WATERBORNE DISEASES ASSOCIATED WITH WELLS AND STREAM WATER SOURCES FROM THREE LOCAL GOVERNMENT AREAS OF RIVERS STATE

OKWELLE, AUSTIN A.
REG. NO.: MCB/Ph.D/2013/002

A DOCTORIAL DISSERTATION CARRIED OUT IN
THE DEPARTMENT OF MICROBIOLOGY
UNIVERSITY OF CALABAR
CALABAR, NIGERIA

SUBMITTED TO

POSTGRADUATE SCHOOL
UNIVERSITY OF CALABAR
CALABAR, NIGERIA

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) IN FOOD AND INDUSTRIAL MICROBIOLOGY

NOVEMBER, 2019

DECLARATION

I, Austin, A. Okwelle with Reg. Number (MCB/Ph.D/13/002) hereby declared that this thesis titled: Waterborne diseases associated with wells and stream water sources from three local government areas of River State, Nigeria" is an original work written by me it is a record of my research work.

Okwelle, Austine A.
(Student/Candidate)

Signature:_____

Date:_____

CERTIFICATION

This is to certify that this thesis titled "Waterborne diseases associated with wells and stream water sources from three Local Government Areas of Rivers State, Nigeria" and carried out by Austin, A. Okwelle with Reg. Number MCB/Ph.D/13/002 has been examined and found worthy of the award of the degree of Doctor of Philosophy (Ph.D) in Food and Industrial Microbiology.

EXTERNAL EXAMINER

1. Name: PROF. C. A. EIOK — Signature: .....
   Status: EXTERNAL EXAMINER — Date: 19-12-2019

CHIEF SUPERVISOR

2. Name: PROF. ERNEST B. E. ASIKONG — Signature: .....
   Status: PROFESSOR — Date: 19-12-2019

SUPERVISOR

3. Name: PROFE J. A. LENNOX — Signature: .....
   Status: PROFESSOR — Date: 19-12-2019

HEAD OF DEPARTMENT

4. Name: DR(MRS) I. A. TAKON — Signature: .....
   Status: SENIOR LECTURER — Date: 19/12/2019

GRADUATE SCHOOL REPRESENTATIVE

5. Name: Prof. Okpok Okon — Signature: .....
   Status: Professor — Date: 19/12/2019

ACKNOWLEDGEMENTS

I wish to first acknowledge the Almighty God for His mercies, direction, protection, guidance and good health through the period of carrying out this programme in the University of Calabar, Cross River State, Calabar, Nigeria. I will also appreciate and commend the effort and diligence of my supervisors: Professor Ernest Bassey Asikong and Professor J. A. Lennox who did a marvellous work directing, supervising and correcting this project. I will forever remember their friendly and brotherly approach and all their assistance towards the completion of this research work.

I also wish to appreciate the concern and contributions of the Head of Department, Departmental Postgraduate Coordinator, all Lecturers of the Microbiology Department for the wonderful job they are doing in the department. The students, especially my fellow postgraduate student group are equally acknowledged for the cooperation exhibited throughout the duration of programme. I will not fail to appreciate Mrs Barine Deedum Bariagara for her support in typing the manuscript and making some necessary corrections. May God bless you all.

I also acknowledge the Federal Republic of Nigeria and the Government of Rivers State for the opportunity and security to carry out the programme in our environment.

ABSTRACT

This study investigated the occurrence of waterborne diseases associated with wells and streams water sources from some communities in Ikwerre, Emohua and Etche Local Government Areas of Rivers State. Water samples were obtained from 24 sampling sites randomly selected from the three LGA's including 6 wells and 2 streams from each LGA. Water samples from each sampling site were obtained using a sterile glass bottle on monthly basis for a period of twelve months covering both the raining and dry seasons. The total heterotrophic bacterial and fungal counts were determined using standard microbiological techniques. Using the membrane filtration technique, *E. coli* was isolated by placing the membrane filter on sterilised Eosin Methylene Blue (EMB) agar medium. To isolate *Salmonella* sp, prepared sterile *Salmonella-Shigella* (SS) agar medium was used, while Thioslpphate Citrate Bile Salts Sucrose (TCBS) medium was used to isolate *Vibrio* sp.The isolates were identified using biochemical tests and molecular analysis to establish their phylogenetic evolutionary tree. The capacity of *E. coli*, *Salmonella* and *Vibrio* species to induce waterborne disease outbreak was evaluated by carrying out enterotoxigenicity test using experimental rats. The antibiogram of *E.coli*, *Salmonella* and *Vibrio* isolated from the three Local Government Areas were determined using the multi disk diffusion method. Some physico-chemical parameters and heavy metals concentrations in each sampling site were determined according to the method described by APHA (1998) and by the use of Atomic Absorption Spectrophotometer (AAS) HACH DR 2400 model respectively.The results show that Emohua Local Government Area had the highest total heterotrophic bacterial count of 5.2 x 10^3cfu/ml. This was followed by Ikwerre LGA with total bacterial count of 4.3 x 10^2cfu/ml, while Etche LGA had 3.1 x

10^2cfu/ml. Total fungal count was also highest in Emohua Local Government Area with 3.1 x 10^4 cfu/ml. Fungal count in Ikwerre Local Government Area was 4.1 x 10^3 cfu/ml, the least fungal count was obtained in Etche Local Government Area with 3.0 x 10^2cfu/ml. The total coliform count ranged from 25cfu/100ml to 50cfu/100ml for the three LGA's, whereas the faecal coliform count was between12cfu/100ml and 20cfu/100ml.The total coliform, *E.coli, Salmonella* and *Vibrio* counts from the three local government areas occurred above the stipulated zero count in 100ml of water. The enterotoxigenicity test of *E. coli, Vibrio* and *Salmonella* isolates showed positive waterborne diseases inducement potential in experimental rats with lumen fluid accumulation ratio of 0.069, 0.067, and 0.071 respectively. The *E.coli, Salmonella* and *Vibrio* species with high enterotoxigenicity value proved to be the major pathogens of public health risk.These pathogens may be responsible for the cases of waterborne illnesses witnessed in the communities. The antibiogram profiles showed that the isolates were highly sensitive to Oflaxicin, Nitrofurantoin, Nalixidic acid, and resistant to Amoxicillin, Augumentin and Cotrimazole antibiotics. Physico-chemical parameters such as total dissolved solids, calcium, magnesium and turbidity concentrations were above WHO (2014) recommended values. Heavy metals such as cadmium, lead and mercury also occurred in higher concentrations. This reveals that the water sources are not ideal for human consumption. There is need to provide potable water sources in the affected communities to prevent the reoccurring outbreak of waterborne diseases.

(Word count: 498)

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Water is one of the nature's most important gifts to mankind, Anju *et al.* (2012). This is because water forms the largest part of most living matter, and it is the most important element to man: he can survive longer without food, than without water. A safe, reliable, affordable, and easily accessible source of water supply is essential for human living and good health. Yet, for several decades, about a billion people in developing countries have not had a safe and sustainable water supply (Jiduna *et al.*, 2013). The presence, growth and transmission of different species of pathogenic microorganisms into different water sources and various kinds of foods consumed by both man and animals constitutes a great danger to the worlds yearning for the availability of good quality water. The activities of these microorganisms result in the contamination of the water making it unwholesome which when consumed by man or animals causes waterborne diseases or food poisoning (Jesse *et al.*, 2017). The World Health Organization (WHO, 2011) described waterborne diseases or illnesses as any disease of an infectious or toxic nature caused by or thought to be caused by the consumption of water or food. This definition also includes diseases that are due to contamination from high levels or concentrations of some physico-chemicals. Divya and Sharon, (2016) stated that more than 250 different cases of waterborne disease are a direct consequence of various pathogens and toxins. Waterborne diseases can be caused by pathogenic microorganisms such as bacteria, viruses protozoa, and intestinal parasites.

Majority of the disease-causing microorganisms transmitted via drinking water are predominantly faecal in origin and are commonly called enteric pathogens, Olatunji

et al., (2015). With regards to the World Health Organization (2014) standards, drinking water should not contain any microorganisms known to be pathogenic or any bacteria indicative of faecal pollution. The use of water contaminated with domestic and industrial waste, human and animal excreta leads to the development of waterborne diseases like gastroenteritis, typhoid fever, cholera, diarrhea and bacillary dysentery, etc.

The spread of these diseases through feacal contamination of water sources particularly in developing and under developed countries are a common phenomenon that has been well reported (Anyanwu & Okoli, 2012). In Ikwerre, Emohua and Etche Local Government Areas as well as most parts of Rivers State, the availability of treated pipe-borne water is rare or non-existence. Consequently, the rich individuals dig boreholes as alternative water sources. The poor or average group, which constitute more than 80% of the population that cannot afford the high cost of borehole drilling are forced to either dig wells or resort to the use of surface stream water as alternative sources of water supply for recreation, drinking, domestic and other sanitary purposes (Niba and Nchang, 2013). The non- availability of portable water to the rural and semi urban settlements necessitates heavy reliance on coastal waters for domestic, agricultural or recreational purposes (Ajibare, 2014). There is a seeming apparent difficulty in estimating the exact morbidity and mortality rates that are the direct consequences of waterborne diseases particularly from rural communities. In the developed and developing countries, it is an increasing public health issue. Although waterborne diseases can lead to a large number of cases of morbidity or mortality in the developed nations, the greater burden is borne by the poor and developing countries all over the world.

According to Rutuja *et al.,* (2018), the World Health Organization estimated that about 1.1 billion people around the world drink unsafe water and 88% of diarrhoeal disease in the world is associated with the use of unsafe water, poor sanitation and unhygienic practices. The report further states that poor water quality, sanitation and hygiene is responsible for 1.7 million deaths a year worldwide, (3.1% of annual deaths) and 3.7% of the annual health burden (disability adjusted life years[DALYs]) world-wide (54.2 million) are mainly through infectious diarrhoea and nine out of ten such deaths occur in children and virtually all of the deaths are in the underdeveloped and developing countries. Many waterborne disease are sometimes mild and self-limiting, however, severe instances do occur especially among the high risk members of the population causing high morbidity and mortality in the group. The infants, young children, the elderly and the immune compromised members of the community represent the high risk groups. About 2.1 million children in developing countries die due to waterborne diarrhoea related disease annually (WHO, 2014).

WHO (2011c) indicated that the population in developing nations are more exposed to suffer from waterborne diseases due to a number of reasons including the prolonged lack of access to good sources of water for drinking and food preparation, inappropriate transportation and storage conditions for food, poor sanitation, and lack of awareness regarding safe and hygienic practices. Not only that, majority of the households populations in developing countries also have very limited capacity to implement rules and regulations regarding water and food safety. There is also the issue of non-existence or ineffective surveillance and monitoring systems for waterborne illness, inspection systems for safety and educational programs concerning awareness of water hygiene (WHO, 2011a). Water and Foodborne disease have an impact on the public health as well as the economy of a country. There is a negative

impact on the trade and industries of the affected countries. The identification of an industries water product as being contaminated can lead to the recalling of the food item resulting in economic loss to that industry. Instances of sporadic or epidemic waterborne outbreaks can lead to the closure of affected food outlet or industry. Such a closure will ultimately result in job losses for workers which impacts negatively on the individuals household, communities and the state at large (Helms *et al.*, 2003).

The occurrence of local waterborne outbreaks can lead to global threat via different routes. For instance, the consumption of food products prepared with contaminated water could affect the health of citizens and may adversely affect the tourists potentials of a country. The loss in revenue may be considerably significant. The sixth goal of the United Nations Sustainable Development Goals (SDG's) is the provision of clean water and sanitation. And to ensure access to good quality water and sanitation at all level by the year 2030. Clean, accessible water for all is an essential part of the world we live. However, due to bad economies and poor infrastructure, millions of people including children die every year from diseases associated with inadequate water supply, sanitation and hygiene.

There is a growing public health interest relating to the uses of water and the outbreak of waterborne diseases. This concern is genuine and threatening considering the fact that water contaminated with pathogenic microorganisms when consumed or used in the preparation of food also leads foodborne disease. Rural communities in many developing countries obtain drinking water from untreated sources. In Nigeria for instance, water supply infrastructures are either still at the development stage or are totally absent in the rural communities (Rossiter *et al.*, 2010). According to a survey by Majuru *et al.*, (2011), about 6.5 million Nigerians have no access to safe source of water. The situation is made worse in the rural areas where only 24% of the

population had access to safe water. So, the provision of clean, reliable and potable water in rural areas remains a major challenge considering the fact that majority of members of the population reside in the rural areas. When provision of clean and safe water is inadequate, residents usually resort to use of contaminated water sources to certify their water needs (Abui *et al.*, 2016).

The major source of water supply for the rural dwellers include hang-dug wells, natural springs, creeks, and streams together with rainfall harvest, many of which are highly unreliable during periods of dry season (Sanjoy & Rakesh, 2013). Onuigbo *et al.*, (2017) showed in a study of the impacts of bacterial pollution on hand- dug well water quality in Enugu, the increasing vulnerability of underground water systems to both microbial and heavy metal contamination. Manji *et al.* (2012) also reported the incidence and prevalence of *Staphylococcus aureus*, coliforms and antibiotic resistant strains of *E. coli* in rural water supplies in Port Harcourt, Rivers State and Odukpani Local Government Areas in Cross River State. While Chigozie and Samuel (2015) noted the prevalence and antimicrobial susceptibility of *Vibrio parahaemolyticus* isolated from seafoods in a Lagos Lagoon, Charles and Anthony (2017) identified *Vibrio* pathogens as a major public health concern in rural water resources in Sub-Saharan Africa. The problem of waterborne diseases, although severe in developing countries, have also been recorded in the developed nations. Earlier, Dworkin *et al.* (1996) had reported that a rural community in Washington D. C. experienced an outbreak of Cryptosporidiosis through the supply of water from two unchlorinated deep wells.

Apart from microorganisms, heavy metals have also been identified as another important contaminant of water resource. This is due to the strong toxicity of heavy metals, especially, at low concentrations (Shabanda and Shabanda, 2016). The toxic

actions of most heavy metals stems from the fact that they are capable of interacting and forming strong bonds with metabolically active groups within a living system. These bonds under normal conditions, serve to provide important linkages which keep an organic molecule in proper configuration or shape to perform some specific functions. But under conditions of an over-supply, these bonds attach at random and cause symptoms of toxicity. The injurious action may be due to, distortion of configuration or shape of important structural or functional organic molecules, replacement of metabolically essential elements, occupation of, or, saturation of important reactive sites on organic molecules to render them metabolically defunct and formation of organometallic complexes or clumps involving a number of macromolecules at the same time and rendering them useless for metabolic activities (Asthana & Meera, 2013).

The use of antibiotics has helped a great deal in the treatment of waterborne diseases caused by the respective microorganisms. However, Stanley (2015) noted that the major problem encountered in antibiotic treatment is the development of resistance by bacteria. The increasing use of antibiotics in food and animals leads to the wide spread occurrence of resistant enteric pathogens to humans. Gideon *et al.,* (2017) reported the antibiotic resistant profile of bacteria isolated from drinking water sources in Amai Kingdom, Delta State, Nigeria. Adekunle *et al.* (2011) stated that the development of antibiotic resistance by enteric pathogens poses a great risk to citizens in areas where diarrhoea infection is problematic. Tolessa *et al.* (2016) stated that bacteria are known to acquire antibiotic resistance through horizontal plasmids transfer mechanisms. Abui *et al.,* (2016) stated that in Nigeria and other many other developing nations, the apparent lack of potable water supplies remains a major problem in most of the communities. In the affected communities, the microbiological

and physico-chemical evaluation of the water source becomes very critical as it serves to reveal the presence of harmful organism that could constitute a treat to the health of the people.

1.2 Statement of the problem

The sixth goal of the United Nations Sustainable Development Goals (SDGs) is clean water and sanitation to ensure access to clean water and sanitation for all by the year 2030. Clean, accessible water for all is on essential part of the world we want to live in. however, due to bad economic or poor infrastructure, millions of people including, children die every year from diseases associated with inadequate water supply sanitation and hygiene (UNSDGs, 2012).

The importance of the use of good quality water to satisfy the food, recreation, domestic and industrial needs of man have been emphasized in many reports including the United Nations Commission on Sustainable Development (2010) on water quality and WHO (2014) guide line on drinking water quality. Although, numerous policies have been initiated and strategies adopted by different member countries of these world organisations, the problems of either unavailability, inadequate or poor quality sources of water supplies still abounds and are confronting most cities and rural communities around the world. In 2015, it was estimated that 663 million people world-wide still use unapproved water sources, including unprotected drinking wells, springs and surface water. Nearly half of the people that use these unprotected drinking water sources are known to live in sub-Saharan-Africa, while one fifth are found in Southern Asia (WHO, 2015).

The United Nations Commission on Sustainable Development Goals (2010) stated that 40% water scarcity affects more than 40 percent of the global population, and that figure is projected to rise. 2.6 billion people have gained access to improved

drinking water sources since 1990, but 663 million people are still without. Each day, nearly 1,000 children die due to preventable water and sanitation-related diseases. 40 billion Women in sub-Saharan Africa collectively spend about 40 billion hours a year collecting water. This significantly impacts their employment opportunities. 2.4 billion people worldwide do not have access to basic sanitation services like toilets or latrines. 80 percent of wastewater from human activities is discharged into waterways without any pollution removal.

In Rivers State, some of the communities in the rural local government areas like Ikwerre, Emohua and Etche Local Government Areas are still shanties and largely underdeveloped. These communities are very poor and basic social amenities like good quality source of water supply still remains a mirage. So, there is heavy dependence on hand-dug wells, shallow streams, rivers and creeks to provide for their water needs. Reliance on these unhealthy water sources have led to the occurrence of waterborne diseases such as amoebic dysentery, gastroenteritis, typhoid fever, cholera, mild/acute diarrhoea and bacillary dysentery among the residents of these local communities.

The development of various types of waterborne illnesses in the people put additional financial burden on the already economically stressed individuals who have to pay bills due to hospitalization and treatments. The losses due to death of children and sometimes parents in cases of epidemics are not quantifiable. A sick or weakened individual cannot function effectively. Therefore, there is also loss in man-hour which breeds low productivity and hunger. All these problems that bedevil residents of the rural areas communities calls for the engagement of the authorities concerned to implement necessary solutions that are better provided through information from co-ordinated research study.

