacteria to surface and sub-surface water, Sangodoyin and Agbawhe (1991).

Agrochemicals include products used on lawns and farm fields to kill weeds and insects and to fertilize plants, and other products used in homes and businesses such as fertilizer, pesticides and insecticides also pollute ground water. When it rains, these chemicals can seep into the ground and eventually into the water. Nitrate based fertilizers are a significant contribution to groundwater pollution. This is because nitrogen in solution is neither fully utilized by plants nor absorbed by the soils. Stock piles of solid materials from construction sites, individual's plants residue are potential groundwater pollutants when precipitation falls on these piles, causing a leaching of heavy metals, salts and other organic and inorganic constituents.

Atmospheric Contaminants

Since groundwater is part of the hydrologic cycle, contaminants in other parts of the cycle, such as the atmosphere or bodies of surface water, can eventually be transferred into our groundwater supplies.

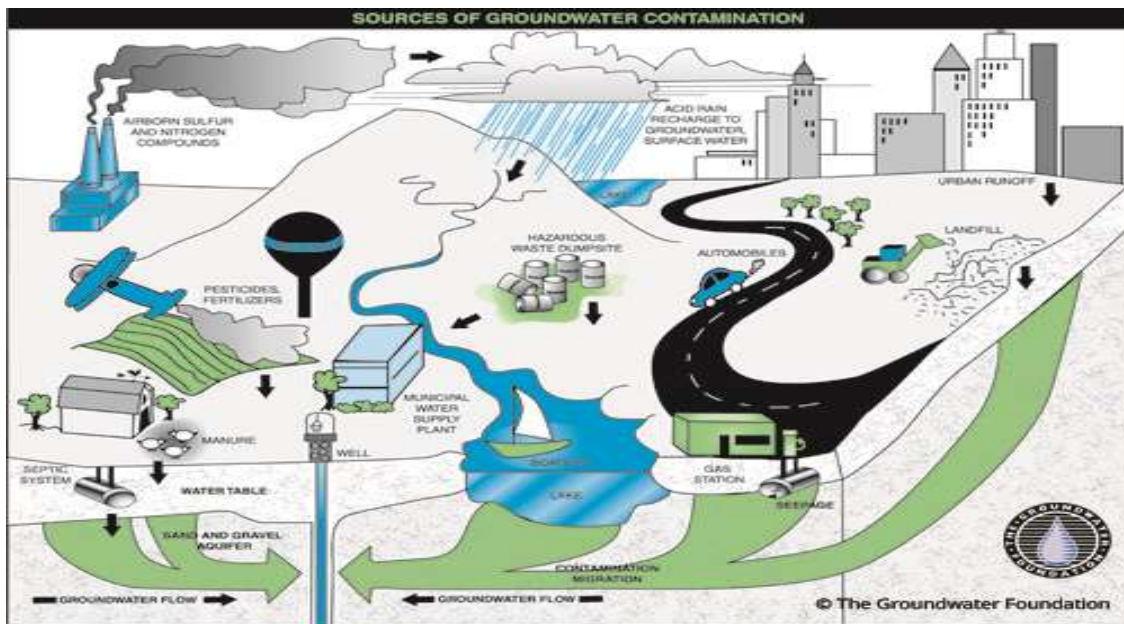


Figure 2. 2. Sources of Groundwater contamination as described by the Groundwater foundation

Groundwater Properties

Groundwater is a very complex matrix. Although each aquifer represents a different water quality, experience has shown that all groundwater has two unique properties for natural water systems:

- The movement of groundwater through the aquifer precludes the transport of chemicals by particulates. Only substances soluble in the groundwater matrix are mobile within the aquifer.
- Groundwater is nearly oxygen-free. In other words, the dissolved ions tend to be in their most reduced state. High iron content of groundwater indicates that the water in the aquifer is carrying ferrous iron at neutral pH values. Ferrous iron groundwater cannot be aerobic groundwater.

In other words, a groundwater sample cannot contain any particulate matter and must be protected from air at all times if the sample is to be truly representative. If groundwater samples that contain particulates and have been exposed to the air are analyzed, then the results obtained do not represent the water within the aquifer. These properties are critical to the analysis of groundwater quality on a macroscopic scale. It is observed that unit pH changes as ferrous iron is oxidized by the oxygen in the air to the insoluble ferric iron. Corresponding changes in specific conductance occur also, Keith (1993).

In passing through the soil, water absorbs soluble substances from the different geological levels. This results in a differing dissolution of inorganic substances and also, in rarer cases and to a lower degree, in a charging with soluble organic substances. A complete chemical analysis of a sample of ground water includes the determination of the concentrations of all of the inorganic constituents present. Dissolved salts in ground water occur as dissociated ions; in addition, other minor constituents are present and reported in elemental form only, Todd (1963). The common anions and cations found in ground waters, together with minor constituents, are listed in Table 2.1. Properties of a ground water evaluated in a physical analysis or indicators include temperature, turbidity, color, and taste. Bacteriological analysis or indicators consists of tests to detect the presence of coliform organisms, which indicate the sanitary quality of water for human consumption, as certain coliform organisms are normally found in intestines of man and animals, the presence of these in ground water is tantamount to its-contact with sewage source, Todd (1963). The concern of this research on some of the major constitutes those can be summarized according to Davis and DeWiest (1966) in Table 2.1 below.

Table 2. 1. The major, secondary and Minor Constituents.

Major constituents (1.0 to 1000 ppm)	
Sodium	Chloride
Bicarbonate	Silica
Calcium	Sulphate
Magnesium	
Secondary constituents (0.01 to 10.0 ppm)	
Iron	Strontium
Carbonate	Nitrate
Potassium	Fluoride
Boron	
Minor constituents (0.0001 to 0.1 ppm)	
Antimony	Arsenic
Lead	Manganese
Aluminum	Barium
Lithium	Molybdenum
Cadmium	Nickel
Chromium	Phosphate
Cobalt	Selenium
Copper	Titanium
Germanium	Uranium
Iodide	Vanadium
Zinc	

Physical Indicators

- **Temperature**

Temperature is the degree of hotness or coldness of a substance. Water temperature is a very important parameter for a body of water. Most physical and biological processes are affected by temperature. Most aquatic life requires an optimum temperature range to thrive and, like terrestrial life, finds survival difficult at extreme temperatures. Higher water temperatures lower the amount of dissolved oxygen for two reasons. First, all gases are less soluble in warmer water. Second, warmer water increases the metabolic rate of aquatic organisms, which increases the consumption of food and dissolved oxygen.

The increase of water temperatures is called thermal pollution and it is a significant problem on some bodies of water. Most thermal pollution comes from the industrialization of rivers and waterways. Industries, especially large power plants, use large amounts of water to cool their machinery and equipment. Along smaller bodies of water, cutting trees takes away the shade and allows water temperatures to rise. Another cause, large-scale logging, increases soil erosion and water turbidity, which, in turn, raises the water temperature to the detriment of aquatic life.

- **Colour**

Colouring gives information on possible contamination of the water. Humic substances cause a yellow to brown colouring (marsh water). The yellowish colouring caused by iron content changes to a yellowish – brown turbidity when standing open to the air. The

intrinsic colour of the water can be neglected, as pure natural water in thin layers is practically colourless.

- **Odour**

Odour gives an indication of possible pollution. It is characterized by intensity and nature. Plastic bottles are useless for testing because of the disturbing influence of their own odour. Odor is recognized as a quality factor affecting acceptability of drinking water, tainting of fish and other aquatic organisms, and esthetics of recreational waters. Most organic and inorganic chemicals contribute taste or odor. These chemicals may originate from municipal and industrial waste discharges, from natural sources such as decomposition of vegetable matter, or from associated microbial activity, and from disinfectants or their products. Safe drinking water is odor-free.

- **Turbidity**

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (total suspended or dissolved solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality.

Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended materials will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settleable solids). Very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles cause the liquid to appear turbid. (Haze technical definition). Turbidity in open water may be caused by growth of phytoplankton. Certain industries such as production, quarrying, mining and coal recovery can generate very high levels of turbidity from colloidal rock particles, EPA (2005). In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal disease, Mann and Tam (2007). This is especially problematic for immune compromised people, because contaminants like viruses or bacteria can become attached to the suspended solids. The suspended solids interfere with water disinfection with chlorine because the particles act as shields for the virus and bacteria. Similarly, suspended solids can protect bacteria from ultraviolet (UV) sterilization of water. In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths, which can inhibit growth of submerge aquatic plants and consequently affect species which are dependent on them, such as fish and shell fish. High turbidity levels can also affect the ability of fish gills to absorb dissolved oxygen. For many mangrove areas, high turbidity is needed to support certain species, such as to protect juvenile fish from predators.

Turbidity is commonly treated using either a settling or filtration process. Depending on the application, chemical reagents, will be dosed into the waste water stream to increase the effectiveness of the settling or filtration process. Potable water treatment and municipal waste water plants often remove turbidity with a combination of sand filtration, settling tanks and clarifiers, Earth (2003).

Electrical Conductivity (EC)

The Electrical conductivity of water is based on the presence of ions. It can be regarded as a non-specific yardstick for the content or the concentration of dissolved dissociable substances in water.

Chemical Indicators

- **pH**

pH is a measure of the acidity or basicity of an aqueous solution. A pH of less than 7 is said to be acidic and a pH greater than 7 is basic or alkaline, and a pH of 7 is neutral. Pure water contains an equal amount of Hydrogen and hydroxide (OH⁻) ions. Hydrogen ions are acidic and the OH⁻ ions are basic, or alkaline. pH measures the -log of the H⁺ concentration. A pH of 7 is neutral; it is equally acidic and alkaline. pH values below 7 become more acidic and they approach zero as the hydrogen ions increasingly outnumber the OH⁻ ions. As the values climb above 7, the water is said to be basic. The water becomes more alkaline as the values approach 14 and the OH⁻ ions outnumber the H⁺ ions.

Many aquatic life forms are very sensitive to acid levels in the water. Pollution tends to make water acidic. Most bodies of water have the highest biological diversity when the pH is near 7. In Niger- Delta aquifer, pH of water as low as 5 has been observed.

Biological Oxygen Demand (BOD)

Aerobic bacteria in water eat organic matter and at the same time remove oxygen. When the organic material in dead aquatic plants is decomposed, it releases the nutrients nitrogen and phosphorus. These nutrients trigger more plant growth and more nutrients, which further lower oxygen levels. If there is too large an amount of organic material in the water, the oxygen levels can drop below what is necessary for other aquatic life forms.

The BOD test gives an approximation of the level of biodegradable waste there is in the water. This biodegradable waste can be leaves and grass clippings from human activities, animal waste and manure from food production, wood pulp from paper mills, or many other carbon-based wastes. Water with a high BOD usually has a high bacteria count as well.

Dissolved Oxygen (DO)

Oxygen is not very soluble in water. What little gets into solution is vital to aquatic life and water quality. Most oxygen dissolved in streams, rivers, and lakes gets there by contact with the atmosphere. In streams and rivers, water splashing over rocks and waterfalls traps oxygen in the water. Waves on rivers and lakes also increase the oxygen level in solution. Photosynthetic plants in the water also contribute a significant amount of oxygen to the water column.

This test measures the amount of oxygen that is dissolved in the water and is available to the aquatic life that lives there. A Dissolved Oxygen value that is too low is often an indicator of possible water pollution. It also shows a potential for further pollution downstream because the ability of the stream to self-cleanse will be reduced.

Total Hardness (TH)

Hardness in water is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations. It is usually expressed as milligrams of calcium carbonate per litre. Hardness is the traditional measure of the capacity of water to react with soap, hard water requiring considerably more soap to produce a lather.

Hardness in Drinking-Water

Natural and treated waters have a wide range of mineral content, from very low levels in rainwater and naturally soft and softened water to higher levels in naturally hard waters. Bottled and packaged waters can be naturally mineralized or naturally soft or demineralized. Thus, the mineral consumption from drinking-water and cooking water will vary widely, depending upon location, treatment and water source.

The degree of hardness of drinking-water is important for aesthetic acceptability by consumers and for economic and operational considerations.

Many hard waters are softened for those reasons using several applicable technologies. The choice of the most appropriate conditioning technology will depend on local circumstances (e.g. water quality issues, piping materials, corrosion) and will be applied either centrally or in individual homes as a consumer preference. Consumers should be informed of the mineral composition of their water, whether or not it is modified. The contribution of drinking-water minerals to mineral nutrition should be considered where changes in supply are proposed or where less traditional sources, such as recycled water, seawater or brackish water, are processed and exploited for drinking-water. The treatments used remove most minerals, and stabilization of water is always necessary prior to distribution.

Drinking-water can be a contributor to calcium and magnesium intake and could be important for those who are marginal for calcium and magnesium. Where drinking-water supplies are supplemented with or replaced by demineralized water that requires conditioning, consideration should be given to adding calcium and magnesium salts to achieve concentrations similar to those that the population received from the original supply. Modification of calcium and magnesium concentrations in drinking-water for health reasons should comply with the technical requirements to provide water suitable for distribution.

Although there is evidence from epidemiological studies for a protective effect of magnesium or hardness on cardiovascular mortality, the evidence is being debated and

does not prove causality. Further studies are being conducted. There are insufficient data to suggest either minimum or maximum concentrations of minerals at this time, as adequate intake will depend on a range of other factors. Therefore, no guideline values are propose.

Exceptionally low values of magnesium and calcium are found in some waters which have undergone natural softening by cation exchange. Most commonly, clay will exchange sodium, if available, for both magnesium and calcium ions.

- **Alkalinity (Carbonate And Bicarbonate HCO_3^-)**

Most carbonate and bicarbonate ions in ground water are derived from the carbon dioxide in the atmosphere, carbon dioxide in the soil, and solution of carbonate rocks. Some ground water and much oil-field water probably obtain bicarbonate from the carbon dioxide generated by diagenesis of organic compounds. Sodium bicarbonate water can be concentrated by evaporation in soil sand desert basins; if it contains much calcium, the bicarbonate will be taken out of the water through precipitation of calcium carbonate. Ground water generally contains bicarbonate more than 10 ppm and not less than 800 ppm. Concentrations between 50 and 400 ppm are most common. Ground water will rarely have pH values of less than 4.5, causing bicarbonate to be converted to carbonic acid or pH values of more than 8.2, so that the bicarbonate ions will dissociate to carbonate ions.

- **Sulfate (SO_4^{2-})**

Despite a relatively large amount of sulfur, mostly in the form of sulfates, in water and in sedimentary rocks, sulfur is only a minor constituent of igneous rocks. Early in the history of the hydrosphere most Sulphate probably originated from the oxidation of sulfides from igneous rocks and volcanic sources, but at present Sulphate is largely recycled from the atmosphere and from the solution of Sulphate minerals in sedimentary rocks particularly organic shale, may also yield large amounts of Sulphate through the oxidation of marcasite and pyrite.

Concentrations of sulfate from less than 0.2 ppm to more than 100,000 ppm are found in nature. The lowest concentrations of Sulphate are in rainwater, snow, and subsurface waters subject to sulfate reduction. The highest concentrations are in magnesium sulfate brines. Ground water from igneous and metamorphic rocks or from sediments derived from them generally contains less than 100ppm and may contain less than 1 ppm of Sulphate reducing bacteria are active in the soil through which recharge water has percolated.

- **Chloride (Cl^-)**

Chloride is a minor constituent of the earth's crust, but a major dissolved constituent of natural water. Sodalite and apatite are the only common minerals in igneous and

metamorphic rocks which contain chloride as an essential constituent; although mica, hornblende, and natural glass may also contain significant amounts.

Most chloride in ground water comes from four different sources. First, it comes from ancient sea water entrapped in sediments; second, its concentrations are found in natural water between about 0.1 ppm in arctic snow and 150,000 ppm in brine. Continental rain and snow may contain from 1.0 to 3.0 ppm, but probably average less than 1.0 ppm. Shallow ground water in regions of heavy precipitation generally contains less than 30 ppm of chloride. Concentrations of 1000 ppm or more are common in ground water from arid regions. Chloride in drinking-water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. The main source of human exposure to chloride is the addition of salt to food, and the intake from this source is usually greatly in excess of that from drinking water.

Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations in excess of about 250 mg/l can give rise to detectable taste in water.

- **Nitrate (N)**

Although igneous rocks contain small amounts of soluble nitrate or ammonia, most of the nitrate in natural water comes from organic sources or from industrial and agricultural chemicals. Nitrate compounds highly soluble, so nitrate is taken out of natural water only through activity of organisms or through evaporation. Common nitrate concentrations in water range from 0.1 to 0.3 in rainwater to as much as 600 ppm in ground water from areas influenced by excessive applications of nitrate fertilizer or runoff from barnyards, where normal ground water contains only from 0.1 to 10.0 ppm nitrate.

Biological Indicators

- **Total Coliform Bacteria**

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* and thermo-tolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures (see below). 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.

- **Indicator Value**

Total coliforms include organisms that can survive and grow in water. Hence, they are not useful as an indicator of faecal pathogens, but they can be used to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms. However, there are better indicators for these purposes.

It has been proposed that total coliforms could be used as a disinfection indicator. However, the test for total coliforms is far slower and less reliable than direct measurement of disinfectant residual. In addition, total coliforms are far more sensitive to disinfection than are enteric viruses and protozoa. HPC measurements detect a wider range of microorganisms and are generally considered a better indicator of distribution system integrity and cleanliness.

- **Source and Occurrence**

Total coliform bacteria (excluding *E. coli*) occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environments. Total coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms.

- **Application in Practice**

Total coliforms are generally measured in 100 ml samples of water. A variety of relatively simple procedures are available based on the production of acid from lactose or the production of the enzyme β -galactosidase. The procedures include membrane filtration followed by incubation of the membranes on selective media at 35–37 °C and counting of colonies after 24 hours. Alternative methods include most probable number procedures using tubes or micro-titre plates and presence/absence tests. Field test kits are available.