1.3 Justification of the study

Water and sanitation are fundamental to human development and well-being. They are not just goals in their own right but also critical to the achievement of the development objectives such as adequate nutrition, education and poverty eradication. Access to safe water and sanitation is therefore a human right, as recognized by the United Nations General Assembly (2010).

The United Nations had in its Millennium Development Goal (MDG) set 2015 to reduce by half the proportion of people without access to safe drinking water and basic sanitation. Sub-Saharan Africa is inhabited by a total of 783 million people, 40% of which do not have access to safe and clean water. The region failed to meet its 2015 Millennium Development Goal (MDG) to improve access to safe and clean water for 40% to 75% of its population. Nigeria is one of those countries that did not meet this goal. In Rivers State, Some communities in Ikwerre, Etche and Emohua Local Government Areas of Rivers State are far from meeting this target. Olatunji, *et al.*, (2015) stated that although, soils do act to attenuate microorganisms by simple filtration, contamination of ground water sources by these organisms including those of public health concern still occur. This situation is correct in Ikwerre, Etche and Emohua LGA's where local sources confirmed that members of the community frequently experienced waterborne diseases like cholera, typhoid fever and diarrhoea, due to consumption of infected water and food.

The rural communities in the three Local Government Areas are still under-developed. Their sources of water for food, drinking, bathing washing and other domestic activities is still hand-dug wells and shallow streams. These rural dwellers are therefore confronted with the occurrence of waterborne diseases as a result of their continued reliance on water from wells and streams that are often times contaminated.

According to Aminata *et al.,* (2018) as we move to the next phase of the Sustainable Development Goals (SDG's), it is important to examine and document communities still without access to safe drinking water. This is why, carrying out a research on the communities in Ikwerre, Etche and Emohua Local Government Areas where the use of water from shallow streams and hand-dug wells are still prevalent is justifiable.

1.4 Aim and objectives of the study

The main aim of this research work is to evaluate the prevalence of waterborne diseases associated with the use of water from hand-dug wells and streams sources in some rural communities in Ikwerre, Emohua and Etche Local Government Areas of Rivers State.

The specific research objectives include;

i. To isolate, enumerate, and identify the of total heterotrophic bacteria and fungi count in the stream and well water sources from the LGAs at monthly intervals for twelve months.
ii. To isolate, enumerate, and identify the total and faecal Coliform, *Escherichia coli, Salmonella* and *Vibrio* species,
iii. To conduct the antibiogram of isolated and *Escherichia coli, Vibrio* and *Salmonella* species.
iv. To carryout enterotoxigenicity test using wistar rat on the isolated *Escherichia coli, Vibrio* and *Salmonella* species.
v. To ascertain the physico-chemical parameters of the stream and well water sources.
vi. To determine the heavy metal levels of the stream and well water sources on a monthly basis.
vii. To subject the data obtained to statistical analysis for comparative inferences.

1.6 Significance of the study

i. The research will be significant in monitoring the biological, physical and chemical status of the water sources in the affected local communities for development purposes.

ii. Since the well-being of the people is dependent on the quality of water they drink or use for other activities, it is important to improve upon the state of knowledge of this resource in the area.

iii. The study will further highlight the poor living conditions of the people and help attract both the Local, State and Federal authorities to do the needful by providing quality potable water to residents of the local government areas.

iv. The study will help residents to learn and adopt good sanitary and hygiene measures that will serve to forestall the occurrence of waterborne diseases in the area.

v. It will also form a basis for future engagement of policy makers, especially in carrying out a clean-up programme in the area as is the case with the other Niger Delta communities.

vi. The overall benefit will not only be to prevent waterborne diseases, but will lead to improved health, poverty reduction, and socio-economic development of the local government areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water and its characteristics

Water is essential to life. Without it, the biosphere that exists on the surface of the earth would not be possible. Natural water is one of the most important substances for the maintenance of life. However, Natural water is never completely pure. Most of the earth's water sources obtain their water supplies through precipitation. During precipitation water passes over (runoff) and through the ground (infiltration), acquiring a wide variety of dissolved or suspended impurities that intensely alters its usefulness (Pooja, 2017). It is characterized by a complex of anomalous properties that make it very different from other substances (e.g. high melting, boiling, and evaporation points, and high dissolving ability). The main part of the Earth's water is concentrated in the hydrosphere. The hydrosphere is the totality of oceans, seas, and surface terrestrial waters, including, lakes, streams, underground water, and all the snow and ice. This sphere covers 70.8 percent of the Earth's surface (the total volume is about 1.39 billion km^3).

2.1.2 The hydrologic water cycle

Earth contains enormous amounts of water in the form of reservoirs. Water exists in the atmosphere, lithosphere, hydrosphere and biosphere. Among all these segments, water masses are in continuous circulation. It is, in general, called as the hydrologic cycle. It is also called as the World's Great Water Cycle, since it is the driving wheel for all the movements of available water resources on the planet earth. It is necessary to identify the cyclic and circulatory routes of water masses in all the spheres of the earth. Several processes and factors are involved in driving the global water circulation (Balasubramanian & Nagaraju, 2015). All water masses are

transformed from one form to another in the course of the hydrological cycle, a continual shift of water on the Earth (in the atmosphere, hydrosphere and the Earth's crust) that occurs under the influence of solar radiation and gravity. This planetary process includes evaporation of water from the Earth's surface, its transfer with the help of air currents from the place of evaporation, condensation of water vapour and precipitation.

2.1.2 Chemical properties of water

Life began in water and the spirit is nurtured by water. It is a universal solvent and as a solvent it provides the ionic balance and nutrients, which support all forms of life (Al-Ghamdi *et al.*, 2014). Earth's water can exist in three phases: liquid, solid, and gaseous. The chemical composition of surface water is created in the process of water circulation on earth, which connects the hydrosphere with the atmosphere, lithosphere, and biosphere. Water, being a universal solvent, is enriched with a wide spectrum of various substances in a gaseous, solid, and liquid state, so it varies greatly in its chemical composition.

2.1.3 Biological properties of water

The biological properties of water systems are caused by the totality of flora and fauna. As the density of water is considerably higher than air, living organisms are able to exist both within the water column (pelagic) and on the bottom (demersal).Water is polar. This is important because it allows water to transport solutes and biological molecules. Water forms (weak) Hydrogen bonds. (This is why when water freezes, it expands.) . This is super important because it allows the top layers of many bodies of water to freeze, without freezing the water all the way through. This insulates the water below, and allows for life to thrive under the ice. Water has adhesive and cohesive

properties, due to H_20 being a polar molecule. Adhesion = water wants to stick to other surfaces, and Cohesion = water wants to stick to itself. Together, they allow for water to travel up plant stems (in the xylem).Water has a high specific heat capacity, and a high heat of vaporization. Because of its Hydrogen bonding, it's really hard to change the temperature of water (depending on how much water there is), and it's hard to heat water up. It also takes a lot of heat release to cool water down. This makes water really good at moderating temperatures, which is really important for climate (Zoe, 2015).

2.2 Types of water

2.2.1 Atmospheric water

Water in the atmosphere mainly comes from evaporation, from the surface of both the ocean and the land. Transpiration and direct evaporation from the surfaces of green plant (evapotranspiration), and evaporation from ice (sublimation) also increase the water content of the atmosphere. Condensation occurs when air, being saturated with water vapor, becomes cooler, and relative humidity reaches 100 percent. Condensation.

2.2.2 Oceans, inland seas, costal zones, and estuaries.

The sea waters are classified as interior (inland), marginal, or inter-insular according to their geographic position and degree of isolation. An inland sea is one almost completely surrounded by land and joining the ocean or adjacent seas only through relatively narrow channels. Interior seas are assumed to be subdivided into continental and intercontinental types. A continental sea is usually shallow, deeply intruding into the land within a continent (e.g. the White and Black Seas, and Hudson Bay). An intercontinental sea is a part of the World Ocean located between continents and connected with the ocean or other seas by channels (e.g. the Mediterranean and the

Red Sea). A marginal or adjacent sea is a part of the World Ocean adjoining the continent and partially separated from it by peninsulas or a group of islands, or simply by the ocean bottom uplifting. Marginal seas can be on the continental shelf (a shelf sea) or on the continental slope (Panin, 2013).

2.2.3 River, reservoirs, lakes, and wetland

Surface water is that water which occurs permanently or intermittently on the land surface in the form of different water bodies: rivers, streams and temporary watercourses, reservoirs, lakes, swamps, mires, glaciers, and snow cover. A river is a watercourse flowing in a self-developed bed augmented by surface and groundwater. With all its tributaries it forms a river system whose character and development is related to climate, relief, geologic structure, and the dimensions of the basin. Rivers can be subdivided into mountain rivers – usually flowing rapidly in narrow valleys – and plain ones, which flow more slowly in wide terracing valleys. A lake is a natural reservoir filled with water within a lake basin not directly linked with the sea. Basins are subdivided according to their origin into tectonic, glacial, fluvial, coastal, sinkhole, volcanic, and dammed (artificial reservoir and ponds) (Panin, 2013).

2.2.4 Groundwater

This term groundwater refers to water in the Earth's crust in all physical states, in the sedimentary rock layers and massive-crystallized rock fractures. There are many groundwater classifications relying on different types of groundwater infiltration and distribution, lithological composition, geological age, and on differences in hydrodynamics, temperature, and chemical composition. The chemical composition of groundwater includes a mixture of many chemical elements, in the form of different ion types, neutral molecules, organic-mineral complexes, colloids, and isotopes. A complex

of climatic, physical-geographical, soil vegetation, structural-geologic and hydrogeological factors, produces groundwater from both infiltration and condensation (Panin, 2013).

Groundwater aquifers

Aquifers are terms used to describe hydrogeologic systems. An aquifer is a geologic unit that is highly permeable and can hold and transmit a large quantity of groundwater. Aquifers can be classified into confined and unconfined aquifers. When an aquifer is surrounded by the water table on the top, it is called an unconfined aquifer. On the other hand, if an aquifer is bounded between two much less permeable units, it is known as a confined aquifer. The pressure of water in confined aquifers is normally higher than pressure in the unconfined aquifers. Hence, when a well is drilled into a confined aquifer, the water level in the well will rise up above the top of the aquifer, and sometimes may even rise above the ground surface, which creates artesian flow. An aquitard is also regarded as a confining bed, and is a much less permeable geologic unit. Because no naturally occurring porous material is completely impermeable, aquifers and aquitards are identified to distinguish their relative degree of high and low permeability, respectively. In general, aquifers are composed of gravel, sandy materials, limestone, or highly fractured rocks, while aquitards consists of clay-rich, poorly sorted sediments, and unfractured rocks. The term aquiclude has been used for describing an impermeable unit, but this term has become obsolete (Ge and Gorelick, 2015).

2.2.4 Soil water

The soil water is the water localized in soil pore space in the form of liquid moisture (both closely attached to soil skeletal particles and water freely able to move

through the soil profile), a solid component in the form of ice in the soil pore space, and gaseous water in the form of soil air.

2.2.5 Glaciers, icebergs, and ground ice

Ice is the most abundant "'mineral" on the Earth. The total mass of ice enclosed in glaciers, icebergs, ground ice, snow cover, and the atmosphere is 2.423 x1022 tons. Ice covers more than 16.3 x 106km2, or percent of the Earth surface. The total ice volume of modern glaciers ranges from 26.8 x 106km3to 30.3 x 106km3. A glacier is a moving natural accumulation of ice on the land, under a negative balance of the solid phase of water.

2.3 Sources of drinking water

Drinking water is classified into two distinct or separate sources such as surface water, and groundwater.

2.3.1 Surface water

Surface water is water that is open to the atmosphere and results from overland. It is also said to be the result of surface runoff. These are two ways of saying the same thing. Specific sources that are classified as surface water include the following: Streams, Rivers, Lakes, Man-made impoundments (lakes made by damming a stream or river) Springs affected by precipitation that falls in the vicinity of the spring (affected means a change in flow or quality). Shallow wells affected by precipitation (affected means a change in level or -quality). Wells drilled next to or in a stream or river Rain catchments Muskeg and tundra ponds.

2.3.2 Ground water

Groundwater is regarded as the water that is below the earth's crust, but not more than 2500 feet below the crust and it is considered usable fresh water. Groundwater

constitutes about two thirds of the freshwater resources of the world and 40% of the drinking water comes from groundwater. Around 97% of the rural population still depends upon the direct groundwater resource for drinking. The contamination of groundwater by diverse anthropogenic organic compounds is a major problem in agricultural and industrialized environment (Blessy & Krishnamurhy, 2014). Groundwater is obtained from borehole wells, and springs that are not influenced by surface water or a local hydrologic event.

2.3.3 Drilled wells

Drilled wells usually obtain water from deep aquifers. A typical depth is about 60 metres (200 feet). When a drilled well is constructed, a hole is bored into the aquifer. The upper part is lined with casing to prevent the collapse of the borehole walls. The following well components are critical in drilled well for preventing surface and subsurface contaminants from entering the water supply: casing, drive shoe, annular seal vermin-proof and vented well cap. The casting also provides a housing for the pumping mechanism and the pipe that takes water from the well to the home.

2.3.4 Dug wells

A dug well consists of an excavation into a shallow aquifer. The typical depth of a dug well is 4.5 to 8 metres (15 to 25 feet). The excavation is lined with concrete crocks, which prevent the collapse of excavated walls. The following well components are critical in a dug well for preventing surface and subsurface contaminants from entering the water supply; crocks, non-toxic, seals, apron and casing cap.

2.4 Water quality

WHO (2014) describes water quality as a term used to express the suitability of water to sustain different uses or processes. Any one use or process will have

particular requirements for the physical, chemical or biological characteristics of water; for example limits on the concentrations of toxic substances for drinking water use. Consequently, water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality. Even though water is the main source for drinking, agriculture and industry, but its quality has been degraded due to the spillage of hazardous chemicals and inappropriate discarding of waste materials, which has led to the contamination of groundwater becoming a major issue of concern worldwide. This must be remediated and controlled to safeguard the environment and for the betterment of the people (Blessy & Krishnamurthy, 2014).

2.5 Water and waterborne diseases

Waterborne diseases comprises illnesses arising from both direct and indirect contact with water, whether by consumption or by skin exposure during bathing or recreational water use. It encompasses disease due to water-associated pathogens and toxic substances (Nwabor, 2016). According to the World Health Organization (WHO, 2011c), waterborne disease or food poisoning is any disease that results from the consumption of food or water containing pathogens such as bacteria, viruses, parasites or food contaminated by poisonous chemicals or bio-toxins. Waterborne diseases have become a growing public health problem in developing as well as developed countries and remains a major cause of morbidity and mortality in the general population (Nyenge and Ndip, 2014). Sources of water supplies for public use may contain pathogens when it has been contaminated with faecal matter.

The World Health Organization (WHO, 2014) estimated that up to 1.5 billion cases of diarrhoea and more than 3 million deaths that affect children every year are directly related to water and food contamination. The waterborne illnesses remains

a major bottleneck to world development efforts especially in the achievement of the targets of Sustainable Developments Goals (SDG's).

The population of developing countries are more vulnerable to suffer from waterborne poisoning due to a number of reasons, such as; Lack of access to clean or potable water, inappropriate transportation and storage of foods, lack of awareness concerning food hygiene and safety practices, limited capacity amongst developing countries to implement rules and regulations relating to food safety, lack of effective surveillance and monitoring systems for food borne illnesses and inspection systems for food safety and lack or non-functional educational programs tailored towards awareness of food hygiene (WHO, 2011 a).

For the sake of public health it is necessary to consider the epidemiology of water borne diseases as this will assist in designing prevention and control activities, allocation of relevant resources to control waterborne diseases, monitoring and evaluation of food or water safety measures, assessment of cost effectiveness of interventions (SaulatJahan, 2014). Another major issue of public health interest is the phenomenon of increasing resistance of food and waterborne pathogens to appropriate doses of antibiotic treatments.

Although numerous efforts have been made by government of different countries and other international agencies with mandate on water and its safety, the problem of lack of potable water and the occurrence water-borne disease are still a serious burden of public health and environmental concern. Despite the huge expenditure on water research globally, although worth the investment, the target and expected outcome are far from being realized and waterborne diseases continue to ravage developing countries especially Africa and Asia. The near absence or unavailability of pipe-borne water and the resort by the rural populace for surface

and underground waters which are incidentally contaminated with faecal matter is responsible for the increasing prevalence of food and waterborne diseases (Nwabor *et al.,* 2016).

The World Health Organization (WHO, 2014) estimated that about 1.8 million people die worldwide from diarrheal diseases annually, many of which are been linked to diseases contracted from the consumption of contaminated waters and seafood. UNICEF, (2010) reports that 884 million people in the world use unimproved drinking water source, and estimates that in 2015, 672 million people will still use an unimproved drinking water source. Over 80 per- cent of people with unimproved drinking water and 70 per cent of people without improved sanitation live in rural areas (DIDWSP, 2012).

In Nigeria, a vast majority of people living along the course of water bodies still source and drink from rivers, wells, streams and other water bodies irrespective of the state of these water bodies without any form of treatment. These natural waters contain numerous microbial species, some of which have not been identified. The number of organisms present varies significantly between different water types, and it is usually accepted that sewage-polluted surface waters contain greater number of bacteria than unpolluted waters. These pathogens, often of faecal source, might be from point sources such as municipal wastewater treatment plants (Chigor *et al.,* 2010; Odjadjare *et al.* (2010) and drainage from areas where livestock are handled (Williams, *et al.,* 2012) or from non-point sources such as domestic and wild animal defecation, malfunctioning sewage and septic systems, storm water drainage and urban runoff (Chigor *et al.,* 2012). The potential of drinking water to transport microbial pathogens to great numbers of people, causing subsequent illness, is well documented in countries at all levels of economic development. The outbreak of Cryptosporidiosis of 1993 in

Milwaukee, Wisconsin, in the United States provides a good example. It was estimated that about 400,000 individuals suffered from gastrointestinal symptoms due, in a large proportion of cases, to Cryptosporidium. In Nigeria, cases of water related diseases abound, however, many of these cases are not recorded since majority of the affected individuals subscribe to self-medication rather than seek professional medical attention. The most common waterborne diseases in Nigeria are Cholera, Hepatitis, and Typhoid (Adenyinka, *et al.*, 2014). Waterborne outbreaks of enteric disease occurs either when public drinking water supplies were not adequately treated after contamination with surface water or when surface waters contaminated with enteric pathogens have been used for recreational and or domestic purpose. Instances of disease outbreak due to contaminated drinking water with microbes are also reported (Raji *et al.*, 2010) with the drinking waters sampled from Sokoto, Shuni and Tambuwal towns having *E. coli, Salmonella, Shigella* and *Vibrio* species far above the WHO (2007) allowable limit and are therefore not potable.