- **Significance in Drinking-Water**

Total coliforms should be absent immediately after disinfection, and the presence of these organisms indicates inadequate treatment. The presence of total coliforms in distribution systems and stored water supplies can reveal regrowth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants.

Heavy Metals

Heavy metals are metals of relatively high density, or of high relative atomic weight. Heavy metals is a member of a loosely defined subset of elements that exhibit metallic properties. It mainly includes the transition metals, some metalloids, lathanides, and actinides, John (2002).

Living organisms requires varying amounts of “heavy metals”. Iron, cobalt, copper, manganese, molybdenum and zinc are required by humans. Excessive levels can be damaging to the organisms. Other heavy metals such as mercury, plutonium and lead are toxic metals and their accumulation over time in the bodies of animals can cause serious illness. Certain elements that are normally toxic are for certain organisms or under certain conditions, beneficial. Examples include vanadium, tungsten, and even cadmium, John (2002).

Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damaged to blood composition, lungs, kidneys, liver and other vital organs. Long- term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer’s disease, Parkinson’s disease, muscular dystrophy and multiple sclerosis. Allergies are not uncommon, and repeated long-term contact with some metals (or their compounds) may cause cancer, (Lone and others (2002).

- **Iron**

Iron is one of the most abundant metals in Earth’s crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/l. Iron may also be present in drinking-water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution.

Iron is an essential element in human nutrition, particularly in the iron (II) oxidation state. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day.

As a precaution against storage in the body of excessive iron, in 1983, The Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a PMTDI of 0.8 mg/kg body weight, which applies to iron from all sources except for iron oxides used as colouring agents and iron supplements taken during pregnancy and lactation or for specific clinical requirements. An allocation of 10% of this PMTDI to drinking-water gives a value of about 2 mg/l, which does not present a hazard to health. The taste and appearance of drinking-water will usually be affected below this level, WHO (2011).

- **Chromium**

Chromium is widely distributed in Earth’s crust. It can exist in valences of +2 to +6. In general, food appears to be the major source of intake. Chromium (III) is an essential nutrient. Provisional guideline value for Total chromium: 0.05 mg/l (50 µg/l). The Occurrence Total chromium concentrations in drinking-water usually less than 2 µg/l, although concentrations as high as 120 µg/l have been reported.

There are no adequate toxicity studies available to provide a basis for a No-observed-adverse-effect level (NOAEL) and this serve as a basis of guideline value derivation. The guideline value was first proposed in 1958 for hexavalent chromium, based on health concerns, but was later changed to a guideline for total chromium because of difficulties in analyzing for the hexavalent form only.

Limit of detection is 0.05–0.2 µg/l for total chromium by AAS. Treatment performance of 0.015 mg/l should be achievable using coagulation.

Chromium in drinking-water is a long-term carcinogenicity study in rats given chromium (III) by the oral route, no increase in tumour incidence was observed. In rats, chromium (VI) is a carcinogen via the inhalation route, although an NTP study has shown evidence for carcinogenicity via the oral route at high doses. However, there is evidence that the dose–response relationship at low doses is non-linear, because chromium (VI) is reduced to chromium (III) in the stomach and gastrointestinal tract.

In epidemiological studies, an association has been found between exposure to chromium (VI) by the inhalation route and lung cancer. IARC has classified chromium (VI) in Group 1 (human carcinogen) and chromium (III) in Group 3 (not classifiable as to its carcinogenicity to humans). Chromium (VI) compounds are active in a wide range of in vitro and in vivo genotoxicity tests, whereas chromium (III) compounds are not.

- **Copper**

Copper is both an essential nutrient and a drinking-water contaminant. It is used to make pipes, valves and fittings and is present in alloys and coatings. Copper sulfate pentahydrate is sometimes added to surface water for the control of algae. Copper concentrations in drinking-water vary widely, with the primary source most often being the corrosion of interior copper plumbing. Levels in running or fully flushed water tend to be low, whereas those in standing or partially flushed water samples are more variable and can be substantially higher (frequently above 1 mg/l). Copper concentrations in treated water often increase during distribution, especially in systems with an acid pH or high-carbonate waters with an alkaline pH.

Food and water are the primary sources of copper exposure in developed countries. Consumption of standing or partially flushed water from a distribution system that includes copper pipes or fittings can considerably increase total daily copper exposure, especially for infants fed formula reconstituted with tap water.

Guideline value is 2 mg/l (2000 µg/l). The Occurrence Concentrations in drinking-water range from ≤0.005 to >30 mg/l, primarily as a result of the corrosion of interior copper plumbing. The Basis of guideline value derivation is to be protective against acute gastrointestinal effects of copper and provide an adequate margin of safety in populations

with normal copper homeostasis. Limit of detection is 0.02–0.1 µg/l by ICP-MS; 0.3 µg/l by ICP–optical emission spectroscopy; 0.5µg/l by flame AAS

Copper is not removed by conventional treatment processes. However, copper is not normally a raw water contaminant. For adults with normal copper homeostasis, the guideline value should permit consumption of 2 or 3 litres of water per day, use of a nutritional supplement and copper from foods without exceeding the tolerable upper intake level of 10 mg/day or eliciting an adverse gastrointestinal response.

Staining of laundry and sanitary ware occurs at copper concentrations above 1 mg/l. At levels above 2.5 mg/l, copper imparts an undesirable bitter taste to water; at higher levels, the colour of water is also impacted. In most instances where copper tubing is used as a plumbing material, concentrations of copper will be below the guideline value. However, there are some conditions, such as highly acidic or aggressive waters, that will give rise to much higher copper concentrations, and the use of copper tubing may not be appropriate in such circumstances.

- **Copper in Drinking-Water**

IPCS concluded that the upper limit of the acceptable range of oral intake in adults is uncertain but is most likely in the range of several (more than 2 or 3 mg/day), but not many, milligrams per day in adults. This evaluation was based solely on studies of gastrointestinal effects of copper-contaminated drinking-water. The available data on toxicity in experimental animals were not considered helpful in establishing the upper limit of the acceptable range of oral intake owing to uncertainty about an appropriate model for humans, but they help to establish a mode of action for the response. The data on the gastrointestinal effects of copper must be used with caution, as the effects observed are influenced by the concentration of ingested copper to a greater extent than the total mass or dose ingested in a 24-hour period.

Recent studies have delineated the threshold for the effects of copper in drinking-water on the gastrointestinal tract, but there is still some uncertainty regarding the long-term effects of copper on sensitive populations, such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis.

Heavy Metal Pollution

Motivation for controlling heavy metal concentrations in gas streams are diverse. Some of them are dangerous to health or to the environment (e.g. mercury, cadmium, lead, and chromium), Michael (2010). some may cause corrosion (e.g. lead) some are harmful in other ways (e.g. arsenic may pollute catalysts), Abdual and Sabah (2001), within the European community the eleven elements of highest concern are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin and thallium, the emissions of which are regulated in waste incinerators. Some of elements are actually necessary for humans in minute amounts (Cobalt, copper, chromium, manganese, nickel)

while others are carcinogenic or toxic, affecting among others, the central nervous system (manganese, mercury, lead, arsenic), the kidneys or liver (mercury, lead, cadmium, copper) or skin, bones or teeth (nickel, cadmium, copper, chromium), Rons and Pia (2001). Heavy metal pollution can arise from many sources but most commonly arises from the purification of metals e.g. the smelting of copper and the preparation of nuclear fuels.

Heavy metals do not decay and thus pose a different kind of challenge for remediation. Plants, mushrooms or microorganism are occasionally successfully used to remove some heavy metals such as mercury. Plants which exhibit hyper accumulation can be used to remove heavy metals from soils by concentrating them in their bio matter. One of the largest problems associated with persistence of heavy metals is the potential bioaccumulation and bio magnification causing heavier exposure for some organisms that is present in the environment alone. Coastal fish (such as the smooth toadfish) and seabirds (such as the Atlantic puffin) are often monitored for the presence of such contaminants. The fungus *Aspergillus Niger* plays a role in the solubilization of heavy metal sulfides.

Analytical Methods

In volumetric titration, chemicals are analysed by titration with a standardized titrant. The titration end-point is identified by the development of colour resulting from the reaction with an indicator, by the change of electrical potential or by the change of pH value.

Colorimetric methods are based on measuring the intensity of colour of a coloured target chemical or reaction product. The optical absorbance is measured using light of a suitable wavelength. The concentration is determined by means of a calibration curve obtained using known concentrations of the determinant. The ultraviolet (UV) method is similar to this method except that UV light is used. For ionic materials, the ion concentration can be measured using anion selective electrode. The measured potential is proportional to the logarithm of the ion concentration. Some organic compounds absorb UV light (wavelength 190–380 nm) in proportion to their concentration. UV absorption is useful for qualitative estimation of organic substances, because a strong correlation may exist between UV absorption and organic carbon content, WHO (2011).

Water Analysis Accuracy

Precision is spread around, that is, high precision means a low standard deviation. For optimum estimates of the precision is obtainable from an analytical laboratory, duplicates should be submitted in different batches, and if it is possible, on different days. For example, different designations should be used. Accuracy, on the other hand, is how close to the true value of the analyses; an analysis may be accurate even if the standard deviation is high. The problem is that in most of the cases the true value is not known. The standard solutions are available that may be run with the samples as part of the

quality assurance procedure. Also, one or more standard or spiked samples are submitted with the samples would allow a relative unbiased of the laboratory accuracy, Hounslow (1995).

Standards

In the setting of standards, agencies make political and technical/scientific decisions about how the water will be used. In the case of natural water bodies, they also make some reasonable estimate of pristine conditions. Different uses raise different concerns and therefore different standards are considered. Natural water bodies will vary in response to environmental conditions. Environmental scientists work to understand how these systems function, which in turn helps to identify the sources and fates of contaminants. Environmental lawyers and policymakers work to define legislation with the intention that water is maintained at an appropriate quality for its identified use.

The vast majority of surface water on the planet is neither potable nor toxic. This remains true when seawater in the oceans (which is too salty to drink) is not counted. Another general perception of water quality is that of a simple property that tells whether water is polluted or not. In fact, water quality is a complex subject, in part because water is a complex medium intrinsically tied to the ecology of the Earth. Industrial and commercial activities (e.g. manufacturing, mining, construction, transport) are a major cause of water pollution as are runoff from agricultural areas, urban runoff and discharge of treated and untreated sewage. Standards for drinking water includes, among others Safe Drinking Water Act (SDWA), WHO drinking water standard and Nigerian standards for drinking water quality (NSDWQ)

World Health Organization (WHO)

The World Health Organization is a specialized agency of the United Nations (UN) that is concerned with international public health. It was established on 7 April 1948, headquartered in Geneva, Switzerland. WHO is a member of the United Nations Development Group. Its predecessor, the Health Organization, was an agency of the League of Nations. The constitution of the World Health Organization had been signed by 61 countries on 22 July 1946, with the first meeting of the World Health Assembly finishing on 24 July 1948. It incorporated the Office International d'Hygiène Publique and the League of Nations Health Organization. Since its creation, it has played a leading role in the eradication of smallpox. Its current priorities include communicable diseases, in particular, HIV/AIDS, malaria and tuberculosis; the mitigation of the effects of non-communicable diseases; sexual and reproductive health, development, and aging; nutrition, food security and healthy eating; occupational health; substance abuse; and drive the development of reporting, publications, and networking. WHO is responsible for the World Health Report, a leading international publication on health, the worldwide World Health Survey, and World Health Day (7 April of every year).

Drinking Water Standard

Groundwater drinking water quality standard according to WHO (2011), are summarized in the table below.

Table 2. 2. Drinking water Specification WHO (2011)

Parameter	WHO Specification
Turbidity	Less than 5 NTU (Desirable)
pH	6.5-8.5 (Desirable)
Conductivity	250 mS/cm
Colour	15 mg/l Pt-Co
Dissolved Oxygen	Less than 75% of the saturation concentration. (Desirable)
Total Hardness	150-500 mg/l (Desirable)
Total Dissolved Solids	-
Chromium	0.05mg/l
Copper	2mg/l
Iron	0.3mg/l (Desirable)
Chloride	250mg/l
Nitrate	50mg/l
Coliform Count	

Water Quality

Water quality refers to the chemical, physical, biological, and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed. The most

common standards used to assess water quality relate to health of ecosystems, safety of human contact and drinking water.

Water Quality Index

Water quality index provides a single number that expresses overall water quality at a certain location and time, based on several water quality parameters. The objective of water quality index is to turn complex water quality data into information that is understandable and usable by the public. A single number cannot tell the whole story of water quality; there are many other water quality parameters that are not included in the index. However, a water quality index based on some very important parameters can provide a simple indicator of water quality. In general, water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of a water body with number. The water quality index (WQI) that reflects the extent of the ground water pollution.

Water Quality Index Scale

The Water Quality Index uses a scale from 0 to 100 to rate the quality of the water, with 100 being the highest possible score. Once the overall WQI score is known, it can be compared against the following scale to determine how healthy the water is on a given day.

Table 2. 3. Water Quality Index Scale Rating

Range	WQI Quality Scale
91 - 100	Excellent water quality
71 - 90	Good water quality
51 - 70	Medium or average water quality
26 - 50	Fair water quality
0 - 25	Poor water quality

Water supplies with ratings falling in the good or excellent range would be able to support a high diversity of aquatic life. In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water. Water supplies achieving only an average rating generally have less diversity of aquatic organisms and frequently have increased algae growth. Water supplies falling into the fair range are only able to support a low diversity of aquatic life and are probably experiencing problems with pollution. Water supplies that fall into the poor category may only be able to support a limited number of aquatic life forms, and it is expected that these waters have abundant quality problems. A water supply with a poor quality rating would not normally be considered acceptable for activities involving direct contact with the water, such as swimming.

METHODOLOGY

Study Area

Woji is located in Obio-akpor Local Government Area of Port Harcourt City in Rivers State Nigeria, which has total Population of about 500,000 and spans an area of 260 km². Woji is situated at Latitude 4.788' and Longitude 7.001' N. It is mainly residential with hospitals, railway and other social amenities. The major industries are the Alcon Jetty, YKC filling station, and Slaughter market, to mention a few. Woji River is a significant surface water source in the area. The region is characterized by two major seasons – wet and dry seasons. The wet season begins in March and ends in October, with a peak in June and July. There is commonly a period of little or no rain in August, popularly known as “August Break”. Annual mean rainfall in the area is over 3000mm, Iloeje (1979); Ojo and others (1992).

The mean maximum monthly temperatures that range from 28°C to 33°C, while the mean minimum monthly temperatures are in the range of 17°C to 24°C. The mean monthly temperature is in the range of 25°C to 28°C. The mean annual temperature for the state is 26°C. The hottest months are February to May. The difference between the dry season and wet season temperatures is only about 2°C. Relative humidity is high in the State throughout the year and decreases slightly in the dry season.

Table 3. 1. The geo-references of the sampling points in the study area.

Points	Sampling stations	Latitude	Longitude
Point 1 – Control	Rumuobiokani	4° 49'51.13"N	7° 1'53.68"E
Point 2	Mgba Street, Woji rd.	4° 50'15.93"N	7° 2'45.64"E
Point 3	Ichegbu Ave.	4° 50'8.99"N	7° 3'18.15"E
Point 4	Amadi – Odum str.	4° 49'46.48"N	7° 2'50.73"E
Point 5	Slaughter Market	4° 48'47.23"N	7° 2'40.12"E
Point 6	Ogbonada Alcon road	4° 48'51.42"N	7° 3'31.81"E
Point 7	Alcon Jetty	4° 48'45.93"N	7° 3'31.07"E
Point 8	John Eke Str	4° 49'13.30"N	7° 3'49.09"E
Point 9	Denis Ufot Str	4° 49'25.79"N	7° 3'11.41"E
Point 10	Calvaj Str.	4° 49'46.03"N	7° 3'38.56"E



Figure 3. 1. A Satellite View of the Study Area

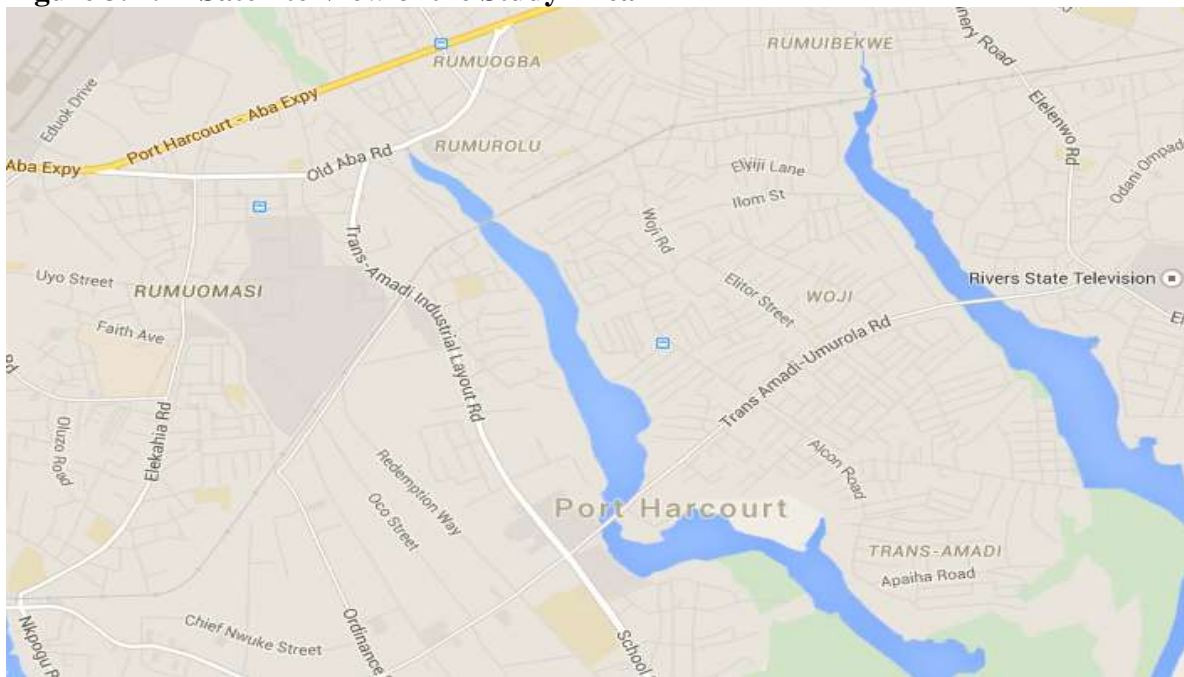


Figure 3. 2. A Map View of the study Area

Data Collection

Duplicate sampling was done for the nine randomly selected areas close to Woji River and slaughter market, the tenth point used as control was selected from Rumuobiokani. Twenty Nalgen bottles of 500mls capacity were used in collecting the samples. This was done by first rinsing the containers with distilled water and then a portion of the sample to be collected. Each sample was aseptically collected, immediately covered to avoid air bubbles and appropriately labelled. The Samples were stored in a cooler containing ice packs and were analyzed on arrival to the laboratory.