2.6 Causes of waterborne diseases

A good number of agents both infectious and non-infectious are known to cause foodborne disease.

2.6.1 Bacterial waterborne pathogens

Bacterial agents are the leading cause of fatal and severe waterborne illnesses worldwide. In France, *Salmonella* was the most frequent cause of bacteria foodborne illness {5,700 - 10,200 cases), in the last decade of the 20th century. This is followed by *Campylobacter* (2,600-3,500 cases) and *Listeria* (304 cases). More than 90% of food-poisoning illnesses are caused by species of *Staphylococcus, Salmonella, Clostridium, Campylobacter, Listeria, Vibrio, Bacillus,* and Entero-pathogenic

Escherichia coli. Nyenje *et al.*, 2012b showed that in South Africa, species of *Listeria, Enterobacter and Aerotmonas* were the most prevalent bacteria in water and most fast foods.

i. *Salmonella* spp

Human Salmonellosis are mostly caused by *Salmonella* serovar typhimurium and serovar enteritidis, nevertheless prevalence of other serovars like serovar Schwarzengrund in Denmark and USA has equally been reported Vugai *et al.*, 2004). Most cases of Salmonellosis is asymptomatic but in symptomatic cases victims present fever, diarrhoea, abdominal cramps and nausea often controlled within a week. The organisms may be excreted in the faeces many weeks after symptoms have subsided.

Globally, Salmonellosis represents an important public health problem. For instance, in Denmark, foodborne cases of salmonellosis cost the country about $ 10.4 - $25.5 million in 2001 and in the USA, the organism is responsible for an estimated 1.4 million cases, 16,000 hospitalizations and more than 500 deaths annually at an estimated annual cost of about $2.3 billion. Salmonellosis also affects countries economically, for example, in 2010; over 550 million eggs were recalled due to possible *Salmonella* contamination, resulting in one of the largest massive recalls. The other products recalled are headcheese, pickles, salami, raw tuna, frozen dinners, alfalfa sprouts, lettuce, tomatoes, and olives (Linscott, 2011).

ii. *Staphylococcus aureus*

Staphylococci are Gram-positive and catalase positive cocci that are ubiquitous in the environment being found in the air, dust, sewage, water, environmental surfaces, humans and animals. Based on their ability to produce coagulase the species of this organism are classified into two. The coagulase-positive *Staphylococci* (CPS), for

example, *S. aureus*is the pathogenic strain that secretes the enterotoxin responsible for food poisoning. On the other hand some strains of the Coagulase-negative *Staphylococci* (CNS) are useful in the fermentation of meat and milk-based products (Becker *et al.,* 2001).

Zell *et al.* (2008) and Even *et al.,* (2010), have all reported the existence of certain CNS enterotoxins producing strains). However, the subject has always been controversial because very little information is available about food poisoning due to CNS (Hennekinne et al., 2010). Loir *et al.,* 2003 noted that, Staphylococcal food poisoning (SFP) result from the ingestion of foods containing preformed Staphylococcal enterotoxins. In most cases food handlers carrying enterotoxin-producing *S. aureus* in their noses or hands are the main source of food contamination due to improper handling and subsequent storage at temperatures which permit growth of *S. aureus* and production of the enterotoxin (Argudin *et al.,* 2010).

Staphylococcal enterotoxins (SEs), are superantigenic toxins (SAgs) that cause food poisoning and toxic shock syndrome in humans throughout the world (Balaban & Rasooly, 2000). SAgs belong to the broad family of pyrogenic toxin superantigens (SEA), the toxins that induce emesis (Schelin *et al.,* 2011). SEAs are able to evade antigen recognition by interacting with major histocompatibility complex (MHC) class II molecules on the surface of antigen presenting cells (APC), and with T-cell receptors (TCR) on specific T-cell subsets (Thomas *et al.,* 2007). This interaction leads to activation of a large number of T-cells followed by proliferation and massive release of chemokines and pro-inflammatory cytokines that may led to adverse effects such as lethal toxic shock syndrome (Balaban and Rasooly, 2000).

iii. *Campylobacter* species

Campylobacter species are Gram-negative, non-sporeforming rods. Most species require a microaerobic atmosphere for optimal growth; however, some species

grow aerobically or anaerobically. Other species such as C. *sputorutn,' C. concisus, C. mucosalis, C. cutvus, C. showae, C.* rectos, C. *gracilis,* and C. *hominis*requiresatmosphere containing increased hydrogen appears for growth (Nachamkin, 2003). *Campylobacters* are a leading cause of bacterial enteritis in most countries and can be transmitted directly from animal to person, through ingestion of faecally contaminated water, food, or by direct contact with animal faeces or contaminated environmental surfaces. Epidemiological studies from different countries have identified sources of *Campylobacter* enteritis in man to include animals, food, water, and milk products (Oporto *et al.,* 2007; Esteban *et al.,* 2008).

iv. *Listeria* species

Species of *Listeria* are Gram- positive, intracellular rods that are present in diverse environments like soil, water, various food products, animals, and humans. *L monocytogenes*is the main human foodborne pathogen responsible for listeriosis. It is a rare but fatal disease with a mortality rate of 20-30% in newborns, the elderly and immunocompromised individuals, some studies have also implicated such other species as *Listeria ivanovii (L. ivanovii),* even though rarely (Guillet *et al.,* 2010; Nyenje *et al.,* 2012b). Apart from ingestion of contaminated food, infection can also be transmitted directly from infected animals to humans, as well as between humans and from mother to child in the uterus or during passage through an infected birth canal (Jacobson, 2008; Allerberger & Wagner, 2010).

Listeriosis usually manifest in two forms, the invasive or non-invasive (febrile gastroenteritis). In immune competent individuals, non-invasive Listeriosis appears as a typical febrile gastroenteritis (watery diarrhoea, nausea and headache), whereas in immune compromised adults, such as the elderly and patients receiving immunosuppressive agents, Listeriosis develops as septicaemia or meningoencephalitis

(Longhi *et al.*, 2004). On the other hand perinatal Listeriosis acquired by the foetus from its infected mother via the placenta can lead to abortion, birth of a stillborn foetus or a baby with generalized infection, and sepsis or meningitis in the neonate (Allerberger and Wagner, 2010). *Listeria* Pathogenesis begins with the penetration of the bacterium through the intestines to the liver where it replicates until the infection is contained by the cell-mediated immune response. It is reported that diarrhoea results from direct invasion of the intestinal mucosal epithelium by the organism.

v. *Vibrio parahaemolyticus*

*Vibrio parahaemolyticus*is the major cause of acute gastroenteritis in humans who consumed contaminated raw or undercooked seafood, it can also lead to severe infections in the immune-compromised person (Hiyoshi *et al.*, 2010). The pathogens was originally identified as the cause of waterborne illness in Osaka, Japan in 1951 where it caused 272 illnesses and 20 deaths; semidried juvenile sardines were the source of infection. Uptil now, *E.coli* has been reported to account for half of all food poisoning cases in Japan and implicated as a common cause of sea-waterborne illness in many Asian countries (Su and Liu, 2007). Although, sporadic outbreaks have been documented in countries such as Spain, Italy and France (Ottaviani *et al.*, 2010).

Ndip *et al.* (2002); Eja *et al.* (2008); Adeleye *et al.* (2010) have all reported on the prevalence of *V. parahaemolyticus* in sea foods especially, shrimps on the African continent from West Africa. Infection with the organism manifest in three major syndromes, i.e. gastroenteritis, wound infections, and septicaemia with gastroenteritis being the most prevalent. Studies have linked the virulence of this organism to the presence of a thermostable direct hemolysin (TDH) and TDH -related hemolysin (TRH) (Boyd *et al.*, 2008). It is suggested that TDH and TRH act on cellular membranes as a

pore-forming toxin that alters ion balance in the intestinal cells thereby leading to secretory response and the diarrhoea observed in gastroenteritis (Nair *et al.*, 2007).

vi. *Escherichia coli*

E. coli is a Gram-negative rod, belonging to the family *Enterobacteriaceae,* and a natural gut coloniser in many host organisms (Tarr *et al.*, 2005). *E. coli* strains is classified according to specific virulence factors and phenotypic features. The strains include;

a) enteroheamorraghic *E. coli* (EHEC) or Shiga toxin-producing *E. coli* (STEC) which produce verocytotoxin or shiga-like toxin, the causative agent of haemorrhagic colitis (HC) and haemolytic-ureamic syndrome (HUS);

b) enterotoxigenic *E, coli* (ETEC) strains which produces enterotoxin causing diarrhoea;

c) enteroinvasive *E. coli* (EIEC) strains, the causative agent of dysentery-like illnesses;

d) enteroaggregative *E. coli* (EAEC), which do not secrete heat-labile enterotoxins but adhere to mucosal cells in an aggregative pattern, and

e) diffusely adherent *E. coli* (DAEC) strains that adhere to the surface of epithelial cells. However, it is noteworthy that foodborne outbreaks have continually been associated with EHEC and EAEC strains (Wu *et al.*, 2011).

Among the EHEC strains, *E. coli* 0157:H7 has been widely reported as the number one cause of waterborne illness (Saghaian *et al.*, 2006). The first devastating outbreak of EHEC (E *coli* 0157:H7) occurred in Japan, in which 2764 confirmed cases were reported; the source was radish sprouts. Since then, outbreaks and sporadic cases have been reported globally. In many of these outbreaks, contaminated meat, meat products, unpasteurized milk and leafy green vegetables and fruits fertilized with contaminated

animal manure remained the source of contamination (CDC, 2011). In 2011, an unusual outbreak of enterohemorrhagic gastroenteritis and haemolytic uremic syndrome (HUS) related to infections with shiga toxin-producing.' *E. coli* 0104:H4 (STEC 0104;H4) occurred in Germany, France before spreading to other European countries and North America (Wu *et al.*, 2011). It was reported that this was the first and largest outbreak of food poisoning due to *E. coli* serotype 0104:H4 worldwide with 3167 enterohemorrhagic gastroenteritis and 908 HUS cases which claimed 50 lives (WHO, 2011).

The mechanism of pathogenesis of EAEC strains involves: bacteria adherence to the intestinal mucosa using aggregative adherence fimbriae (AAF); fimbriae allow the organism to adhere to each other in a "stacked-brick" pattern and produce mucus, thereby forming a biofilm on the surface of enterocytes. This leads to the release of toxins and elicitation of inflammatory response, mucosal toxicity, and intestinal secretion (Frank *et al.*, 2011), so, E. *coli* 0104:H4 is recognized as typical EAEC strain that forms AAF to enhance bacteria attachment to the intestinal wall and STEC/EHEC that produces shiga-toxin. *E. coli* virulence factors can be encoded by mobile genetic elements like plasmids and bacteriophages which can be transferred horizontally. Brzuszkiewicz *et al.*, (2011), found that *E. coli* 0104:H4 strain acquired the stx-producing gene from the stx-phage which is characteristic for EHEC strains, and stated that the enhanced adherence factor encouraged the absorption of stx-toxin which lead to the higher percentage of HUS cases.

2.6.2 Viral waterborne pathogens

Viruses are very minute microorganisms which range in size from 0.02 to 0.4 micrometres in diameter and are responsible for a wide range of diseases in plants, animals and humans. They are considered as the most common pathogens spread

through food. In the USA for instance, viruses cause 67% of food related illnesses, compared to 9.7% and 14.2% for *Salmonella* and *Campylobacter,* respectively. Viruses are intracellular obligate parasites which can only multiply within living cells of the host; hence, the number of viral particles in food does not increase and sensory features of the contaminated and non-contaminated food are normally the same (Koopmans and Duizer, 2004). Many waterborne viruses have been identified including, rotaviruses, noroviruses, enteric adenoviruses, hepatitis A virus (HAV), enteroviruses, human astroviruses, aichiviruses, toroviruses, coronaviruses and picobirnaviruses (Chitimbar *et al.,* 2012).

i. Noroviruses

Noroviruses (NoVs) are non-enveloped single stranded (ss) RNA viruses which are members of the family *Caliciviridae.* There arefive genogroups, Gl to GV, of which Gl, Gll and GIV are known to infect humans; genotype Gil.4 is widespread in outbreaks (Koopmans, 2008). NoVs are the leading causes of epidemic gastroenteritis across the age groups, resulting in leading to over 267,000,000 annual infections worldwide (Barrabeig*et al.,* 2010). A surveillance study in New Zealand conducted between 2001-2007 showed that of the total outbreaks, 19.9% were associated with environmental sources, 17.6% with foodborne infection and 61.0% with person-to-person transmission (Lim *et al.,* 2010). Likewise, norovirus outbreaks resulting from contamination by an infected food-handler, water, both directly (example consumption of tainted water) or indirectly (example via washed fruits, by swimming or canoeing in recreational waters) has been documented. Norovirus infections generally manifest as gastroenteritis; characterised by acute onset of nausea (81%), vomiting (54%), diarrhoea (85%) and abdominal cramps (72%). Normal symptoms like fever (51%), rigors, muscle and joint pain and headache are prevalent. The symptoms in healthy individuals are usually mild

and self-limiting while, in vulnerable members, more serious illnesses are common (Teunis *et al.*, 2008).

ii. Hepatitis A Virus (HAV)

HAV is a non-enveloped single-stranded (ss) RNA virus. It is a member of the Hepatovirus genus, belonging to the *Picornaviridae*family. It has only one serotype and six genotypes; genotypes I, II and III cause acute hepatitis in humans and immunity after infection is lifelong (Fiore, 2004). Although, endemic worldwide, countries with low socio-economic standards have high incidence rates of HAV; exemplified by immunological surveys where almost 90% of children are infected before the age of 10 years, though most infections are asymptomatic (Nainan *et al.*, 2006).

HAV infections leads to a number of symptoms such as: fever, anorexia, nausea and abdominal discomfort, followed within a few days by jaundice. HAV infection may also result in liver damage, usually from the host's immune response to the infection of the hepatocytes. The liver damage may lead to death in some cases. The virus has a low case fatality rate of 0.3% but increases with age and underlying chronic liver diseases (Nainan*et al.*, 2006). The correct pathogenesis of HAV is unknown; but, it is suggested that once the virus has been acquired, it enters and replicates in the small intestines (Kumar *et al.*, 2010). This initial replication is followed by a viremic stage and transportation to the liver where the virus is further replicated in the hepatocytes (Koopmans *et al.*, 2008). The virus is liberated into the bile canaliculi from where it passes back into the intestinal tract, and the infected individuals (asymptomatic and symptomatic) then sheds the virus in the faeces in high titers.

2.6.3 Fungal waterborne pathogens

Filamentous fungi and moulds are capable of producing a large an enormous number of secondary metabolites, such as antibiotics and mycotoxins. Mycotoxin

refers to those secondary metabolites which, at a low concentration, are toxic to humans and animals (Sanchez-Hervas *et al.,* 2008). Mycotoxins have been identified as causative agents of human waterborne intoxication, as well as human hepatic and extra-hepatic carcinogenesis (Wild and Gong, 2010). The clinical symptoms include diarrhoea, liver and kidney damage, pulmonary oedema, vomiting, haemorrhaging and tumours (Bryden, 2012). The most frequent toxigenic fungi are *Aspergillus, Penicillium* and *Fusarium* species (Sanchez-Hervas *et al.,* 2008).

2.6.4 Parasitic waterborne pathogens

Parasitic foodborne diseases are generally under-recognised; but are becoming more common in humans worldwide, with infections in childhood, pregnancy and those related to HIV/AIDS being of major importance (Dorny *et al.,* 2009). The parasites of interest are *Giardia lamblia, Entamoeba histolytica, Cryptosporidium parvum, Toxoplasma gondii, Trichinella spiralis* etc.

iii. Cryptosporidium

Cryptosporidium are protozoan members of the Phylum Apicomplexa, which affect many vertebrate hosts. C. *hominis* (anthroponotic origin) and C. *parvum* (zoonotic origin) are responsible for more than 90% of cryptosporidiosis in human host. This accounts for more than 3.1 million deaths each year among children less than 15 years of age (Fayer, 2004). In North and South America, Australia, and Africa, C. *hominis*is more prevalent whereas C. *parvum* causes more human infections in the USA and Europe, especially in the UK (Omoruyi *et al.,* 2011). Cryptosporidiosis is most prevalent during early childhood in developing countries, with as many as 45% of children experiencing the disease before the age of two years

The organism is transmitted directly through the faecal-oral route or indirectly via contaminated water supply, food or environment (Miler *et al.,* 2006). The ingested pathogen in the form of oocytes, excyst in the gastrointestinal tract and release infective sporozoites. These attach to the apical membrane of the host epithelial cells where they mature into merozoites by asexual reproduction. The merozoites are in turn released into the intestinal lumen where they can either infect other epithelial cells or mature into gametocytes. These gametocytes later releases the oocysts which are excreted in faeces into the environment to start another life cycle.

iv. Toxoplasma *gondii*

Toxoplasmosis is a common disease caused by T. *gondii,* an obligate intracellular parasite that forms cysts in mammalian cells. *T. gondii* infects nearly one third of the global population and many mammalian and avian species. The major sources of human infection are the ingestion of tissue cysts in raw or undercooked meat, food or water contaminated with sporulated oocysts or by transplacental transmission (Jimenez-Coello *et al.,* 2012). Toxoplasmosis is the second major cause of waterborne illness related deaths and fourth leading cause of foodborne illness related hospitalizations in the USA (Scallan *et al.,* 2011). In South America, Asia and Africa have a higher presence of sero-positive individuals; high temperature and humid conditions in these continents make it conducive for the persistence of viable sporulated oocysts in the environment (Mercier *et al.,* 2010).

The life cycle is complicated and involves two hosts; an intermediate host, normally warm-blooded animals and a definitive host (domestic cats). There are three infectious stages: tachyzoites, bradyzoites contained in tissue cysts, and sporozoites contained in sporulated oocysts (Alayande *et al.,* 2012). The life cycle begins, with the shedding of oocysts by the definitive host in the faeces. The oocysts sporulate and

become infective in a few days in the environment. Intermediate hosts are infected after ingesting water or food contaminated with the cat faeces. In the gut, oocysts change into tachyzoites which later moves to other parts of the body via the bloodstream and further develop into tissue cyst (bradyzoites) in skeletal, ocular muscle and neural tissue where they can persist for many decades (Alayande *et al.,* 2012).

v. *Giardia intestinalis*

Giardia intestinalis (also known as G. *lamblia* or G. *duodenalis)* are ubiquitous enteric protozoan pathogens that infect humans, domestic animals and wildlife worldwide. Giardiasis is related to the socioeconomic level of a country, with prevalence ranging between 2 - 7% in most industrialized countries and approaching 40% in developing nations. Majority of these infections occur in children (Julio *et al.,* 2012). A study in a refugee camp of Guma in Nigeria documented a prevalence of 40% in children (Nyamngee *et al.,* 2009), while in Rwanda, a 60% prevalence was noted among children under age 5 years (Ignatius *et al.,* 2012). The infection results from the ingestion of the cyst in faecally contaminated food or water or through person-to-person and to a lesser extent, animal-to-person transmission. The parasite has a two-stage life cycle: a reproductive trophozoite and an environmentally resistant cyst stage. An ingested cyst passes into the duodenum, where encystament occurs, releasing four trophozoites which multiply quickly by asexual reproduction to colonise the small intestine. Clinical symptoms occur during the trophozoite stage, as a result of damage to the mucous membrane.

vi. *Entamoeba hystolytica*

Entamoeba histolytica (E. histolytica) is serious cause of diarrhoea in people in tropical and subtropical countries. According to the WHO, *E. histolytica* is the second

leading parasitic cause of death (after malaria) and has been estimated to infect 50,000,000 people worldwide of whom 40,000 - 100,000 die yearly (Babiker *et al.*, 2009). Man is major reservoir of E. *histolytica,* passing virulent cysts that are transmitted mainly by ingestion of contaminated food or water or through an infected food handler and also occurs when produce is freshened or crops are irrigated with contaminated water. Human infection normally starts with the ingestion of the cyst in food or water contaminated with human faecal material. Cysts can survive the acidic pH of the stomach and migrate into the intestine where the cysts undergo excystment and mature into trophozoites which are passed to the colon. In the intestine, many of the trophozoites encyst and both trophozoites and cysts are excreted along with the faeces. The cysts can survive for prolonged periods outside the host while the trophozoites live only for a few hours.

2.7 Classification of waterborne diseases based on route of transmission

Waterborne diseases can be transmitted through four main routes: Water- borne route, Water-washed route, Water-based route and Insect vector route or water related route (Nwabor *et al.*, 2016).

2.7.1 Waterborne diseases

Waterborne diseases refers to those diseases that are transmitted through the direct drinking of water contaminated with pathogenic microorganisms. Contaminated drinking water when used in the preparation of food serve as the source of waterborne disease through consumption of the same microorganisms. Many waterborne diseases are characterized by diarrhoea, which involves excessive stooling, often resulting to dehydration and possibly death. Most waterborne diseases are often transmitted via the faecal-oral route, and this occurs when human faecal material is ingested through

drinking contaminated water or eating contaminated food which normally arises from poor sewage treatment and improper sanitation. Faecal pollution of drinking-water may be occasional and the magnitude of faecal contamination maybe low or fluctuate widely. In communities where contamination levels are low, supplies may not carry life-threatening risks and the population may have used the same source for time immemorial. However, where contamination levels are high, consumers (especially the visitors, the very young, the old and those suffering from immunodeficiency-related diseases) may be at a significant risk of infection (Nwabor *et al.*, 2016). In rural African regions, faecal contamination of water arises from runoffs from nearby bushes and forest which serve as defecation sites for rural dwellers. Some of the organisms remarkable for their role in the outbreak of waterborne disease include Cholera, Amoebic dysentery, Bacillary dysentery (Shigellosis), Cryptosporidiosis, Typhoid, Giardiasis, Paratyphoid, Balantidiasis, Salmonellosis, *Campylobacter enteritis*, *Rotavirus* diarrhoea *E. coli* diarrhoea, Hepatitis A, Leptospirosis and Poliomyelitis (Cheesbrough, 2006).

2.7.2 Water-washed diseases

Water washed or water scarce diseases are those diseases which thrive in conditions of freshwater scarcity and poor sanitation. Control of water-washed diseases depends more on the available quantity of water than the water quality. Examples of water washed diseases includes; Scabies, Typhus, Yaws, Relapsing fever, Impetigo, Trachoma, Conjunctivitis and Skin ulcers. Four types of water-washed infections includes; soil-transmitted helminthes, acute respiratory infections (ARI), skin and eye diseases, and diseases caused by fleas, lice, mites or ticks. In all of these situations, regular washing and improved personal hygiene play a key role in preventing transmission of the disease (UNICEF, 2008).

2.7.3 Water-based diseases

Water-based diseases are infections caused by parasitic pathogens found in aquatic host organisms. These host organisms are the; snails, crustacean cyclops, fishes, or other aquatic animals. Human beings become infected through the ingestion of the infective stages or via skin penetration. Examples of water based diseases includes Schistosomiasis (Cercariae released from snail, penetrate skin), Dracunculiasis (larvae ingested in Crustacean), Paragonimiasis (Metacercariae ingested in crab or crayfish) and Clonorchiasis (Metacercariae ingested in fish). These diseases can be prevented by avoiding contact with contaminated water, or by the use of protective clothing or barrier creams. (Nwabor *et al.*, 2016).

2.7.4 Water related diseases or insect vector-based diseases

These diseases do not have direct relationship with the quality of drinking water. They are those diseases that are transmitted by insect vectors which breed in or around water bodies. When human beings are bitten by these insect vectors, they become infected. However, consideration of vector control during the design, construction and operation of surface water reservoirs and canals (for drinking water or irrigation purposes) can reduce the potential for water related disease transmission. Prevalence of water related diseases are high in tropical Africa as a result of poor environmental management and sanitation. Drainages are often waterlogged, hence constituting breeding sites for these insect vectors. Malaria is one of the water related diseases endemic in 117 countries with about 3.2 billion people living in risk areas all over the world (WHO/UNICEF, 2005). The report further stated that there are about 350 to 500 million clinical cases of malaria worldwide each year with over 1 million deaths. About 59% of all clinical cases occur in Africa, 38% in Asia, and 3% in the Americas. Other examples of water related diseases are Yellow fever, sleeping sickness

spread by Tse tse fly and River blindness or Onchocerciasis spread by Black fly, *Simulium damnosum.*

2.8 Bacteriological analysis of water

Microbial contamination is the most serious public health risk associated with drinking-water supplies. However, it is impractical to analyse water for every individual pathogen, many of which can cause disease at very low concentration. Since most diarrhoea-causing pathogens are faecal in origin, it is more practical to analyse water for indicator species that are also present in faecal matter. The use of indicator organisms in the bacteriological analysis of water remains the mainstay of water bacteriology. For many years, total coliforms have been used as indicators in evaluating water quality for several water uses with respect to faecal contamination (Hughes and Thompson, 2004). Not all coliforms are from faecal source. Hence, feacal coliforms and pathogenic forms such as *Escherichia coli* are now used largely as bacteriological indicators. The term "total coliforms" refers to a large group of Gram- negative, rod-shaped bacteria that share several characteristics. The group includes thermotolerant (ferment lactose and produce gas at 45.5°C) coliforms and bacteria of faecal origin as well as some bacteria that may be isolated from environmental sources. Thus the presence of total coliforms may or may not indicate faecal contamination. In extreme cases, a high count for the total coliform group may be associated with a low or even zero count for thermotolerant coliforms. Such a result would not necessarily indicate the presence of faecal contamination. It might be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliform. In the laboratory total coliforms are grown in or on a medium containing lactose at a temperature range of 35-37°C. They are provisionally identified by the production of acid and gas from the fermentation of lactose. Unlike coliforms from environmental

sources, coliforms that come from faecal matter can tolerate higher temperatures. These are more closely associated with faecal pollution than total coliforms. The most specific indicator of faecal contamination is *E. coli*, which unlike some faecal coliforms never multiplies in the aquatic environment (UNICEF, 2008). *E. coli* is now internationally acknowledged as the most appropriate indicator of faecal pollution. In water source, its level of occurrence is correlated with the inputs of faecal pollution (human or animal) (Edberg *et al.*, 2000). Other organisms used as indicators of faecal pollution of water includes: Faecal *Streptococci, Enterococci, Clostridium perfringens, Pseudomonas aeruginosa* , Hydrogen sulphide (H_2S)-producing bacteria, Coliphages and other bacteriophages.

2.8.1 Conventional methods for bacteriological analysis of water

The analysis of water for the presence of coliform bacteria has for long been carried out using two conventional methods. These are the multiple fermentation tube or most probable number technique (MPN) and the membrane filtration methods. In recent years, two alternatives: the enzyme substrate (defined substrate method) and H_2S methods, have been gaining increasing popularity (UNICEF, 2008).

2.8.2 Multiple Tube Fermentation (MTF) or Most Probable

i. Number Technique (MPN)

The MPN technique has been used for the analysis of drinking-water for many years with satisfactory results. It is most suitable in the analysis of very turbid water samples or if semi- solids such as sediments or sludges are to be analysed. It is traditional to report the results of the multiple fermentation tube tests for coliforms as a most probable number (MPN) index. It is an index of the number of coliform bacteria that, probably, would give the results shown by the test. It is not a count of the actual

number of indicator bacteria present in the sample. Although this test is simple to perform, it is time- consuming, requiring 48 hours for the presumptive results (WHO, 2001). Multiple samples of the water under test are added to a nutrient broth in sterile tubes and incubated at a particular temperature for a fixed time (usually 24 hours). If the water source is unprotected or contamination is suspected, serial dilutions of the water (usually 10, 1, and 0.1 mL) may be made. Three or five tubes per dilution are commonly used, though ten tubes may be used for greater sensitivity. As coliform bacteria grow, they produce acid and gas, changing the broth colour and producing bubbles, which are captured in a small inverted durham tube. By counting the number of tubes showing a positive result, and comparing with standard tables, a statistical estimate of the MPN of bacteria can be made, with results reported as MPN per 100 ml. Since some non-coliform bacteria can also ferment lactose, this first test is called a "presumptive" test. Bacteria from a positive tube can be inoculated into a medium that selects more specifically for coliforms, leading to "confirmed" results. Finally, the test can be "completed" by subjecting positive samples from the confirmed test to a number of additional identification steps. Each of the three steps (presumptive, confirmed and completed) requires 1-2 days of incubation. Typically only the first two steps are performed in coliform and faecal coliform analysis, while all three phases are done for periodic quality control or for positive identification of *E. coli.* Disadvantages to this method include the large number of tubes needed and the long time requirement for the full test. Accordingly, this test is most conveniently applied in a laboratory setting, though the presumptive test is sometimes made with field kits. Another disadvantage of this method (and other MPN methods) is that the result is a statistical approximation with fairly low precision, and as such should only be considered semi-quantitative (UNICEF, 2008).

2.8.3 Membrane filtration methods

The membrane filter method gives a direct count of total coliforms and faecal coliforms present in a given sample of water. A measured amount of water is filtered through a membrane with a pore size of about 0.45 μm, which traps the bacteria on its surface. The membrane is then placed on selective agar or a thin absorbent pad that has been saturated with a medium designed to grow or permit differentiation of the organisms sought (Pepper and Gerba (2004). The success of this method depends on using effective differential or selective media that will enable easy identification of colonies.

The membrane filter technique shows remarkable advantage over the MPN technique in that it could be used to test relatively large numbers of samples and yields results more rapidly than the multiple fermentation tube technique. However, this method is inappropriate for turbid waters, which can clog the membrane or prevent the growth of target bacteria on the filter. The technique is hence unsuitable for natural waters containing very high levels of suspended material, sludges and sediments, all of which could block the filter before an adequate volume of water has passed through. When small quantities of sample (for example, of sewage effluent or of grossly polluted surface water) are to be tested, it is necessary to dilute a portion of the sample in sterile diluent to ensure that there is sufficient volume to filter across the entire surface of the membrane. Another concern with this method is that it may not detect stressed or injured coliforms. It was originally designed for use in the laboratory but portable equipment is now available that permits use of the technique in the field.

2.8.4 Defined Substrate Technology (DST)

Defined Substrate Technology (DST) is a new approach for the simultaneous detection, specific identification, and confirmation of total coliforms and *Escherichia*

coli in water. This test uses specific indicator nutrients: ortho- nitrophenyl- β -D-galactopyranoside (ONPG) and 4-methylumbelliferyl- β -D-glucuronide (MUG). Enzymes produced by these indicator organisms react with these specific indicator nutrients in the nutrient medium and generally produce a striking colour change that is easy to identify. These tests are more rapid than conventional methods; some can produce results in 24 hours or less. Furthermore, they are more specific than conventional tests, so confirmatory tests are generally not necessary. Colilert was the first commercial DST test to receive U.S. Environmental Protection Agency approval for drinking water analysis (Pepper & Gerba, 2004). Two of the most relevant enzyme tests for drinking water are: Beta-galactosidase and Beta-glucuronidase. Coliform bacteria produce the beta-galactosidase enzyme, hence when a water sample is incubated with the Colilert reagent for 24 hours, if a coliform is present, indicator nutrient is hydrolyzed by the enzyme β -galactosidase of the organism, thereby releasing the indicator portion, ortho-nitrophenyl (ONPG). The free indicator imparts a yellow color to the solution. On the other hand, over 95% of *E. coli* produces the beta-glucuronidase enzyme, an additional constitutive enzyme that hydrolyzes the second indicator nutrient, MUG. As a result of this hydrolysis, MUG is cleaved into a nutrient portion (glucuronide), which is metabolized, and an indicator portion, methyl umbelliferone, which fluoresces under ultraviolet light. DST can easily be used in a qualitative way to measure the presence (P) or absence (A) of coliforms or *E. coli* (P/A test). A single sample of undiluted water is incubated for the appropriate time, with a positive result indicating contamination, but giving no information regarding the level of contamination

2.8.5 Hydrogen Sulfide (H_2S) Test

Waters containing coliform bacteria also consistently contained organisms producing hydrogen sulfide (H_2S). Since H_2S reacts rapidly with iron to form a black iron sulfide precipitate, an iron-rich growth medium is used to detect faecal contamination of water. When water samples are incubated in the medium at 30-37°C for 12 to18 hours, production of a black colour indicates contamination with H_2S producing organisms (Manja *et al.*, 1982). The H_2S test does not specifically test for standard indicator species such as total coliforms, faecal coliforms or *E. coli*. Rather, a large number of bacteria can lead to H_2S production (e.g. *Citrobacter, Enterobacter, Salmonella, Clostridium perfringens*). Most of these are faecal in origin. However both human and animal faeces contain H_2 S-producing organisms, so the H_2S test, like the total coliform test, is not specific for human faecal contamination. The H_2S test is not mature enough to replace conventional methods, but can play a valuable role in screening water supplies. Testing water for faecal contamination with the H_2S method is certainly preferable to not testing at all (UNICEF, 2008).

2.8.6 Molecular methods for bacteriological analysis of water

Traditional methods for the detection and identification of bacteria rely on growing the organism in pure culture and identifying it by a combination of staining methods, biochemical reactions and other tests. This applies equally to detection of environmental organisms (in soil or water), bacteria in food (including milk and drinking water) or pathogens in samples from patients with an infectious disease. However these methods are slow, requiring at least 24 hrs or several weeks for slow-growing organisms such as Mycobacterium tuberculosis. In addition, there are some bacteria such as Mycobacterium leprae (the causative agent of leprosy) that still cannot be grown in the laboratory. The use of molecular techniques which rely on the

amplification and detection of specific nucleic acids offers a fast and reliable alternative and hence, they are the choice methods. The molecular techniques includes; multiplex PCR, reverse transcription PCR, and microarrays.

i. Multiplex PCR (mPCR)

Multiplex PCR is a recent molecular method used in the detection of bacteria in samples. The advantage of mPCR is increased specificity because more than one gene is targeted (Imani *et al.*, 2013). Further, when the method is combined with real-time PCR, target quantification is possible. The researchers used seven primer pairs to differentiate EPEC (typical and atypical), EAEC, ETEC, EIEC, and STEC (Aranda, 2007). The method involved targeting eae (structural gene for intimin of EPEC and EHEC) and bfpA (structural gene for the bilus-forming pili of ypical EPEC) for EPEC, aggR (transcriptional activator for the AAFs of EAEC) for EAEC, elt and est for ETEC (heat-labile and heat-stable enterotoxins of ETEC), ipaH (invasion plasmid antigen H found in EIEC and Shigella) for EIEC, and stx (Shiga toxins 1 and 2 and variants) for STEC. The assay was tested for specificity with reference strains and clinical isolates and was used to detect *E. coli* in stool samples of children with and without diarrhoea. They found that typical EPEC was the most commonly isolated category of diarrheagenic *E. coli*. A multiplex technique that targeted the *Vibrio cholera* virulent genes hlyA, ctxB, tcp1 have been proposed to be a reliable method to detect toxigenic-pathogenic strains of *V. cholera* (Imani *et al.*, 2013). Various mPCR methods have also been developed to identify specific groups of *E. coli* (Raph & Ji-Dong, 2010).

ii. Reverse Transcription PCR

Although DNA based PCR methods are reliable, the inability of DNA-based molecular methods to distinguish between live and dead cells is a significant limitation

toward monitoring possible pathogens in water samples coli. Another major limitation of the standard PCR methods is it inability to detect the presence of certain viruses involved in waterborne disease outbreaks. To address these limitations, researches have investigated the potentials of mRNA as possible target for detecting viable bacteria cells (Raph & Ji-Dong, 2010). Early studies targeted *E. coli* mRNA for two genes (groEL and rpoH) involved in stress response, as well as a gene (tufA) for an abundant cellular housekeeping protein, and concluded that mRNA was indeed an effective indicator of viability. In order to obtain a sensitive method for detecting a specific mRNA, a DNA copy is made initially using an RNA-directed DNA polymerase reverse transcriptase. Following the initial reverse transcription, a standard PCR can be used to amplify the DNA strand produced. This method, reverse transcript PCR or RT-PCR, provides a very sensitive method of detecting the presence of a specific transcript within small sections of a bacterial population. A serious limitation of RT-PCR as described above is that it is not easily quantifiable. It can be used to detect a transcript but not (or at least not easily) to determine how much of that transcript is present (Dale & Park, 2004).The specificity of mRNA detection methods has been further advanced by combining reverse transcription with other molecular techniques such as multiplex PCR (RT mPCR). For example, viable *E. coli* 0157:H7 was detected using RT mPCR targeting the lipopolysaccharide gene (rfbE) and the H7 flagellin gene (fliC). Reverse transcription has also been combined with real-time multiplex PCR technologies (RT mRT PCR). For example, techniques have been developed to detect mRNA encoded by rfbE and eae genes of *E. coli* 0157:H7 in pure cultures and bovine faeces (Sharma & Dean-Nystrom, 2006).