Data Analysis

The samples were sent to the laboratory for analysis after the in-situ parameters have been analyzed onsite. The following parameters were measured and the Water Quality Index calculated.

pH / Temperature (ASTMD1293)

pH reading was done in-situ using a portable Temperature and pH probe of Hanna microprocessor model. A three-point standardization with a buffer solution is done before taking the pH reading.

Electrical Conductivity (EC)

This measurement was done in-situ with a portable bench top ysi model 3200 conductivity/total dissolved solids/resistance, salinity temperature instrument. The meter is equipped with an internal temperature correction. After equipment calibration and standardization with a calibration standard. The probe is rinsed repeated with distilled water and gently dipped in the solution until a stable reading was obtained and recorded.

Dissolved Oxygen

This was done in-situ using Winkler's method. An excess of Manganese (II) salt, iodide (I-) and hydroxide (OH-) ions were added to the samples causing a white precipitate of $Mn(OH)_2$ to form. This precipitate was then oxidized by the dissolved oxygen in the water sample into a brown Manganese precipitate. The sample was acidified with Hydrochloric acid converting the precipitate from iodide ion to iodine. The amount of dissolved oxygen is directly proportional to the titration of iodine with a thiosulphate solution. The presence of oxygen is indicated by the formation of a brownish – Orange precipitate.

Biological Oxygen Demand

The method involves filling the samples to overflowing, in an airtight bottle of the specified size and incubating it at the specified temperature for 5days. Dissolved Oxygen is measured before and after the 5-day incubation period and BOD is computed from the difference between initial and final (DO).

Equation 3. 1. BOD Calculation

$$\text{BOD (mg/l)} = \frac{\text{DO}_1 - \text{DO}_2}{B}$$

Where DO_1 = initial dissolved oxygen (immediately after preparation)

DO_2 = final dissolved oxygen (after 5 days incubation)

B = Volume of sample used.

1.1.1. Chloride (ASTMD4458)

A portion of the sample was titrated with Silver Nitrate in the presence of chromate ions. Chloride ions react preferentially with silver ions. Excess silver ions react with chromate to form silver chromate, which indicates the end point of the reaction. Salinity as chloride is reported in mg/l after calculations.

Equation 3. 2. Chloride Calculation

$$\text{Mg Cl}^-/\text{L} = \frac{(A - B) \times N \times 35450}{\text{mL sample}}$$

where:

A = mL titration of AgNO_3 for sample,

B = mL titration for blank, and

N = normality of AgNO_3 .

Metals Analysis

The heavy metals analyzed in the borehole water samples include Chromium, Copper and Iron. The concentration in mg/l of the specified heavy metals in the collected samples were determined using Hach spectrophotometer. Specific metal standards in the linear range of the sample were used to calibrate the equipment. (HACH, 2001).

Copper

Copper in the sample reacts with a salt of bicinchoninic acid contained in CuVer 1 or CuVer 2 Copper Reagent to form a purple coloured complex in proportion to the copper concentration. Test results are measured at 560nm.

Iron

FerroVer Iron Reagent converts all soluble iron and most insoluble forms of iron in the sample to soluble ferrous iron. The ferrous iron reacts with the 1, 10 phenanthroline indicator in the reagent to form an orange colour in proportion to the iron concentration. Test results are measured at 510nm.

Turbidity (APHA 2130B)

Turbidity of collected samples were analyzed using a HACH Turbidimeter 2100A as described in the Standard Method APHA 2130-B and measured in Nephelometric Turbidity Units (NTU). This method is based on a comparison of the intensity of light

scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity.

Total Dissolved Solids (APHA 2540C)

This was determined by evaporation and gravimetry using a 0.45 micron filter paper, evaporating dish and an oven with a temperature of 103 to 105°C.

Total Hardness (APHA 3500-Ca B)

This is done by Complexometric-Titrimetry Method. EDTA (Ethylene diamine tetra acetic acid or its salt) is added to a water sample containing calcium and magnesium ions after adjusting the pH of the sample to 10 for the determination of calcium and magnesium or from pH of 12 to 13 for the determination of calcium alone. At pH 10, EDTA initially complexes with calcium and then magnesium ions. The end point is detected by use of Erichrome black T (total hardness). At a pH of 12 to 13 magnesium is precipitated and calcium forms complex with EDTA. The concentration of calcium is determined from the volume of EDTA used in the second aliquot (Ca-hardness). Magnesium is determined by the difference between the total hardness and calcium hardness titre values.

Equation 3. 3. Total Hardness Calculation

$$\text{mgCaCO}_3/\text{L} = \frac{\text{A} \times \text{B} \times 1000}{\text{ml sample}}$$

where :

A = ml of EDTA standard solution (titrant) used for the water sample

B = mgCaCO₃ equivalent to 1.00 mL EDTA titrant

Sulphate

Sulphate ions in the sample react with barium in the SulfaVer 4 and form a precipitate of barium sulfate. The amount of turbidity formed is proportional to the sulfate concentration. Test results are measured at 450 nm.

Alkalinity

This method applies titrimetry and potentiometric principles. Alkalinity is caused by the presence of a number of different ions, but is usually attributed to the presence of Carbonate, Bicarbonate and Hydroxyl ions. Hence, an aliquot of the sample is titrated with standard acid solution to the phenolphthalein and methyl orange end points. The endpoints of titration represent pH values of approximately 8.3 and 4.5 respectively.

Equation 3. 4. Total Alkalinity Calculation

$$\text{Mg/L Total Alkalinity (as CaCO}_3) = \frac{\text{ml acid} \times \text{Normality acid} \times 50 \times 1000}{\text{ml sample}}$$

1.2. Water Quality Index

The WQI is based on the results of nine chemical/physical tests:

- Dissolved Oxygen (DO)
- Fecal Coliform (FC)
- pH
- Biochemical Oxygen Demand (BOD)
- Temperature Change
- Total Phosphates
- Nitrates
- Turbidity
- Total Dissolved Solids (TDS)

These tests were chosen because they significantly impact aquatic organisms and are inexpensive to perform. After completing the nine tests, the results are recorded and transferred to a weighting curve chart where a numerical value (Q-value) is obtained.

For each test, the Q-value is then multiplied by a “weighting factor.”

The nine resulting values are then added to arrive at an overall water quality index (WQI).

Quality Control / Quality Assurance

The following quality control / assurance precautions were taken in order to achieve results of high confidence level:

- All sampling bottles were new, washed with detergent, and rinsed properly with distilled water, oven-dried at 105 Celsius for at least one hour ready for use.
- All reagents and sampling bottles were kept in the coolers containing ice block before going to the field.
- The sample container were filled to the brim to discourage air bubbles for BOD and DO samples.
- All samples were clearly labeled stating: Sample Location /source, Sample Type, Time/Date collected, Name of sampler, Parameters for test.
- All analysis, were performed by operators of proven competence. Work instructions and procedures used for the analysis were adopted from ASTM and APHA
- Emphasis was on accuracy, precision and sensitivity of the analytical methods.
- Reagent and chemicals used were of analytical or American Chemical Society (ACS) grade and were of good quality.
- Calibration status of field and laboratory equipment was checked before every sampling trip and analysis. Recalibrated was done if any was found to be out of range.
- Sample analyses were performed in duplicate and mean values were reported.

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- Reagent blanks were analyzed to monitor the purity of the reagents as well as the overall procedural blank. For every batch of ten samples, sample blanks were measured and subtracted from those of the sample
- Results were recorded into analysts' notebook before transferring to the analysis result sheet.

RESULTS AND DISCUSSION

Results

The physico-chemical parameters of the ten boreholes investigated with the WHO specification are presented in Table 4.1. Table 4.2 presents the metal ions present in the ten borehole samples and the WHO specifications. Table 4.3 shows the weighted mean for the nine WQI parameters. Table 4.4 demonstrates Q-value of the nine WQI parameters for the various investigated points while Table 4.5 shows the Water Quality Index of the Various Investigated Points. Graph 4.1.1 shows the correlation between Iron, Colour, Odour and pH at various investigated points.

Table 4. 1. Average Results of the Physico-chemical parameters measured for the ten borehole samples investigated.