2.9 Heavy metal concentrations, food and water borne diseases

When rain falls to the ground, the water does not stop moving. Part of the water flows through the land surface to streams or lakes, others are used up by plants, while some evaporates and returns to the atmosphere, the remaining seeps underground, into pores between sand, clay and rock formations called aquifers (Akoto & Adiyah, 2007). In many countries, some communities obtain their drinking water from these aquifers. Private or commercial water suppliers drill wells through soil and rock into the aquifers to reach the ground to obtain water and supply the public with these drinking water. Many personal home owners also have their own private wells drilled on their property to tap ground water. Unfortunately, the ground water can become contaminated by human activity which introduce chemicals into the environment. These chemicals can enter the soil and rock, polluting the aquifer and eventually the well (Emhermmed *et al.*, 2014).

One of the most critical environmental issues of general concern today is ground water contamination and among the wide variety of contaminants that affect water resources, heavy metals are given particular attention due to their strong toxicity even at low concentrations (Marcovecchio *et al.*, 2007). Heavy metals are those elements that have atomic weights between 63.546 and 200.590 and a specific gravity greater than 4.0 i.e. at least 5 times that of water. They occur in water in colloidal, particulate and dissolved phases (Adepoju-Bello *et al.*, 2009) with their presence in water bodies being either of natural origin (e.g. eroded minerals within sediments, leaching of ore deposits and volcanism extruded products) or of anthropogenic origin (i.e solid waste disposal industrial or domestic effluents harbour channel dredging) (Marcovecchio *et al.*, 2007).

Most of the heavy metals like cobalt, iron, copper, chromium, manganese, nickel and zinc in trace amounts are essential for metabolic activities and growth of

microorganism, when ever concentrations increase than threshold levels, they have deleterious effects on various organisms (Mohammed & Fohad, 2016).

Ingestion of heavy metals can leads to serious health effects with different symptoms depending on the nature and quantity of the metal intake. The heavy metal toxicity is produced by forming complexes with proteins, in which carboxylic acid (-COOH), amine ($-NH_2$), and thiol (-SH) functional groups are involved. These modified biological molecules lose their ability to function properly resulting in the malfunction or death of the affected cells. When metals bind to these functional groups, they inactivate important enzyme systems or affect protein structure, which is linked to the catalytic properties of the enzymes. This type of toxin may also cause the formation of radicals which are dangerous chemicals that cause the oxidation of biological molecules (Momodu and Anyakora, 2010). The most common heavy metals that humans are exposed to are Aluminium. Arsenic, Cadmium, Lead and Mercury.

Because aluminum competes with calcium for absorption, increased amounts of dietary aluminum may contribute to the reduced skeletal mineralization (osteopenia) observed in preterm infants and infants with growth retardation. Aluminum in large doses can cause neurotoxicity, and is associated with altered function of the blood—brain barrier. Cadmium is highly toxic and accounts for several cases of food poisoning. Trace amounts of cadmium can cause adverse changes in the arteries of human kidney. It replaces zinc biochemically and leads to high blood pressures, kidney damage (Rajappa *et al.*, 2010).

Contamination of drinking water with high level of copper may lead to chronic anemia. Elemental or metallic mercury and its compounds arc toxic and exposure to excessive levels can permanently damage or fatally injure the brain and kidneys. Metallic mercury when absorbed through the skin may result in allergic reactions. Ingestion of inorganic mercury compounds can lead to, severe renal and gastrointestinal toxicity. Water-soluble barium compounds are poisonous. Lead enters the human body

in many ways. It can be inhaled in dust from lead paints, or waste gases from leaded gasoline. It is found in trace amounts in various foods, notably in fish, which are heavily subjected to industrial pollution (Emhermmed *et al.*, 2014).

In addition, Lead and Mercury may cause the development of autoimmunity in which a person's immune system attacks its own cells. This can lead to joint diseases and ailment of the kidneys, circulatory system and neurons at higher concentrations. Lead and Mercury can cause irreversible brain damage. In Nigeria today, the use of ground water has become an agent of development because the government is unable to meet the ever increasing water demand. Thus, inhabitants have had to look for alternative ground water sources such as shallow wells and boreholes. The quality of these ground water sources are affected by the characteristics of the media through which the water passes on its way to the ground water one of saturation (Adeyemi *et al.*, 2007), thus, the heavy metals discharged by industries, traffic, municipal wastes, hazardous waste sites as well as from fertilizer for agricultural purposes and accidental oil spillages from tankers can result in a steady rise in contamination of ground water. There is therefore the need to assess the quality of ground water sources by examining the level of heavy metals concentrations against the World Health Organization specified maximum contaminant levels.

2.10 Antibiotics, heavy metals resistance and waterborne disease

Antibiotic resistance is the ability of bacteria to resist the effects of antibiotic treatment, i.e that the bacteria are not killed, their growth is not stopped by exposure to a particular type of antibiotics (CDC, 2016). Antibiotic resistance is one of the world's most pressing public health problems. Illnesses that were once easily treatable with antibiotics are becoming more difficult to cure and more expensive to treat. Infections from common antibiotic resistant waterborne bacteria, such as

Salmonella, can cause more severe health, outcomes than infections with bacteria that are not resistance to antibiotic (NARMS, 2017).

Antimicrobial resistance is a complex, urgent global health concern. There is increasing interest about the emergence of multidrug – resistant superbugs. These superbugs result in infections responsive to treatment with few if any currently available antimicrobial agents. Use of antimicrobials exerts selective pressure on pathogens as well as on commensal organisms that are part of the normal flora of humans; this favours the emergence of resistant strains (Samantha and Janeas, 2016). Multiple antibiotic resistant (MARB) and antimicrobial drugs enter the environment via wastewater, especially from hospitals and pharmaceutical plants and through agricultural runoff, leading to contamination of surface and ground water. MARB can infect humans via contaminated food and drinking water, or directly from the environment. Agricultural runoff and sewage either treated or untreated, are also the main sources of MARB in coastal seawater(Saif *et al.,* 2014).

Recently, in human beings lifestyle diseases are increasing the consumption of antibiotics and also enhances and released a huge amount of un-metabolized drugs in sewage which contaminate water bodies. Several other anthropogenic activities increases the antibiotics and metals concentration in water bodies, increasing concentrations of both antibiotics and metals beyond the tolerance limit create an evolutionary force of adaptation in harsh environment. These heavy metals and antibiotic stress are attaining a modification in the genetic makeup of chromosomal and plasmid DNA of bacteria, which occurred by genetic mutation and genetic elements transfer from the resistant bacteria in the surrounding environment. (Mohammed & Fohad, 2016)

Antibiotic and heavy metals resistant gene present together has been observed on the same plasmid. Potentially pathogenic bacteria are continuously coming into water bodies from the hospital and sewage water, which may contain a mobile genetic element like plasmids interns and transposon. These transposable genetic elements are able to transfer horizontally to other non-pathogenic bacteria, which become pathogenic, or virulent due to acquired resistance to multiple antibiotics. Likewise, antibiotic resistance can be co-selected with metals tolerance. When bacterial isolates of *Pseudomonas aeruginosa* was exposed to a small concentration of zinc, then induce resistance against imipenem, mechanistically. OprDporin gene repressed which prevent the influx of the antibiotic. Similarly, researcher found that copper was able to induce imipenem resistance in bacteria. Most of the industrial discharge contains a huge amount of heavy metals which contaminate nearby water bodies (Chen *et al.,* 2015).

Methicillin resistant *Staphylococcus aureus* (MRSA) strains are now reportedly been isolated in livestock (LA-MRSA) and various foods especially meat and milk, posing a threat over a potential spread of MRSA to consumers via the food chain (Scott *et al.,* 2010). Contamination of meat with MRSA is mostly as a result of cross contamination from the colonized body sites of the animal to the carcass, through the environment of processing facilities or by people involved in the handling of carcasses or meat (Weese *et al.,* 2010). MRSA bears the *mecA*gene which alters penicillin binding proteins (PBP) having low affinity for all beta-lactam antimicrobials (Scott *et al.,* 2010). Hence, transmission of these MRSA strains through the food will contribute to the growing problem of antimicrobial resistance.

Erythromycin is recognized as the drug of choice for treatment of *Campylobacter* gastroenteritis, and ciprofloxacin and tetracycline are recommended as alternative drugs (Nachamkin*et al.,* 2000). Notwithstanding, resistance of these isolates has been reported to these antibiotics (Oporto *et al.,* 2009). *C. jejuni* and *C. coli* isolates

with resistance to various antimicrobial agents have been identified in both developed and developing countries (Van Looveren *et al.*, 2001). A significant increase in the prevalence of resistance to macrolides among *Campylobacter* spp. has been found since the 1990s, and this is described as an emerging public health problem (Altekruse *et al.*, 1999).

Researches on the virulence of *E. coli* 0104:H4 strain indicates that they have special characteristics of both EHEC and EAEC genes, encoding the production of shiga-toxin (stx) and resistance to multi-antibiotics (Brzuszkiewicz *et al.*, 2011). Resistance to heavy metals can be conferred by mobile generic elements or chromosomal and acquired adaptations strategies like (i) efflux metal ion from outside of membrane, (ii) accumulation and complexation of metal ions inside or between the cell membrane (iii) reduction of 'oxidation state of *metal* ions (vi) mutation of cellular target factors and (v) enhance exopolysaccharide production to bind metal ion outside the membrane overall metal resistance activities similar to antibiotic resistance. Co-resistance is defined as the existence of two or more tolerant/ resistance genes on one mobile genetic element. Coexistence of both heavy metals and antibiotic resistance genes founds in numerous environments like gastrointestinal tracts, soil, water, animal manure and poultry farm sites, Organisms are accumulating heavy metals inside inclusion bodies and organs because heavy metals are persistent material unable to degrade and convert other forms except oxidation state (Lu *et al.*, 2014).

The appearance and spread of antibiotic resistance genes and their transfer to pathogens is connected with the increased morbidity and mortality. Drug resistance genes carried by these bacteria multiply in their hosts, can be transferred to other bacterial populations through various mechanisms and are subject to evolution. This transfer of resistance genes from one population to another is a major issue in controlling infections and preventing health hazards due to consumption of contaminated water.

2.11 Water treatment methods

The importance of water treatment is to improve on the quality by removing the contaminants such as the physical, chemical and biological materials that make water unwholesome for drinking, recreation, domestic and other industrial purposes. The process of water treatment involves series of stages which are interrelated, but the first few steps come under the preliminary treatment, after which the water is progressed for next set of treatment procedures.

2.11.1 Screening

Through this process, large floating objects and debris are removed from the water. The various screens used for screening process are manual bars, mechanical bars, drum-screen, band screen, disc screen and passive well screens (Blessy & Krishnamurthy, 2014).

2.11.2 Coagulation

Coagulants with charges opposite to those of the suspended solids are added to water to neutralize the negative charges on dispersed non-settleable solids. The selection of coagulant depends upon the nature of the suspended solids to be detached, the raw water setting, the facility design and the cost of the amount of essential chemicals (Haris,2007).

2.11.3 Flocculation

Flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles. The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs called pinflocs. The floc size continues to build through additional collisions and interaction

with inorganic polymers formed by the coagulant or with organic polymers added. It requires around 20-45 minutes for this step to take place (Kumar and Awasthi, 2009).

2.11.4 Sedimentation

Sedimentation basins are used in conventional plants. Direct-filtration plants skip the sedimentation stage and go directly to filtration. Detention times for sedimentation are in the range of 1 to 4 hours (Shuler & Kargi, 2002).

2.11.5 Filtration

It is the final step in removing suspended matter. It is the process of passing water through a material bed in order to remove impurities. Although the sand filter was often sufficient to reduce the concentration of target parameters below the stated goal, the BAC filter significantly improved the quality of the water. The slow sand filter effectively reduced iron and arsenic concentrations. The BAC filter effectively reduced the DOC to less than 1 mg/L. Together, the sand and BAC filters reduced colour and turbidity (Blessy & Krishnamurthy, 2014).

i. Slow rate gravity filtration

It has low filtration rates ranging from 45 to 150 gpd/sqft (0.03 to 0.10 gpm/sqft) and the filter media used is 24" to 30" deep silica sand bed (Elberling, 2002).

ii. Rapid rate gravity filtration

In rapid filtration sand is commonly used as the filter medium but the process is quite different from slow sand filtration. This is so because much coarser sand is used with an effective grain size in the range 0.4-1.2 mm, and the filtration rate is much higher, generally between 5 and 15 m3/m2.h (120-360 m3/m2.day) (Elberling, 2002).

iii. Bioreactors

Bioreactors have been utilized with success for waste-water treatment for over 100 years. Bioreactor processes can be distinguished on the basis of biomass retardment mechanism. Biomass grows on a carrier in attached growth, i.e. biofilm systems or as a suspension in sludge processes. Mostly, the traditional methods of water treatment are unable to eliminate salts and according to the EIPPCB (European Integrated Pollution Prevention and Control Bureau), the textile industry produce more than 0.2 million of tons of salts in the environment every year which leads to aquatic ecosystems equilibrium alteration. Moreover, salts in surface waters can affect also the agricultural activity and salinization of underground fresh water can critically compromise the drinking water resources (Tigini, 2010).

2.12 Aeration

Oxygen in the air will react with hydrogen sulfide to form an odorless, dissolved form of sulfur called sulfate. Some yellow sulfur particles may also form after the water is aerated. In an aeration system, compressed air can be injected into the water system. The air must then be removed from the water to prevent knocking or air-blocks in the water system. Another approach is to spray water into a non-pressurized tank. A second pump is needed to re-pressurize the water system. It is common for odours to be present near these aeration systems as hydrogen sulfide gas is released from the water (Binnie *et al.*, 2002).

2.12.1 Methane removal

Methane (CH_4) is a naturally occurring hydrocarbon that is colourless, odourless and tasteless. Methane is the chief constituent of natural gas, and high concentrations of the gas can cause oxygen-deficient atmospheres, flammable situations, or

explosive environments. Methane is lighter than air and very often can be removed from a well when it is properly vented to the atmosphere. Proper venting is extremely important and can significantly reduce the amount of methane, as it can trigger an explosion in enclosed/confined spaces containing oxygen, coupled with an ignition source (an open flame or an electrical spark). Methane can act as an asphyxiate by displacing air in structures and replacing oxygen in animal circulatory systems; burning methane also can produce other toxic gases such as
carbon monoxide (Carson & Mumford, 2002).

2.12.2 Hydrogen sulfide removal

Hydrogen sulfide is formed by sulfur bacteria that may occur naturally in water. These bacteria use the sulfur in decaying plants, rocks, or soil as their food or energy source and as a by-product produce hydrogen sulfide. The sulfur bacteria do not cause disease, but their presence in water can cause a bad taste or odor. Water containing hydrogen sulfide usually does not pose a health risk, but does give water a nuisance "rotten egg" smell and taste. Water supplies with as little as 1.0 ppm (part per million) hydrogen sulfide are corrosive, may tarnish copper and silverware, and occasionally release a blackmaterial that stains laundry and porcelain (Manahan, 2004).

2.12.3 Carbon filters

Very small amounts of hydrogen sulfide can be removed from water with activated carbon filters. The hydrogen sulfide is adsorbed onto the surface of the carbon particles. Periodically, the activated carbon filter must be replaced depending on the amount of hydrogen sulfide in the water. Moderate to high levels of hydrogen sulfide in water will require very frequent filter replacement (Bansal and Goyal, 2010).

2.12.4 Ion exchange

Ion exchange (IX) is the most broadly working nitrate treatment technology, used at well sites or other points of entry into potable water division systems. Such systems usually treat less than one million gallons of water per day (MGD) to as much as 10 MGD. Although nitrate-selective IX resins have been urbanized, most are more selective toward sulfate than nitrate, therefore the impact of sulfate on nitrate exchange capacity must be considered . These technologies are simple to design, operate and monitor. They are cost-effective for smaller applications such as direct treatment of groundwater at well sites, usually feature fully automated regeneration sensors and equipment, and are regenerated using sodium chloride It is most suitable for waters with total dissolved solids (TDS) concentrations of less than 500 mg/l. Salts and organics in water eventually foul resins, but many systems operate for 5 to 10 years without requiring resin replacement. The primary disadvantage of these systems is the production and costly disposal of concentrated brines, which can contain high concentrations of sodium chloride, nitrate, sulfate, and arsenate. Brines can be disposed of in sewers where adequate dilution is available, but long-term salinity control in some areas may limit this option in the future. Research is now underway to biologically treat ion exchange regeneration brines to remove nitrate and prolong their use prior to disposal. Another major challenge is nitrate removal and the release of nitrosamines or their precursors, which appear to be by-products or impurities in the resins that are used (Doudrick *et al.*, 2011).

2.12.5 Metal removal and softening

After the storage tank, the water was softened to reduce hardness for washing and bathing. An ultraviolet (UV) disinfection lamp was installed after the softener on one ground water system to deal with microbiological problems . The need to ensure

total removal of heavy metals is an important process during water treatment. For drinking and cooking water at each site, a reverse osmosis (RO) membrane, complete with booster pump, was installed as an additional protective barrier at the kitchen sink. The RO unit reduces sulphate, sodium, total dissolved solids and hardness, which are parameters which the BAC filter will not treat. The RO unit will also remove micro-organisms including bacteria, viruses and parasites, provided it is properly operated and maintained (Jaishanka *et al.*, 2014).

2.13 Pre-chlorination and chlorination

The processes involved before chlorination comes under pre-chlorination step. Chlorine will quickly react with hydrogen sulfide to form a tasteless, odorless, yellow particle. A small amount of chlorine, usually household laundry bleach, can be automatically added to any size water system to remove hydrogen sulfide. The yellow sulfur particles that remain in the water will form a yellow film on clothing and fixtures . A sand or aggregate filter can remove the yellow particles. Backwashing the filter is necessary every few days, or every few weeks, to flush out the accumulated sulfur particles (NMWSOCM, (2013).)

2.14 Disinfection

New wells, or old installations after rehabilitation, usually are bacterially contaminated and should be disinfected prior to being placed in service. Chlorine always should be used outdoors or in well-ventilated places because breathing the fumes is dangerous. In heavy concentrations, chlorine also is harmful to skin and clothing. The chlorine must be thoroughly mixed with the water, and then sufficient chlorine contact time must be provided to kill all disease-causing and nuisance organisms (Cheremisinoff, 2001).

2.14.1 Fluoridation

This step will remove the fluoride concentration in water. Nitrate in drinking waters poses human health risks, and nitrate contamination of groundwater has become widespread nowadays. In a study of more than 40 states in US, nitrate was the most frequently reported groundwater contaminant of concern. Most of the wells with elevated nitrate levels are in the areas that are or were used for agriculture. Nitrate is a stable, highly soluble ion that is difficult to remove by traditional coagulation or adsorption processes. Current options for treating nitrate contaminated groundwater include blending and ion exchange, the most common approaches, as well as membrane separation and biological de-nitrification. Chemical de-nitrification technologies are still in development (Crittenden, 2012).

2.14.2 Blending

High-nitrate groundwater is largely managed by blending the groundwater with surface water that has lower nitrate concentrations.

2.14.3 Biosorption

Among various biological approaches, biosorption can be seen as one of the most valuable choice for the removal of pollutants from water sources. Biosorption is a physico-chemical process, in which the removal of substances from solution by biological material takes place. The main advantage includes high efficiency, cost effectiveness and good capacity of removing pollutants from large volumes. There is a major need to generate performance data on real or simulated industrial effluents, since many biotic and abiotic factors can affect biosorption process (Barakat, 2011).

2.15 Modern water treatment processes

2.15.1 Biological de-nitrification

Microbe-induced nitrate reduction can be accomplished using organic carbon electron donors such as methanol or acetic acid, or inorganic electron donors such as hydrogen or reduced sulfur. However, the dissolved oxygen content of the water must be lowered to about 0.1 mg/l for reduction to occur. Recent advances in hollow-fiber membranes allow autotrophic bacteria to grow on the outside of the membrane in nitrate laden water while hydrogen gas is slowly supplied from within the membranes. Nitrate and oxygen permeate into the biofilms growing on the membranes and are reduced in the anoxic environment within the biofilm; this approach shows significant promise for nitrate reduction. Biological de-nitrification systems do not produce concentrated brine streams, but biofilm growth must be managed. The most significant drawbacks of biological systems are that they require start-up time after prolonged periods of closure (such as in response to seasonal water demand), require more operator support than non-biological systems, and are less mature in the marketplace than IX systems (Zhou, 2013).

2.15.2 Chemical de-nitrification

Metals such as platinum, palladium, tin and copper can chemically reduce nitrate to other forms, but they usually require a low pH, often need the addition of hydrogen gas or another strong reductant, and perform best with added heat. As a result, full-scale treatment systems based on these catalysts are not yet used for drinking-water applications. Zero-valent iron (Fe0) has gained the most attention as a nitrate reductant system. Both in-situ groundwater and above-ground treatment systems have been demonstrated at several sites and commercial vendors have recently entered the marketplace. Oxidation of the iron frees electrons, which are then available for

nitrate reduction. Like biological de-nitrification, these systems require low dissolved-oxygen levels to proceed favourably. The precise reactions for zero-valent iron and other chemical reduction processes are not well known for groundwater matrices but in most cases nitrate reduction in groundwater does not proceed to innocuous gases as it does in distilled water or in biological de-nitrification systems. The bioden process is based on the natural biological de-nitrification, which takes place in soil and ground water. However, in this process the de-nitrification is enhanced under controlled conditions in a fixed bed biofilter. In order to meet drinking water requirements, the de-nitrification process needs an aerobic post-treatment. It consists of the following steps such as substrate dosing, denitrifying biofilter, aeration, flock-filtration, polishing filter, safety disinfection, backwash

system and backwash water recycling. As substrate a carbon and phosphate source are dosed into the raw water. Normally all other nutrients are normally sufficiently present in the raw water (Doudrick, 2011).

2.16 Treatment processes for heavily polluted water

2.16.1 Dissolved Air Floatation (DAF)

The DAF range of water treatment plants excel in treating lake and reservoir water containing high levels of colour, algae and turbidity. The treatment plants also provide excellent treatment of cold water with high levels of iron and manganese. This process offers exceptional algae removal, ease of operation, good tolerance to changing raw water surroundings, rapid start-up, low volumes of plant waste and notably lower building costs (Logsdonl, 2004).

2.16.2 Ozonation

It is a water treatment process usually performed to destroy bacteria and other microorganisms through an infusion of ozone. Specifically it targets cryptosporidium, bacteria and other naturally-occurring organisms. It also reduces the formation of tri-halo-methanes (THMs), which result from the interaction of chlorine and naturally-occurring organic material in the source water . Granular activated carbon (GAC) adsorption GAC has an extremely large amount of adsorption surface area, generally around 73 acre/lb (650m2/gram) to 112 acre/lb (1000 m2/gram). GAC is made of tiny clusters of carbon atoms stacked upon one another, and is produced by heating the carbon source (coal, lignite, wood, nutshells or peat) in the absence of air which produces a high carbon content material (USDIBR, 2010).

2.16.4 Membrane based processes

Reverse osmosis (RO) and electro-dialysis (ED) are expensive options to remove nitrate, and are primarily used to treat waters high in TDS rather than solely nitrate pollution. These methods are currently used for nitrate removal in smaller communities and military bases (Zhou, 2013). ED-based systems utilize electric current to pass positive ions (cations) or negative ions (anions) through a semi permeable membrane. The current can be adjusted to pass only cations and reject anions, such as nitrate. However, these membrane-based technologies require significant external energy inputs, which lead to high operating costs. Both RO and ED produce concentrated brine streams that require disposal; pretreatment is usually necessary to prevent membrane fouling. Membrane treatment processes such as these can be a viable treatment option for municipalities with existing membrane technologies (Ganzi *et al.*, 2010).

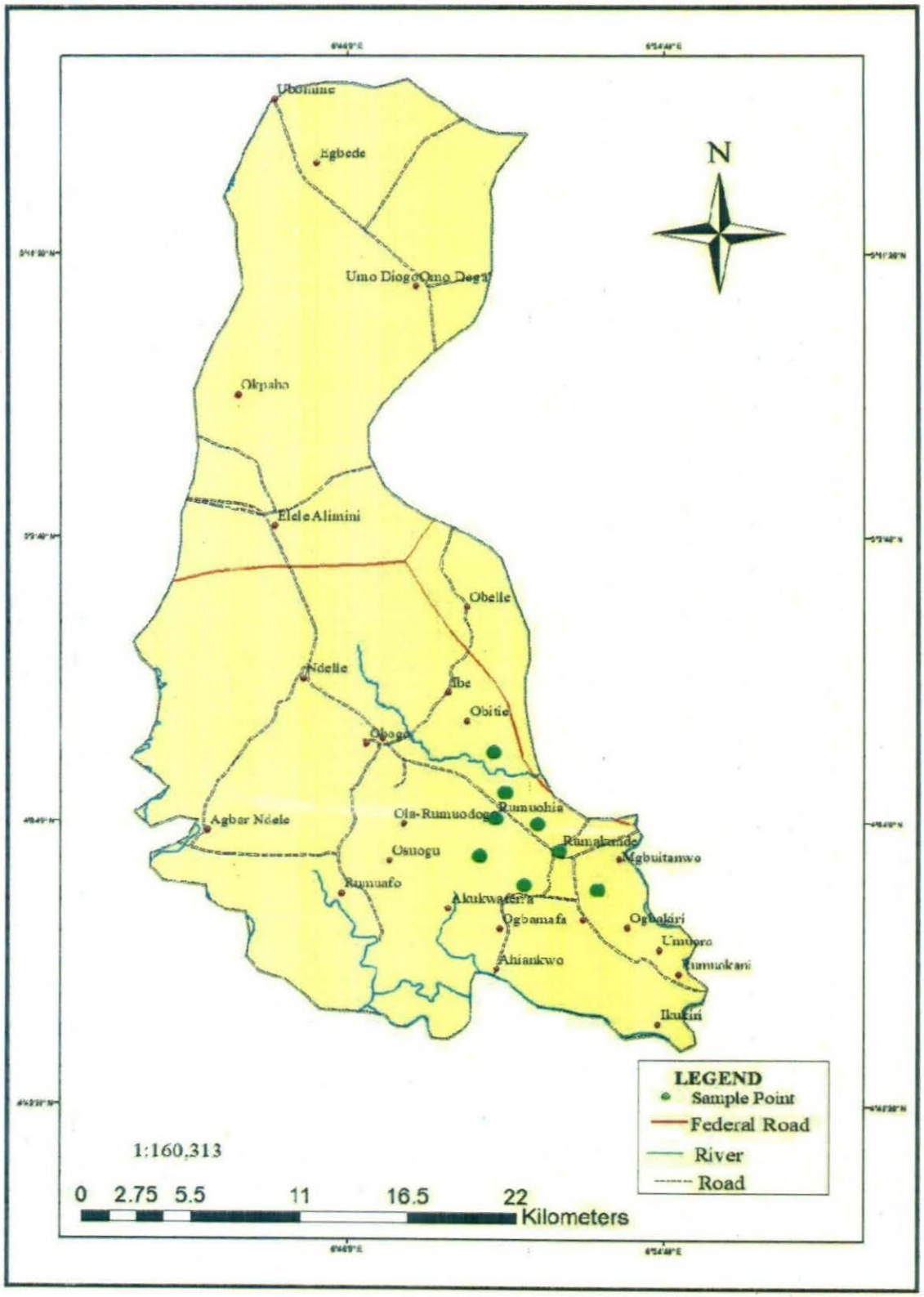


FIG. I: Map of Rivers State showing sample sites in Emohua LGA

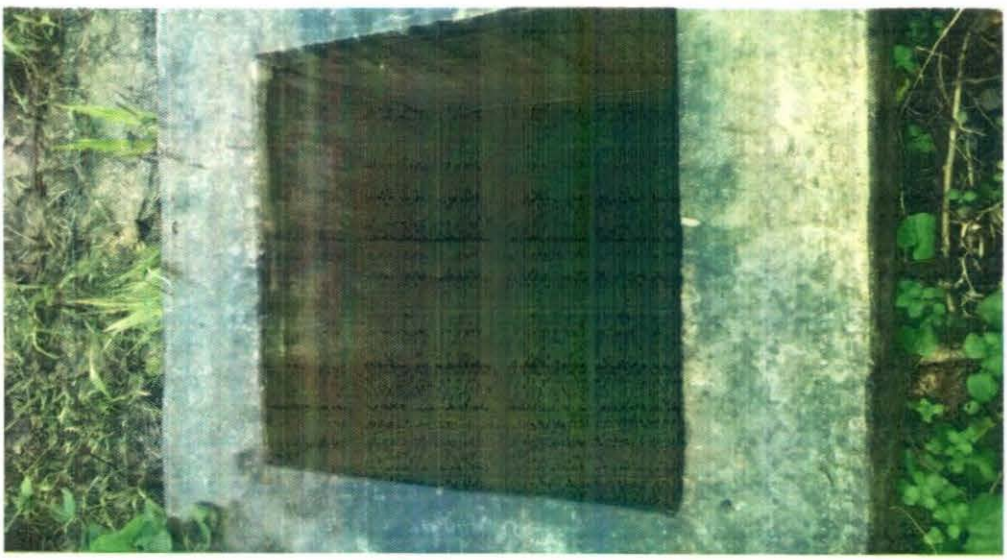


PLATE 1: Site One (Rumu-Nne Well)

This is a family well lying between latitude 4.8733022°N and Longitude 6.360332^{0}E. It serves for both drinking and domestic purposes as shown in plate 1

PLATE 2: Site Two (Boma Well)

This well is a privately owned and located between latitude 4.870085^0N and longitude 6.86283^0E. It is used for drinking and other domestic purposes

PLATE 3: Site Three (Rumu-Oba Well)

This is a compound well with concrete wall lining and covered. It is used for cooking, drinking and other domestic purposes located between latitude 4.871591^0 N and longitude 6.856102^0 E.

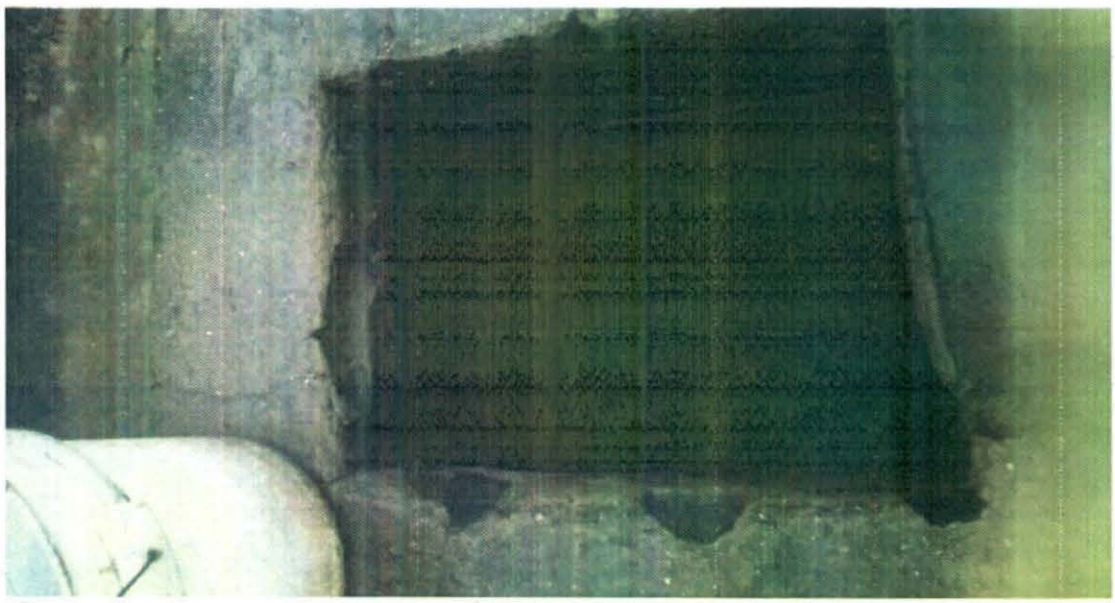


PLATE 4: Site four (Eze Wobasi well)

This is a family well, located uptown and highly patronised. It is used for drinking and other domestic purposes. The well lies between latitude 4.870691^0N and Longitude 0.856093^0E.

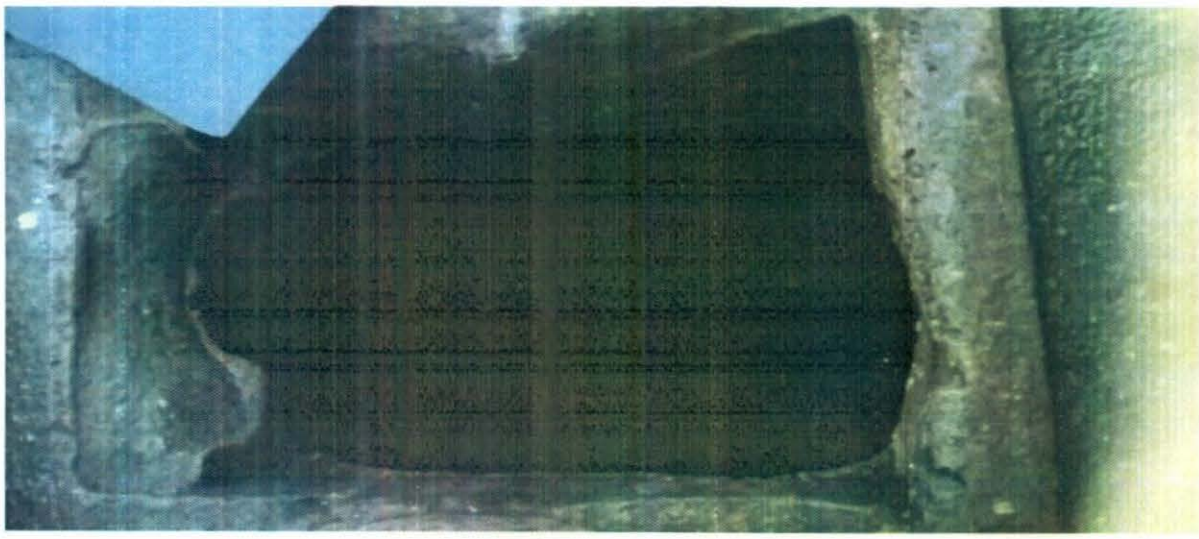


PLATE 5: Site Five (Chief Okogbule Well)

This is also a family well, used for drinking and other domestic purposes. It is dug under a tree and located between latitude 4.877182^0N and longitude 6.858324^0E.

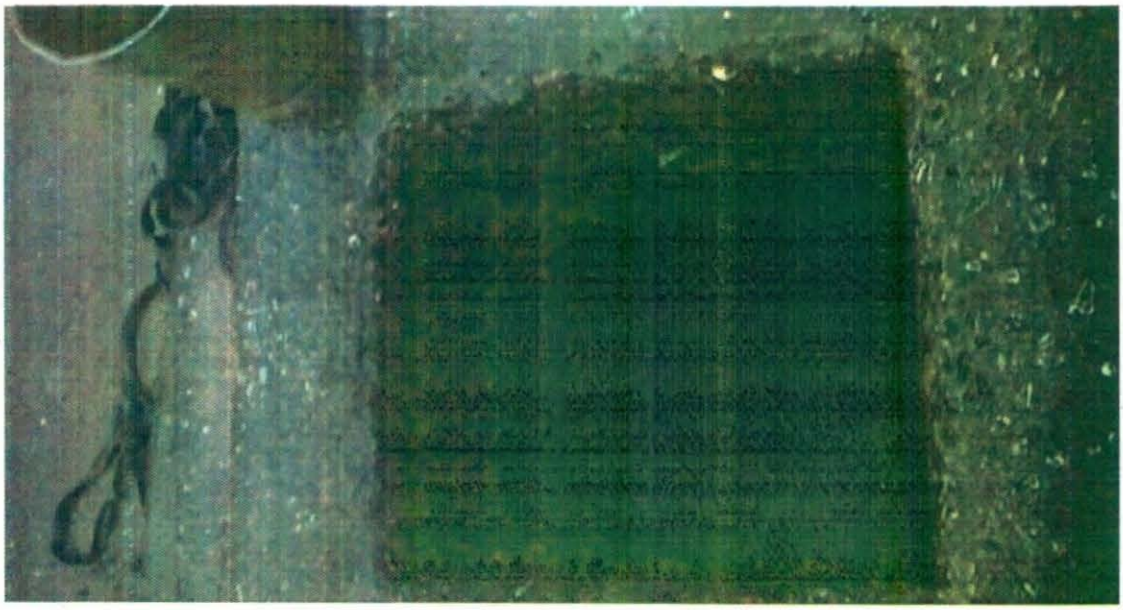


PLATE 6: Site Six (Chief Wogbo Well)

This is a private well, located within latitude 4.891850 ^{0}N and Longitude 6.869533^{0}E. The inhabitants use it for drinking.