Parameter	WHO Spec.	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
Colour (Hazen/Visual)	15.00 Colourless	5.0 colourless	6.00 colourless	6.00 colourless	3.00 colourless	17.00 / Slightly coloured	5.00 colourless	20.00 / Slightly coloured	7.00 colourless	2.00 colourless	5.00 colourless
Odor / Taste	Odorless Tasteless	Odorless Tasteless	Odorless Tasteless	Odorless Tasteless	Odorless Tasteless	Odorless Metallic	Odorless Tasteless	Odorless Metallic	Odorless Tasteless	Odorless Tasteless	Odorless Tasteless
pH @ 25°C	6.50 – 8.50	6.99	6.65	8.42	8.10	5.32	6.72	6.02	8.23	7.82	8.67
EC (us/cm)	NA	76.00	153.00	148.10	137.00	146.80	61.50	97.40	142.50	113.20	59.7
Temperature °C	NA	24.5	27.50	28.47	26.86	30.0	27.50	28.4	27.95	28.00	27.43
Turbidity (NTU)	5.00	0.11	2.57	3.28	1.95	6.15	4.38	6.72	0.58	3.67	3.81
Chloride (mg/l)	250.00	11.72	18.23	19.00	11.62	15.81	16.52	10.98	12.05	9.25	14.20
Sulphate (mg/l)	400.00	2.00	5.00	8.00	2.00	2.00	4.00	5.00	3.00	7.00	2.00
DO (%sat)	4 - 10	8.96	5.70	6.10	4.87	7.71	5.68	4.69	6.58	5.84	6.10
BOD (mg/l)	4.00	0.89	3.84	2.32	3.42	2.94	1.98	3.50	1.25	2.49	1.92
Nitrates (mg/l)	45.00	0.02	0.19	0.05	1.05	2.45	0.15	0.27	1.62	0.85	0.49
FC (count/100cm ³)	0.00	0.00	0.00	0.00	0.00	5	0.00	2	0.00	0.00	0.00
TDS (mg/l)	500.00	83.00	107.00	70.56	108.50	153.40	95.80	92.51	85.34	100.62	93.56
TH (mg/l)	500.00	26.84	30.40	29.51	51.84	31.50	40.76	52.62	32.50	42.85	25.82
Alkalinity (mg/l)	200.00	45.00	95.00	84.30	55.32	105.2	162.2	76.30	82.30	85.10	96.2
Phosphate (mg/l)	0.1	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005

Table 4. 2. Metal ion levels in the investigated borehole samples.

Parameter	WHO Specification	Point 1 Control	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
Iron (mg/l)	0.30	0.06	0.04	0.02	0.06	0.38	0.05	0.45	0.06	0.03	0.24
Copper (mg/l)	1.00	0.02	0.08	0.04	0.02	0.01	0.06	0.09	0.02	0.02	0.03
Chromium (mg/l)	0.05	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table 4. 3. Weighted mean for the nine WQI parameters

Parameter	Weight (W _i)
pH	0.12
Temperature Change	0.11
Dissolved oxygen	0.18
Biochemical Oxygen Demand	0.12
Turbidity	0.09
Phosphate	0.11
Nitrates	0.10
Feecal Coliform	0.17

Table 4.4. Q-value of the nine WQI parameters for the various investigated points.

Parameter	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
pH	89	67	75	83	32	83	56	80	88	67
Temperature	14	12	11	12	10	12	11	11	11	12
Dissolved oxygen	7	5	5	5	6	6	4	6	5	5
BOD	91	66	79	70	73	81	69	88	77	82
Turbidity	96	82	89	92	83	87	82	96	88	88
Phosphate	98	98	98	98	98	98	98	98	98	98
Nitrates	98	97	98	72	49	97	95	61	77	89
Feecal Coliform	98	98	98	98	79	98	90	98	98	98

Table 4. 4. Water Quality Index of the various investigated points.

Sampling Point	WQI	Quality
Point 1	70.19	Good
Point 2	62.74	Medium
Point 3	65.93	Medium
Point 4	63.42	Medium
Point 5	51.67	Medium
Point 6	67.16	Medium
Point 7	60.08	Medium
Point 8	64.58	Medium
Point 9	65.20	Medium
Point 10	64.45	Medium

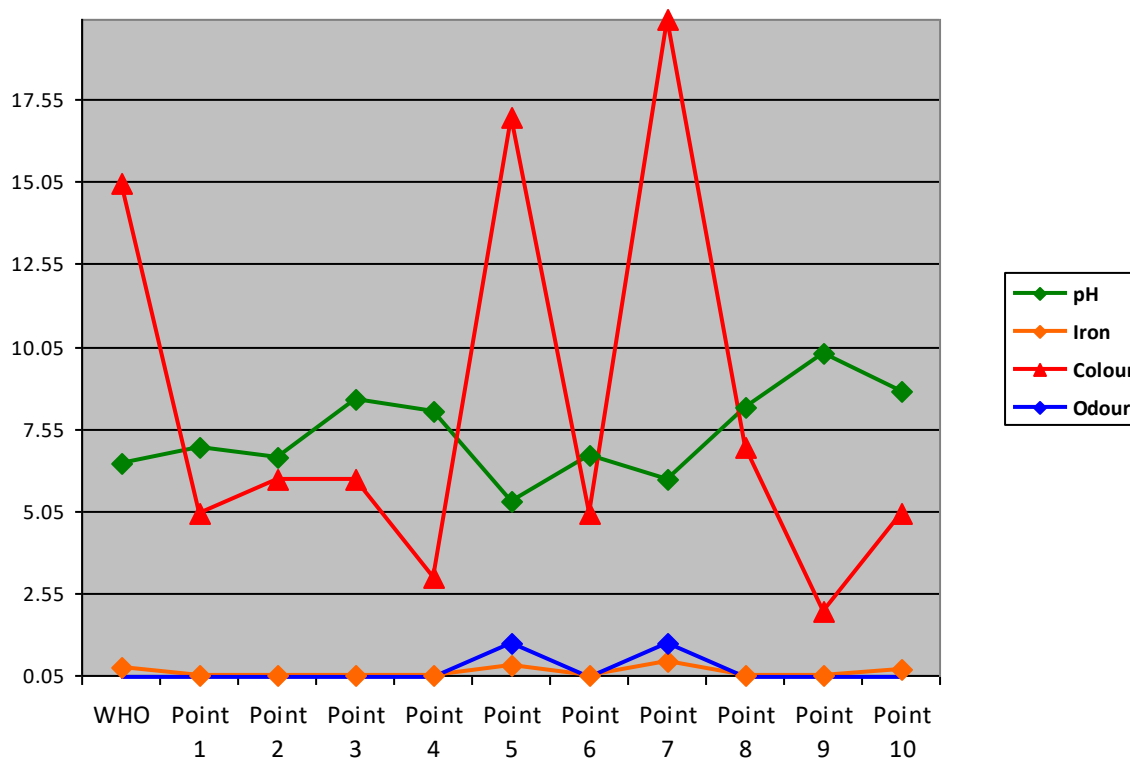


Figure 4.1. pH, Iron, Colour and Odour relationship of the various investigated point

DISCUSSION

In spite of the increasing need for water resources in both developed and developing countries, understanding of pollutants in these aquatic environments is quite strewn. In addition, chemical pollutants that enter surface waters through various pathways may pose a significant health hazard even at extremely low concentrations, especially persistent chemicals (McMichael et al., 2001). pH is the measure of hydrogen ion or hydroxide ion concentration in a solution. The results were within the acceptable range of 6.5 – 8.5 except for Points 2, 5, 7 and 10. Point 2 and 10 are slightly alkaline with Point 5 and 7 being slightly acidic. According to the World Health Organization, health effects are most pronounced in pH extremes. Drinking water with an elevated pH above 11 can cause skin, eye and mucous membrane irritation. On the opposite end of the scale, pH values below 4 also cause irritation due to the corrosive effects of low pH levels. WHO warns that extreme pH levels can worsen existing skin conditions.

The pH is of major importance in determining the corrosivity of water. In general, the lower the pH, the higher the level of corrosion. However, pH is only one of a variety of factors affecting corrosion. Exposure to extreme pH values results in irritation to the eyes, skin, and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, solutions of pH 10–12.5 have been reported to cause hair fibers to swell. In sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive. In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health.

The results exceeded the WHO standard of 5 NTU with point 5 and 7 having as high as 6.15 and 6.72 NTU respectively and relatively high Feecal Coliform values of 5 and 2 count/100cm³ as against the WHO standard value of 0.00 count/100cm³. This agrees with the findings of Yisa et al, 2010 and Mark et al, 1981. High turbidity indicated high risk to disease causing microorganisms such as viruses, parasites, some bacterial and carriers of variety of materials such as pesticides, heavy metals. . Excessive turbidity in water can cause problem for water purification processes such as flocculation and filtration which may increase treatment cost. Again, turbidity causes decrease in photosynthesis process since turbidity precludes deep penetration of light in water, Muoghalu and Omocho (2000).

Feecal Coliforms presence is an indicator of fecal contamination. This may be due to the close distance of septic systems and the groundwater sources. An improperly designed, located, constructed, or maintained septic system can leak bacteria, viruses, household chemicals, and other contaminants into the groundwater causing serious problems, Sangodoyin (1993).