PLATE 7: Site Seven (Mini-Abaka)

It is a shallow stream located within latitude 4.89145^0 N and longitude 6.869477^0 E.

PLATE 8: Site Eight(Mini -Wacha)

It is a shallow stream, located within latitude 4.894671^0N and longitude 6.873011^0 E.

S3.3.2 Ikwerre Local Government Area

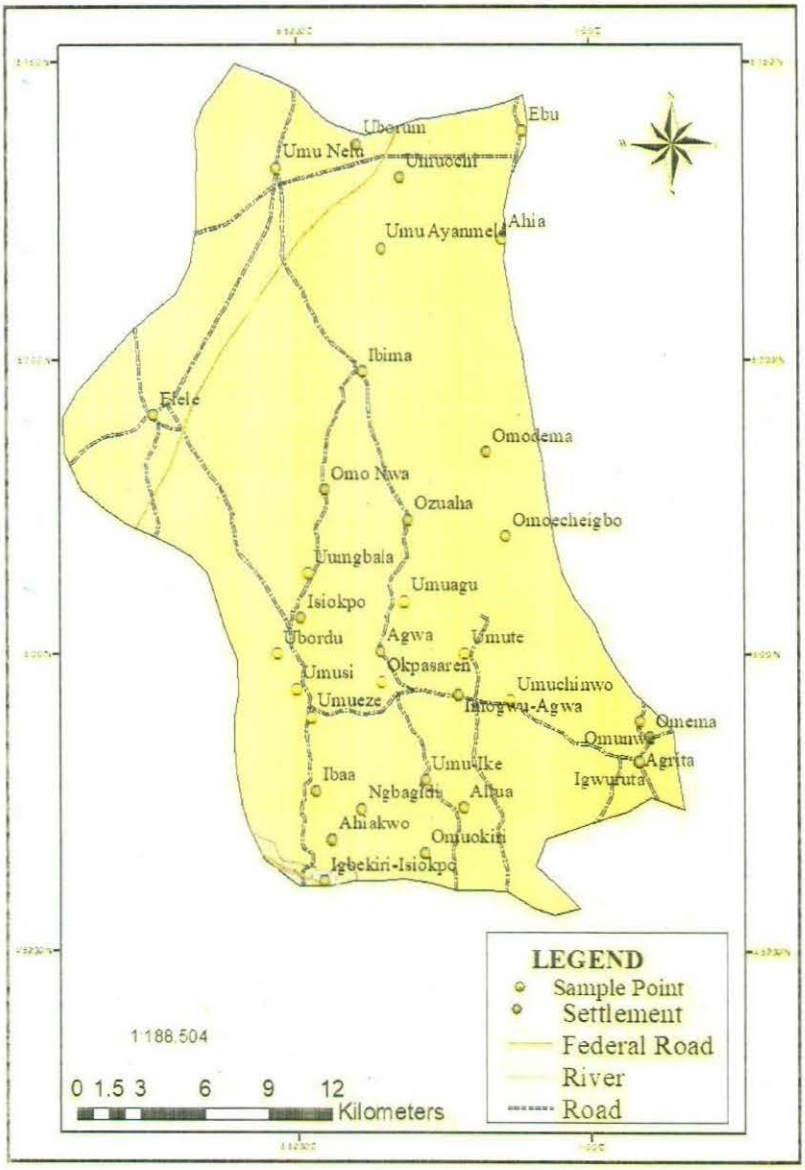


FIG. 2: Map of Ikwerre Local Government Area showing the communities and sampling sites location.

Sample

Site 1: Chief Wali Well
Site 2: Rumu Igwe well
Site 3: Mr. Owens well
Site 4: Afoma well
Site 5: Rumuwori well
Site 6: Rumuobasi well
Site 7: Mini Ohia (stream)
Site 8: Mini Oriji (stream)

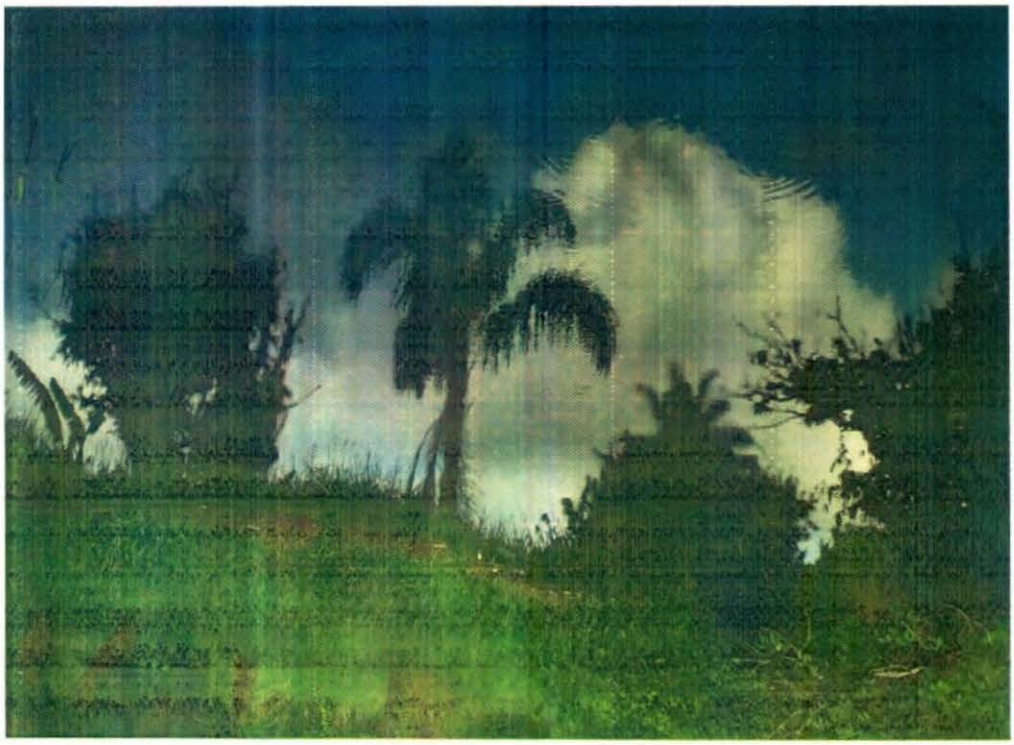


PLATE 10: Mini Oriji (stream) used as site eight in Ikwerre LGA

3.3.3 Etche Local Government Area

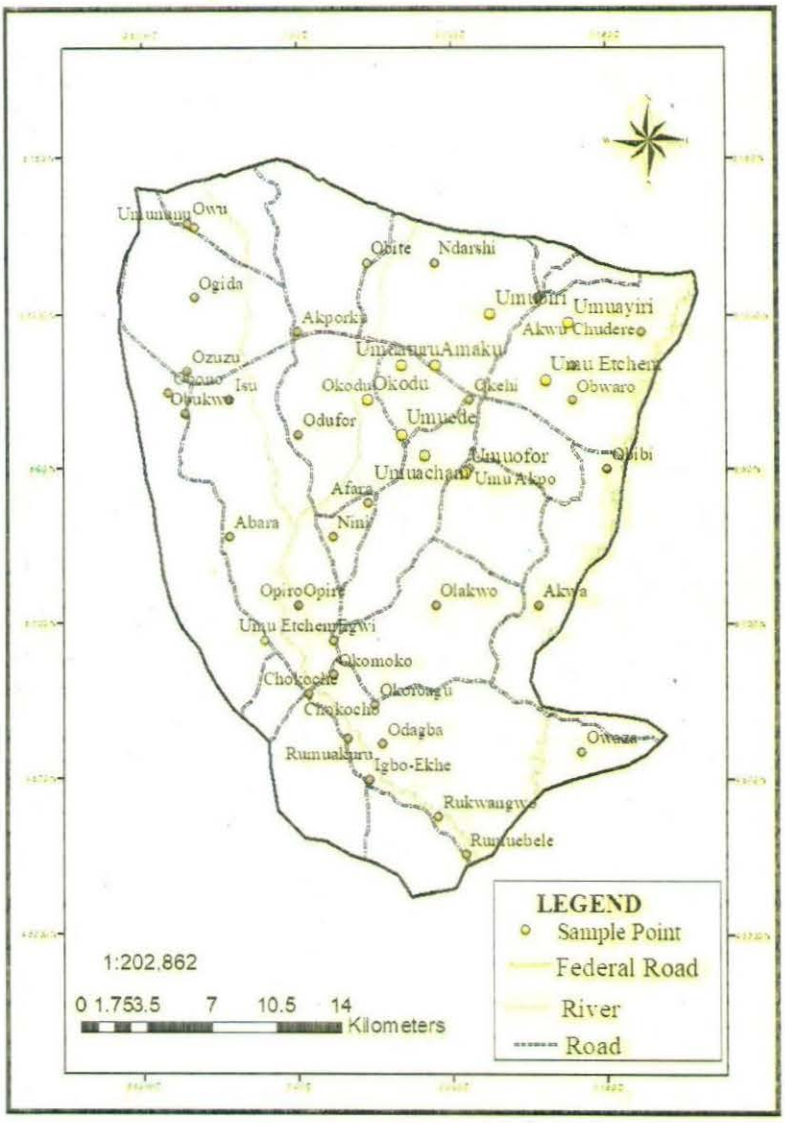


FIG. 3: The map of Etche Local Government Area showing locations of sample sites.

Sample
Site 1: Chief Akagbo Well
Site 2: Napoleon well
Site 3: Omuacho well
Site 4: Mr. Bernard well
Site 5: Appolo well
Site 6: Chief Nweke well
Site 7: Oge Etche (stream)
Site 8: Mba (stream)

PLATE 11: Oge Etche (stream) used as sample site seven in Etche LGA

3.4 Collection of well and stream water samples

Six clean sterile glass bottles were used to collect well water samples from each of the six hand-dug wells in the community and transferred immediately into already labeled sterile two litre plastic bottle containers. The samples were collected in duplicate for physio- chemical, microbiological and heavy metals analysis. Collection of stream water samples was done by entering into the water body up to the knee level and plunging the neck of the sterile glass bottle containers to about 30cm down ward below the water to let the container fill with space left to allow for mixing.

Stream water samples collected with clean glass bottle containers were filtered immediately through a membrane of 0.45 μm. The samples for heavy metals analysis were acidified with trioxonitrate (V) acid in order to stabilise the oxidation state of the metal. All the samples were taken to Divine Integrated Laboratory Services, Port Harcourt, in a cold sample box for analysis.

3.4.1 Sterilisation of materials

All glass wares used were sterilised in a hot air oven. Plastic containers were sterilised by rinsing the inside with 70% ethanol. All media used for growth of the test organism were sterilised in autoclave for 121°C for 15 minutes, unless otherwise stated.

3.5 Preparation of reagents and media

The reagents and media used are described in the relevant sections of the materials and methods and prepared according to the manufacturers' instructions.

3.6 Determination of microbial content of water samples

3.6.1 Isolation and estimation of total heterotrophic bacteria count

Sterilized nutrient agar medium was prepared in a clean petri dish plates and used for isolation and estimation of total heterotrophic bacteria count. The medium

was prepared with reference to the manufacturers instruction. The water sample in each container was gently mixed very well. Then, using a sterile pipette, one milliliter (1.0 ml) of the well mixed water sample was transferred into sterile test tube containing 9 ml of sterile normal saline and 1 in 10 serial dilution was carried out. Using another sterile pipette, 0.1ml aliquot of the 10^{-5} dilution was aseptically removed and carefully dropped on the surface of sterile nutrient agar plates. The inoculum was evenly spread with sterile glass rod. The inoculated petri dish plates were inverted and incubated for 24 hours at 37^{0}C. Petri dish plates showing discrete colonies of bacteria growth between 30 to 300 colonies were counted and recorded as total heterotrophic bacteria.

3.6.2 Estimation of total coliform bacteria in water samples

The presence and probable number of coliform bacteria in the water samples was estimated using the membrane filtration technique in line with (APHA, 1998) procedure. The membrane filtration apparatus consisting of porous support, erlermeyer flask and vacuum pump was sterilized and set up. Using sterilized forceps (dipped in ethanol and flamed), the membrane filter disc (0.45 μm) was removed and placed on the surface of the porous support. Then, the funnel was placed and held infirm position on top of the porous support with clamps. 100ml of 10^{-5} serial dilution of water sample was transferred into the funnel and suction from vacuum pump was applied. The vacuum pump was terminated after the sample have passed through the membrane filter, and the funnel removed. The membrane filter disc was carefully removed suing sterilized forceps and transferred on to the surface of freshly prepared MacConkey agar plates. The plates were incubated at 37^{0}c for 24 hours. Colonies showing yellow colours that developed on the plates were counted as total coliform

bacteria and recorded as colony forming unit per 100ml (cfu/100ml) of water samples analysed.

3.6.3 Isolation and estimation of total *Escherichia coli* Species

The APHA (1998) membrane filter techniques was adopted as described above. To isolate *E. coli*, the membrane filter removed after water filtration was placed on the surface of a differential medium Eosin Methylene Blue (EMB) Agar. The EMB agar medium was prepared according to manufacturer's instructions and incubated at 37^0C for 24 hours. Colonies showing typical yellow and metallic or non-metallic sheen are counted as *E. coli*. *E. coli* imparts metallic sheen due to precipitation of eosin methylene blue complex, while other enteric bacteria do not show metallic sheen.

3.6.4 Isolation and estimation of total *Salmonella* species

To isolate Salmonella species from the water samples, the APHA (1998) procedure as described above was used. However, the 10^{-2} serial dilution was used and 10ml aliquot of water transferred into the funnel. At the end of filtration, the membrane filter was removed and placed on the surface of prepared Salmonella and Shigella (SS) agar petri dish plates. The SS agar medium was prepared according to instructions of the manufacturers and plates incubated at 37^0C for 24 hours.

3.6.5 Isolation and estimation of total vibrio species

Vibrio species were isolated using the membrane filter techniques as described by APHA(1998). 10ml of the 10^{-2} serial dilution was poured into the filtration funnel. After filtration, the membrane filter disc was removed and placed on the surface of already prepared Thiosulphate Citrate Bile Salts Sucrose (TCBS) agar

plates. Preparation of TCBS medium was according to manufacturers instruction. Inoculated petri dish plates were incubated at 37^0C for 24 hours.

3.6.6 Storage and purification of isolates

Discrete colonies were picked and sub-cultured onto Nutrient Agar plates using streak plate method. Stock cultures were prepared on sterile Nutrient Agar in Bijou bottles, coded for ease of identification and stored in the refrigerator (4^0C) until needed for further tests.

3.7 Identification and characterization of bacterial species

The colonies isolated and sub-cultured from the water samples were characterized and identified using their cultural, morphological and physiological features and microscopic examination. Gram staining of the isolates was done and biochemical tests including, coagulase, urease, catalase, oxidase, indole, methyl red, voges proskauer, motility, salt tolerance, hydrogen sulphide and fermentation tests. Probable identification was established with reference to the combined schemes proposed by Harrigan McCance (1976); Cruickshank *et al.* (1980); Cheeseborough (1984); Holt *et al.* (1994).

3.8 Identification of fungal isolates

The pure culture of fungal isolates were identified using their cultural, morphological and physiological characteristics. Slides of fungi were prepared in lactophenol cotton blue and examined microscopically. Probable identification of the species was done using the taxonomic keys described by Harrigan and McCance (1976) and Samson et al., (1981).

3.9 Molecular Identification

3.9.1 DNA extraction (Boiling method)

Five milliliters of an overnight broth culture of the bacterial isolate in Luria Bertani (LB) was spun at 14000rpm for 3 min. The cells were re-suspended in 500ul of normal saline and heated at 95^0C for 20 min. The heated bactererial suspension was cooled on ice and spun for 3 min at 14000rpm. The supernatant containing the DNA was transferred to a 1.5ml microcentrifuge tube and stored at -20°C for other downstream reactions.

3.9.2 DNA quantification

The extracted genomic DNA was quantified using the Nanodrop 1000 spectrophotometer. The software of the equipment was launched by double clicking on the Nanodrop icon. The equipment was initialized with 2 ul of sterile distilled water and blanked using normal saline. Two microlitre of the extracted DNA was loaded onto the lower pedestral, the upper pedestral was brought down to contact the extracted DNA on the lower pedestral. The DNA concentration was measured by clicking on the "measure" button.

3.9.3 16S rRNA Amplification

The 16s rRNA region of the rRNA genes of the isolates were amplified using the 27F: 5'-AGAGTTTGATCMTGGCTCAG-3' and 1492R: 5'-CGGTTACCTTGTTACGACTT-3' primers on a ABI 9700 Applied Biosystems thermal cycler at a final volume of 25 microlitres for 35 cycles. The PCR mix included: the X2 Dream taq Master mix supplied by Inqaba, South Africa (taq polymerase, DNTPs, MgCl), the primers at a concentration of 0.4M and the extracted DNA as template. The PCR conditions were as follows: Initial denaturation, 95°C for 5 minutes;

denaturation, 95°C for 30 seconds; anealing, 52°C for 30 seconds; extension, 72°C for 30 seconds for 35 cycles and final extention, 72°C for 5 minutes. The product was resolved on a 1% agarose gel at 120V for 20 minutes and visualized on a blue light transilluminator.