The temperature of the investigated points fall within the range of 24.5°C to 30.0 °C. high temperature in drinking water leads to low oxygen because the rate of dissolution of gases in water decreases with increasing temperature. Low oxygen in water affects taste and other aesthetic property of water.

Point 5 shows a slightly coloured value of 17 with a metallic taste while Point 7 has a slightly coloured value of 20 with a metallic taste. These were out of range from the WHO standard values of 15 (Colourless) for colour and Odorless for Taste. Taste and odour can originate from natural inorganic and organic chemical contaminants and biological sources or processes (e.g. aquatic microorganisms), from contamination by synthetic chemicals, from corrosion or as a result of problems with water treatment (e.g. chlorination). Taste and odour may also develop during storage and distribution as a result of microbial activity.

High values of Iron were observed in Point 5 and 7 which has a value of 0.38 mg/l and 0.45 mg/l respectively as compared with the WHO standard value of 0.3mg/l. This may be due to rusty pipes or reduced effectiveness of water treatment for other contaminants. Iron is considered a secondary household water contaminant with no known health related issues at concentrations normally found in household drinking water. This is because unlike lead and copper, ingesting iron from drinking water is not directly associated with adverse health effects. The effects associated with iron contamination can be grouped into two categories.

- Aesthetic effects are undesirable tastes or odors. Iron in quantities greater than 0.3 milligrams per liter (mg/L) in drinking water can cause an unpleasant metallic taste and rusty color.
- Physical/Technical effects are damages to water equipment and reduced effectiveness of water treatment for other contaminants. This may cause additional costs to water utilities. Corrosion of distribution system pipes can produce sediment or loose deposits that block or slow down water flow. The effect of pH on water are as below:
 - Low pH: bitter metallic taste; corrosion
 - High pH: slippery feel; soda taste; deposits

As shown in Graph 4.1, the relationship between Iron, pH, colour and taste. There is a proportional increase in Iron, colour and taste as pH tends to be acidic.

The overall water quality indexes according to Table 4.1.5 revealed that the quality of the Control sample was “Good” and for the various investigated points was “Medium.”

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

The results were within the acceptable range of 6.5 – 8.5 except for Points 2, 5, 7 and 10. Point 2 and 10 are slightly alkaline with Point 5 and 7 being slightly acidic. The results exceeded the WHO standard of 5 NTU with point 5 and 7 having as high as 6.15 and 6.72 NTU respectively and relatively high Faecal Coliform values of 5 and 2 count/100cm³ as against the WHO standard value of 0.00 count/100cm³. The temperature of the investigated points fall within the range of 24.5°C to 30.0 °C. Point 5 shows a slightly coloured value of 17 with a metallic taste while Point 7 has a slightly coloured value of 20 with a metallic taste. These were out of range from the WHO standard values of 15 (Colourless) for colour and Odorless for Taste. High values of Iron were observed in Point 5 and 7 which has a value of 0.38 mg/l and 0.45 mg/l respectively as compared with the WHO standard value of 0.3mg/l.

CONCLUSION

This study revealed that all the treated physico-chemical parameters monitored in the effluent water from the facilities compartment, complied with the specified DPR limit exception of iron that exceeded the limit with the value of 4.02mg/l. The observed non-

conformances for iron could be due to plant ineffectiveness or as a result of personnel's incompetent.

The study as also proved that there is need for untreated effluent to be treated before disposal based on the fact that when the untreated were compared with treated it showed a significant difference.

Recommendation

Water contaminants can be removed or drastically minimized to an acceptable limit by using physical or chemical means. Some proven techniques for Particulate matter (Turbidity), Iron, Colour, pH and Taste treatment or removal are recommended below.

Sangodoyin (1987) gave the following considerations as a way of reducing groundwater contamination or pollution:

- A well should be sited uphill of a polluting source. This is with a view to diverting to drain from the well into a polluting source rather than converse, Ojo (2002).
- The distance between a well and a polluting source should not less than 30 m (100 feet).
- Well construction should start towards the end of the dry season.

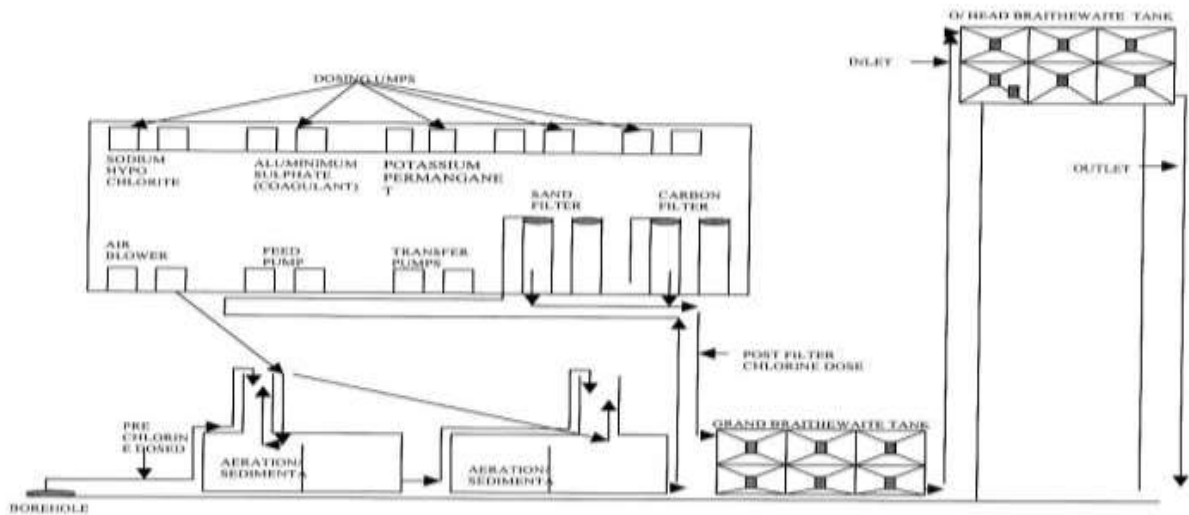


Figure 5. 1. Flow Diagram of SPDC Soku Water Treatment Plant, Nwaogazie (2011)

The flow-diagram of the Soku Water Treatment Plant portrays a case of aeration-filtration method. Pre-chlorination add value to the chlorine-oxidation process. The system appears to be the most adequate of all SPDC water treatment plants in the sense that it has the following components:

- Pre-chlorination to aid chemical oxidation;
- Aeration-sedimentation unit;
- Sodium Hypochlorite as pH adjuster;
- Aluminum sulphate as coagulant to aid sedimentation;
- Potassium permanganate to regenerate sand filter;
- Carbon filter to aid the adsorption of dissolved metals (heavy metals); and
- Post chlorination for disinfection, Nwaogazie (2011).

Chlorination

Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and on-site chlorine generators. Liquefied chlorine gas is supplied in pressurized containers. The gas is withdrawn from the cylinder and dosed into water by a chlorinator, which both controls and measures the gas flow rate. Sodium hypochlorite solution is dosed using a positive-displacement electric dosing pump or gravity feed system. Calcium hypochlorite has to be dissolved in water, then mixed with the main supply. Chlorine, whether in the form of chlorine gas from a cylinder, sodium hypochlorite or calcium hypochlorite, dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl).

Different techniques of chlorination can be used, including breakpoint chlorination, marginal chlorination and superchlorination/dechlorination. Breakpoint chlorination is a method in which the chlorine dose is sufficient to rapidly oxidize all the ammonia nitrogen in the water and to leave a suitable free residual chlorine available to protect the water against reinfection from the point of chlorination to the point of use. Superchlorination/dechlorination is the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction, followed by reduction of excess free chlorine residual. Removing excess chlorine is important to prevent taste problems.

It is used mainly when the bacterial load is variable or the detention time in a tank is not enough. Marginal chlorination is used where water supplies are of high quality and is the simple dosing of chlorine to produce a desired level of free residual chlorine. The chlorine demand in these supplies is very low, and a breakpoint might not even occur. Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal or chemical conversion of some chemicals—for example, decomposition of easily oxidized pesticides, such as aldicarb; oxidation of dissolved species (e.g. manganese (II)) to form insoluble products

that can be removed by subsequent filtration; and oxidation of dissolved species to more easily removable forms (e.g. arsenite to arsenate).

A disadvantage of chlorine is its ability to react with natural organic matter to produce trihalomethanes and other halogenated disinfection by-products. However, by-product formation may be controlled by optimization of the treatment system.

Filtration

Particulate matter can be removed from raw waters by rapid gravity, horizontal, pressure or slow sand filters. Slow sand filtration is essentially a biological process, whereas the others are physical treatment processes. Rapid gravity, horizontal and pressure filters can be used for filtration of raw water, without pretreatment. Rapid gravity and pressure filters are commonly used to filter water that has been pretreated by coagulation and sedimentation. An alternative process is direct filtration, in which coagulation is added to the water, which then passes directly onto the filter where the precipitated floc (with contaminants) is removed; the application of direct filtration is limited by the available storage within the filter to accommodate solids.

Rapid gravity sand filters usually consist of open rectangular tanks (usually 100 m^2) containing silica sand (size range 0.5–1.0 mm) to a depth of between 0.6 and 2.0m. The water flows downwards, and solids become concentrated in the upper layers of the bed. The flow rate is generally in the range 4–20 $\text{m}^3/\text{m}^2\cdot\text{h}$. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, sometimes preceded by scouring of the sand with air. A dilute sludge that requires disposal is produced.

In addition to single-medium sand filters, dual-media or multimedia filters are used. Such filters incorporate different materials, such that the structure is from coarse to fine as the water passes through the filter.

Materials of suitable density are used in order to maintain the segregation of the different layers following backwashing. A common example of a dual-media filter is the anthracite–sand filter, which typically consists of a 0.2 m deep layer of 1.5 mm anthracite over a 0.6 m deep layer of silica sand. Anthracite, sand and garnet can be used in multimedia filters. The advantage of dual-media and multimedia filters is that there is more efficient use of the whole bed depth for particle retention—the rate of headloss development can be half that of single-medium filters, which can allow higher flow rates without increasing headloss development.

Rapid gravity filters are most commonly used to remove floc from coagulated waters. They may also be used to reduce turbidity (including adsorbed chemicals) and oxidized iron and manganese from raw waters.

Roughing filters can be applied as pre-filters prior to other processes such as slow sand filters. Roughing filters with coarse gravel or crushed stones as the filter medium can successfully treat water of high turbidity (>50 nephelometric turbidity units). The main advantage of roughing filtration is that as the water passes through the filter, particles are removed by both filtration and gravity settling. Horizontal filters can be up to 10 m long and are operated at filtration rates of 0.3–1.0 m³/m²·h.

Pressure filters are sometimes used where it is necessary to maintain head in order to eliminate the need for pumping into supply. The filter bed is enclosed in a cylindrical shell. Small pressure filters, capable of treating up to about 15 m³/h, can be manufactured in glass-reinforced plastics. Larger pressure filters, up to 4 m in diameter, are manufactured in specially coated steel. Operation and performance are generally as described for the rapid gravity filter, and similar facilities are required for backwashing and disposal of the dilute sludge.

Slow sand filters usually consist of tanks containing sand (effective size range 0.15–0.3mm) to a depth of between 0.5 and 1.5 m. The raw water flows downwards, and turbidity and microorganisms are removed primarily in the top few centimetres of the sand. A biological layer, known as the “schmutzdecke”, develops on the surface of the filter and can be effective in removing microorganisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimetres of sand containing the accumulated solids are removed and replaced periodically. Slow sand filters are operated at a water flow rate of between 0.1 and 0.3 m³/m²·h. Slow sand filters are more suitable for low-turbidity water or water that has been pre-filtered. They are used to remove algae and microorganisms, including protozoa, and, if preceded by micro-straining or coarse filtration, to reduce turbidity (including adsorbed chemicals). Slow sand filtration is effective for the removal of some organics, including certain pesticides and also ammonia.

Bank filtration is a process that produces an influx of surface water through the groundwater, via the bed and banks of the surface water body. This is commonly achieved through abstraction from boreholes adjacent to the surface water source. It is a relatively simple and low-cost means for removing particulates and microorganisms from surface water by placing pumping wells in alluvial sediments of the river or stream banks. The sediments act as both a filter and bio-filter, trapping and reducing the concentrations of microorganisms and many organic pollutants. Bank filtration wells can be either horizontal or vertical, depending upon the hydrogeological circumstances and required production rate. Horizontal wells are often used where alluvial deposits are shallow or where high pumping rates are required. Bank filtration can remove particles, bacteria, viruses, parasites, heavy metals and easily biodegradable compounds. Bank filtration attenuates concentration peaks, providing uniform quality of raw water feed to downstream treatment. The performance of bank filtration can be highly dependent upon

several factors, including soil and geological conditions as well as the quality of the source water. Bank filters can become clogged, resulting in pressure drops. Site-specific testing is needed to determine whether the appropriate geology is present as well as the effectiveness and operational parameters.

Ion exchange

Ion exchange is a process in which ions of like charge are exchanged between the water phase and the solid resin phase. Water softening is achieved by cat-ion exchange. Water is passed through a bed of cationic resin, and the calcium ions and magnesium ions in the water are replaced by sodium ions. When the ion exchange resin is exhausted (i.e. the sodium ions are depleted), it is regenerated using a solution of sodium chloride

The process of “dealkalization” can also soften water. Water is passed through a bed of weakly acidic resin, and the calcium and magnesium ions are replaced by hydrogen ions. The hydrogen ions react with the carbonate and bicarbonate ions to produce carbon dioxide. The hardness of the water is thus reduced without any increase in sodium levels. Anion exchange can be used to remove contaminants such as nitrate, fluoride, arsenate and uranium (as the uranyl anion), which are exchanged for chloride. Several appropriate resins are available for this purpose.

An ion exchange plant normally consists of two or more resin beds contained in pressure shells with appropriate pumps, pipework and ancillary equipment for regeneration. The pressure shells are typically up to 4 m in diameter, containing 0.6–1.5m depth of resin. Cation exchange can be used for removal of certain heavy metals. Potential applications of anionic resins, in addition to nitrate removal, are for removal of arsenic and selenium species

REFERENCES

- Chindah A. C., Braide A. S. and Sibendu O. C. (2004). Distribution of Hydrocarbons and Heavy metals in sediment and a crustacean (Shrimps – *Penaeus notialis*) from the Bonny/New Calabar river estuary, Niger-Delta. *Ajeam-Ragae*, 9, 1-14.
- Furtado A. A. L., Albuquerque R. T., Leite S, G. F. and Pecanha R. P. (1998). Effect of hydraulicretention time on nitrification in an airlift biological reactor. *Brazillian Journal of Chemical Engineering* 15, 1-7.
- Iioje NP (1979). *A New Geography of West Africa*, Longman Group Limited, Nigeria.
- Todd DL (1980). *Groundwater Hydrology*, John Wiley and sons, New York, pp.267 – 315.
- Yisa J., Jimoh T. and Oyibo Michael Ohiemi (2013). *Underground Water Assessment using Water Quality Index*.
- APHA *Standard Methods for the Examination of Water & Wastewater* (2005), 21st Edition by American Public Health Association pp. 4500–C1– B.

- American Standard Testing and Materials (ASTM), (1995) Water and Environmental Technology, vols. I and II.
- APHA. (1992). Standard methods for the examination of water and waste water, 18th Ed. American public health association (APHA), American water works association (AWWA), water pollution control federation (WPCF), Washington, DC.66-71.
- HACH, 2001. Hach Company, Direct Reading (DR)/3000 spectrophotometer Manual. DR/2010 spectrophotometer Handbook(2001).
- John H. Duffus “heavy metal” a meaningless term? (IUPAC technical report) “ pure and applied chemistry, 2002, Vol. 74, Pp. 793-807.
- Hounslow A.W. (1995).Water Quality Data Analysis and Interpretation.-397 p. Lewis Publishers. USA.
- Onojake M. C. and Abrakasa S. (2012) Multivariate Statistical Analysis on Pollution Level of Woji River in Port Harcourt, Nigeria. International journal of Environment and Bioenergy, 2(1) pp. 43 – 52.
- Wiki Books (2014) Drinking Water Quality Standards, Available online http://en.wikipedia.org/wiki/Drinking_water_quality_standards
- Wiki Books (2014) Obio-Akpor, Available online <http://en.wikipedia.org/wiki/Obio-Akpor>
- Wiki Books (2014) Port Harcourt, Available online http://en.wikipedia.org/wiki/Port_Harcourt
- Wiki Books (2014) World Health organization, Available online http://en.wikipedia.org/wiki/World_Health_Organization
- LGA Information Booklet Obio-Akpor LGA (2011) Patent Medicine Vendors (Pmvs)- Listing in Rivers State Pp.11 Available online http://www.thephss.org/pmv/lga_files/ObioAkpor-Info.pdf
- World Health Organization (WHO) (2011). Guidelines for Drinking-water Quality, Fourth Edition.
- Chapman M (1992). Water Quality Assessments. Chapman and Hall Ltd. WHO, UNEP, UNESCO Church Livingstone, Edinburgh, London and New York, pp. 484-488.
- Sangodoyin AY (1987). Lecture note on Advances hydraulics and water resources Department of Agricultural and Environmental Engineering. University of Ibadan, Ibadan.
- Sangodoyin AY (1993). Considerations on Contamination of Groundwater by Waste Disposal System in Nigeria Environmental Technology, 14(10): 957-264.
- Sangodoyin AY, Agbawhe OM (1991). Environmental Study on Surface and Groundwater Pollutants from Abattoir Effluents. Bioresource Tech., 41 (1992): 193-200.
- Ogedengbe O (1980). Impact of agricultural practices on water quality. Proceedings of the 1st National Conference on Water Pollution and Pesticide Residue in Foods, pp. 160-167.

Ojo OI (2002). Construction and maintenance of Borehole in Anambra State (PTF sponsored project experience) M.Sc Seminar Report University of Ibadan. Department of Agricultural and Environmental Engineering.