3.9.4 Sequencing

Sequencing was done using the BigDye Terminator kit on on a 3510 ABI sequencer by Inqaba Biotechnological, Pretoria South Africa. The sequencing was done at a final volume of 10ul, the components included 0.25 ul BigDye® terminator v1.1/v3.1, 2.25ul of 5 x BigDye sequencing buffer, 10uM Primer PCR primer, and 2-10ng PCR template per 100bp. The sequencing condition were as follows 32 cycles of 96°C for 10s, 55°C for 5s and 60°C for 4min.

3.9.5 Phylogenetic analysis

Obtained sequences were edited using the bioinformatics algorithm Trace edit, similar sequences were downloaded from the National Center for Biotechnology Information (NCBI) data base using BLASTN. These sequences were aligned using MAFFT. The evolutionary history was inferred using the Neighbor-Joining method in MEGA 6.0 (Saitou and Nei, 1987). The bootstrap consensus tree inferred from 500 replicates (Felsenstein, 1985) is taken to represent the evolutionary history of the taxa analyzed. The evolutionary distances were computed using the Jukes-Cantor method (Jukes and Cantor 1969).

3.9 Antibiogram profile test

Antibiotic sensitivity test of the isolates was carried out using the disk diffusion method described by Bauer *et al.*(1979). The Sensitive Test Agar (LAB M) medium was used. The medium was prepared according to manufacturer's

instruction. The medium was allowed to cool to 45-50^{0}C and poured into sterile petri dish plates and allowed to solidify. When set, the agar plates were dried for thirty (30) minutes at 35^{0}C by placing them upright in the incubator with the lid tilted. The inoculum of each isolate prepared was from an 18 hour broth culture adjusted to obtain turbidity comparable to 0.5 McFarland Standard. 0.5ml of 1.175% (w/v) barium chloride dehydrate ($BaCl_2$ $2H_2O$) solution was added to 99.5ml of 1% tetraoxosulphate (IV) (H_2SO_4) acid to obtain the turbidity standard and used to standardize the bacteria inoculum. 18 hours broth culture diluted with sterile saline was used to make adjustments. Sterile cotton tipped applicator was dipped into standardized bacterial solution. The swab was then used to streak the entire dried surface of the medium. The inoculated plates were incubated for 5 minutes to remove excess moisture.

The antibiotic disc (Abtek Biological Limited, Liverpool) was then placed at equidistance from each other on the plate with the aid of a pair of sterile forceps. The discs were pressed firmly onto the agar medium with the sterile forceps to ensure adequate contact with the agar. The inoculated plates were incubated for 18-24 hours at 35^{0}C. The antibiotics discs used for the test are; oflaxcin (5μ), gentamicin (10μ), nallixidic (30μg), nitrofurantoin (200μg), cotrimazle (25μ), amoxicillin (25μg), tetracycline (25μg) and augumentin (30μg). A ruler was used to measure the diameter of each zone of inhibition (including the diameter of the disc) and recorded in millimeters (mm). measurement was made on the under-surface of the plate against the light without opening the lid. The measurements were compared to a zone size interpretative chart (NCCLS, 2006), and the organisms were grouped as resistant, intermediate or susceptible to the test antibiotics according to the chart.

3.10 Multi antibiotic resistant index (MARI)

This was carried out as described by Matyar *et al.* (2007) with slight modification. MARI= resistant antibiotics ÷ total antibiotics tested. MARI value > 0.2 indicate existence of isolate(s) from high risk contaminated source with frequent use of antibiotic(s) while values $\leq$ 0.2 show bacteria from source with less antibiotics usage (Krumperman, 1985).

3.11 Enterotoxigenicity test

Enterotoxigenicity test was done according to the methods described by Dean *et al.* (1972); Baselski *et al.* (1977); Takeda *et al.* (1978).

3.11.1 Experimental animals used

Wistar rats were obtained from the animal House Unit of the Department of Biochemistry, University of Port Harcourt, Choba, Nigeria are used for the enterotexigenicity test.

3.10.2 Preparation of enterotoxic inoculum

The bacterial enterotoxic inoculum was prepared by inoculating tryptic soy broth with isolates from stock cultures of eight *Escherichiacoli*, Virbrio and Salmnella species from the water samples (i.e one isolate from each sampling site). Clinical isolates of *Escherichia coli,* vibrio species and *Salmonella typhi* obtained from University of Port Harcourt Teaching Hospital (UPTH) Port Harcourt served as control. The broth was incubated at 37^0C for 24 hours in a shaker (Stuart, Obital Incubator S150). The cultures were centrifuged and the supernatant used to inoculate the rats. The rats were separated and randomly placed in groups of three before the test. Using syringes each set of three rats were inoculated with 0.1m of *Echerichia coli, Vibrio* and *Salmonella sp.* and the Tryptic Soy Broth (TSB)

respectively. Three sets of rats were kept uninoculated. All the inoculated rats were kept at room temperature (37^0C) for 4 hours after which they were killed with chloroform. The gut (intestine) of each rat was surgically removed from the body and each weighed separately. The fluid accumulation (FA) ratio of (weight of entire intestine) divided by (total body weight-weight of entire intestine) of each animal was calculated. The standard gut-to–weight ratio of >0.065 as described by Baselski *et al.* (1977) was used as standard.

3.11 Physico-chemical analysis of water sample

The physio-chemical parameters analysed include pH, conductivity, temperature, turbidity, total hardness, total dissolved solids, nitrates, phosphates, chloride, dissolved oxygen, biological oxygen demand (BOD). The APHA (1998) described methods for water analysis was used for all the physio-chemical parameters tested for the well and stream water samples.

3.11.1 pH

pH of the well and stream water was measured by inserting the pH probe directly into the sample and the reading taken from the digital display. This was determined *in-situ* using 340i WTW calibrated with 7.0 and 10.0 buffer solutions according to manufacturers instruction.

3.11.2 Conductivity

Conductivity was determined with the Suntex Conductivity meter. This was done by switching on the conductivity meter adjusting the reading portion and dipping the electrode into each water sample and recording the reading appropriately.

3.11.3 Temperature

Temperature of the water samples was determined *in-sutu* using the mercury-in-glass thermometer. The thermometer glass rod was immersed below the water surface and allowed to stand for 3 minutes, to allow the mercury thread rise to a stable reading. The thermometer was brought out and the temperature reading recorded instantly.

3.11.4 Turbidity determination

The Hach colorimeter (DR 890) was used to measure turbidity of water samples. The water samples were gently agitated to allow for disappearance of the air bubbles. A clean 10ml plastic curvette filled with distilled water was used to adjust the meter using the zero control knobs to 000. A second clean 10ml plastic cuvette was filled with the water sample and the surface wiped with clean soft tissue paper. The cuvette was now placed in the central recess of the meter ensuring that the location arrow on the cuvette is to the right and covered with the lid. The magnetic switch was turned on and turbidity reading measured in Nephlometric Turbidity Units (NTU) was taken directly from the instrument.

3.11.5 Total hardness

Total hardness of the water samples was determined trimetrically. Fifty milliliters (50ml) of the water sample was measured into a 250 ml conical flask. Two milliliters (ml) of the pH 10 Ammonia buffer (NH_4CL-NH_4OH) solution was added and swirled followed by addition of 2 drops of the indicator (0.5% Eriochrome black T) solution. A red wine colour developed as the mixture swirled. Standard 0.01M ethylene diamine tetra acetate (EDTA) titrant was added slowly with continuous stirring until the reddish tings disappeared and colour changed to

blue. The blank was prepared with distilled water and analysed following the same procedure. The total hardness can be calculated thus:

$$\text{Total hardness } (CaCO_3)\ \text{mgl / l} = \frac{V \times N \times 50 \times 1000}{SV}$$

Where V = Volume titrant

N = Normality of EDTA

50 = Equivalent weight of $CaCO_3$

SV = Sample Volume (ml)

3.11.6 Total dissolved solids

The concentration of Total Dissolved Solids (TDS) of the water samples was calculated from conductivity measurement using the relationship as thus: TDS mg/l = Conductivity (μS/cm) x 0.65 (water sample), where: μS/cm is microsiemen per centimeter, mg/l is milligramme per litre of water sample.

3.11.7 Determination of nitrate level

The level of Nitrate in the water samples were determined colorimetrically using spectrophotometer. The method is based on the formation of yellow complex between brucine sulphate and nitrate in the presence of sulphuric acid. 0.01 ml, 1.00ml, 2.00ml, 3.00ml and 4.00ml of the intermediate standard nitrate solution was measured in to separate100ml volumetric flask and diluted to the mark with distilled water. The solutions have nitrate ion concentrations of 0.00, 0.50, 1.00, 1.50 and 2.00 mg/l, respectively and serve as the working standard solutions. 1 ml of each working standard solution was transferred into separate sample vial and 0.5ml of brucine reagent was added. 2ml of sulphuric acid was quickly added and mixed for 30 secs. The mixture was allowed to stand for 5 mins, mixed again with 2ml of distilled

water added. The absorbance was measured after 10 minutes with UV4-100 spectrophotometer at 640nm wavelength with 10mm cell. At the end of the calibration run, the measured absorbance of the standard solution was plotted against the known concentration values. Two standards and a calibration blank (distilled water) were analysed to check the reliability of the calibration curve before every analysis. 1ml of water sample was transferred into a vial, mixed and analysed following the procedure described for preparation of working standard solution for calibration. Analysis sequence is in the order, calibration blank, standards, procedural blank, quality control standard (QC.STD) samples (including duplicates). The concentration of Nitrate in water sample was calculated follows;

NO^-_3 mg/ = mg/l NO^-_3 from the graph-reagent blank

3.11.8 Determination of phosphate concentration

The concentration of phosphate in the water samples was also determined colorimetrically using the UV4-100 Unicam Spectrophotometer. The method is based on the formation of a blue colour complex by the addition of stannous chloride to the water sample. 0.001, 1.00ml, 3.00ml and 4.00ml of the standard phosphate solution were measured into separate 100ml volumetric flask. The solutions have phosphate ion concentrations of 0.00, 0.50, 1.00, 1.50 and 2.00mg/l, respectively and served as the working standard solutions. 4ml of molybdate reagent was added to each flask and mixed thoroughly. This was followed by the addition of ten drops (0.5ml) of stannous chloride solution and mixed again. Distilled water was used to dilute the solution up to the 100ml mark. The absorbance was measured after 10 minutes with UV4-100 spectrophotometer at 640nm wavelength with 100mm cell.

At the end of the calibration run, the measured absorbance of the standard was plotted against the known concentration values. Two standards and calibration blank (distilled water) were analysed to check the reliability of the calibration curve before every analysis. One drop of phenolphthalein indicator was added to 100ml of water sample and transferred into a vial, mixed and analysed following the procedure described from preparation of working standard solution for calibration alone above. Analysis sequence is in the order; calibration blank, standards, procedural blank, quality control standard (QC.STD) samples (including duplicates). Phosphate in water samples was calculated as follows;

$$PO_4^{3-}\ mg/l = mgP \frac{(\text{in approximate } 104.5ml \text{ final volume}) \times 1000}{\text{Sample volume (ml)}}$$

3.11.9 Determination of chloride

The titrimetric method was used to determine the chloride level in accordance with section 4500C1-B APHA (1998). The method requires titration of an aliquot of the water sample in the presence of potassium chromate and Volhard solution as indicators respectively to a brick-red endpoint with silver nitrate ($AgNO_3$) 50ml of each water sample was measured into clean conical flask. The pH of the solution was adjusted to the phenolphthalein endpoint (pH 8.3) using tetraoxosulphate (VI) acid and sodium hydroxide (NaOH) solution (10g/l). 1 ml of potassium chromate indicator solution was added and mixed. Drops of the standard 0.01N $AgNO_3$ solution was also added from a 25ml burette until the brick-red (pink) colour appeared throughout the sample. The procedure was repeated using exactly one half of the original sample. A blank was prepared with 50ml distilled water and carried through the same process as the sample.

The concentration of chloride in the water sample was calculated as follows;

$$\text{Chloride (mg/l)} = \frac{(V_1 - V_2) \times N \times 35450}{S}$$

Where:

V_1= Standard $AgNO_3$ solution used in titrating water sample (ml)

V_2= Standard $AgNO_3$ solution used in titrating one-half of the sample (ml)

N = Normality of standard $AgNO_3$

S = Sample volume (50ml) used for the analysis (ml)

3.11.10 Determination of dissolved oxygen

The concentration of Dissolved oxygen was determined using the Winkler's method as described in APHA (1998). This was done by adding 1ml Winkler I and II reagents to water sample in 125 ml brown bottle. 1ml starch solution was added to the solution to form a deep blue solution. The solution was titrated against standard silver nitrate ($AgNO_3$) to reach a colourless endpoint and the volume was recorded.

3.11.11 Determination of Biological Oxygen Demand (BODs)

The 5 – day biological oxygen demand (BOD_5) of the water samples was determined using the Winkler's method (APHA, 1998). This was done by determination of the BOD of the water sample, one at the beginning and the other after five days of incubation at 20^0C. The value difference between day 1 and 5 becomes the biological oxygen demand measured in mg/l.

3.11.12 Heavy metals analysis

The water samples were analysed for the presence of some heavy metals including magnesium, iron, calcium, lead, mercury, copper, zinc, cadmium and nickel using the Atomic Absorption Spectrophotometer (AAS) (HACH DR 2400) model.

The method involves direct aspiration of the water sample into an air/acetylene of nitrous oxide/acetylene flame in the presence of energy at specific wavelength generated by hollow cathode lamp peculiar only to the metal under investigation. Before analysis, the AAS was calibrated with standards of known concentrations to obtain a calibration curve for the individual metal.

CHAPTER FOUR

RESULTS

The results of data obtained from the analysis of microbiological and physico-chemical parameters of well and stream water sources from selected communities in Ikwerre, Emohua and Etche Local Government Areas of Rivers State are presented in the following tables and figures below;

4.1 Microbiological quality of water samples from Ikwerre, Emohua and Etche Local Government Areas

4.1.1 Total aerobic heterotrophic bacterial (THB) counts of well water source from Ikwerre, Emohua and Etche LGA's.

The changes in the counts of the total heterotrophic bacterial population of well water samples is presented in figure 4.1a. The total heterotrophic bacterial counts ranged from 2.68 x 10^2 cfu/ml in the month of March to 1.34 x 10^3 cfu/ml in July for Ikwerre LGA, and 3.10 x 10^3 cfu/ml in October to 1.71 x 10^4 cfu/ml in July for Emohua LGA, while Etche had 1.93 x 10^2 cfu/ml (March) to 3.57 x 10^2 cfu/ml in July. Total aerobic heterotrophic bacteria count occurred more in Emohua LGA with count of 1.7 x10^4 cfu/ml than in Ikwerre and Etche LGA's. Analysis of Variance (table 1) at $p < 0.05$ reveals that there was significant difference between the mean total heterotrophic bacterial counts of the well water sources in the three LGA's.

4.1.2 Total aerobic heterotrophic bacterial (THB) count of stream water sources

The occurrence of mean total aerobic heterotrophic bacteria from stream water sources in the three LGA's is presented in figure 5. Etche LGA showed mean bacterial counts ranging from 2.25 x 10^2 cfu/ml in the month of October to 3.85 x 10^2 cfu/ml in June, while Emohua LGA had mean counts from 2.75 x 10^2cfu/ml in November to 2.35 x 10^4 cfu/ml in October, and in Ikwerre LGA, the counts are 3.30 x 10^2 cfu/ml and 2.90 x 10^3cfu/ml. The highest bacterial count occurred in Emohua LGA. The analysis of variance showed there was significant difference in the bacterial count from the three local government areas (table 2).

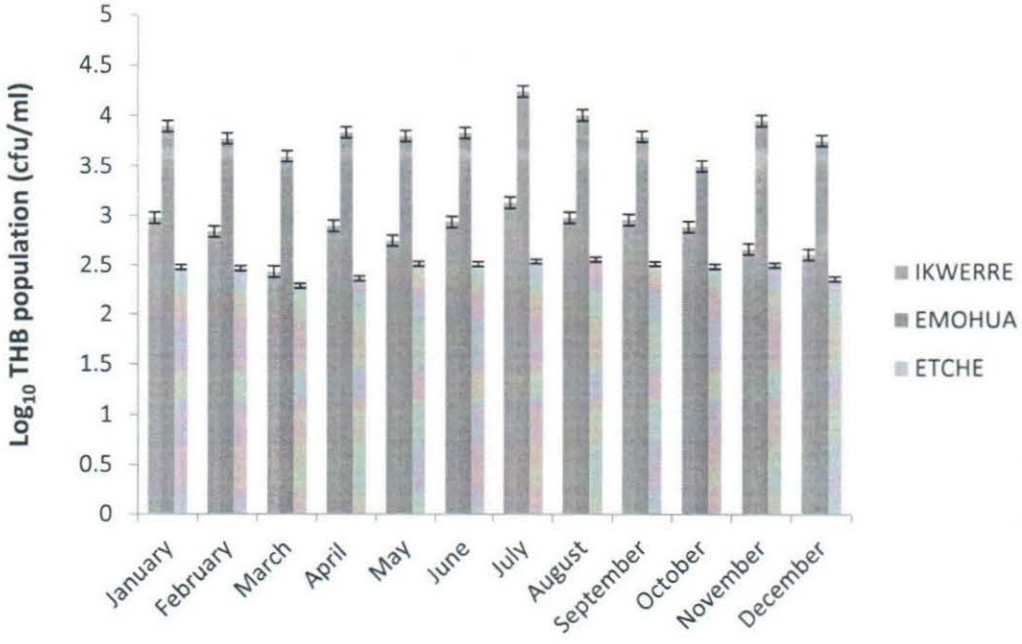


FIG. 4: Mean heterotrophic bacterial count of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 1

Analysis of Variance (ANOVA) of mean heterotrophic bacterial count from well water sources.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	8904	742	86044.91
Emohua	12	87917	7326.42	13059904
Etche	12	3501	291.75	2518.386

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	372175212.1	2	186087606	42.4584	3.2849
Within Groups	144633145.2	33	4382822.58		
Total	516808357.2	35			

From table 1above, it can be seen that the calculated F (F= 42.4584) is greater than the tabulated F(F *crit*= 3.2849). There is thus a significant difference between the total heterotrophic bacterial count of water from wells in Ikwerre, Emohua, and Etche LGA's from the month of January to December.

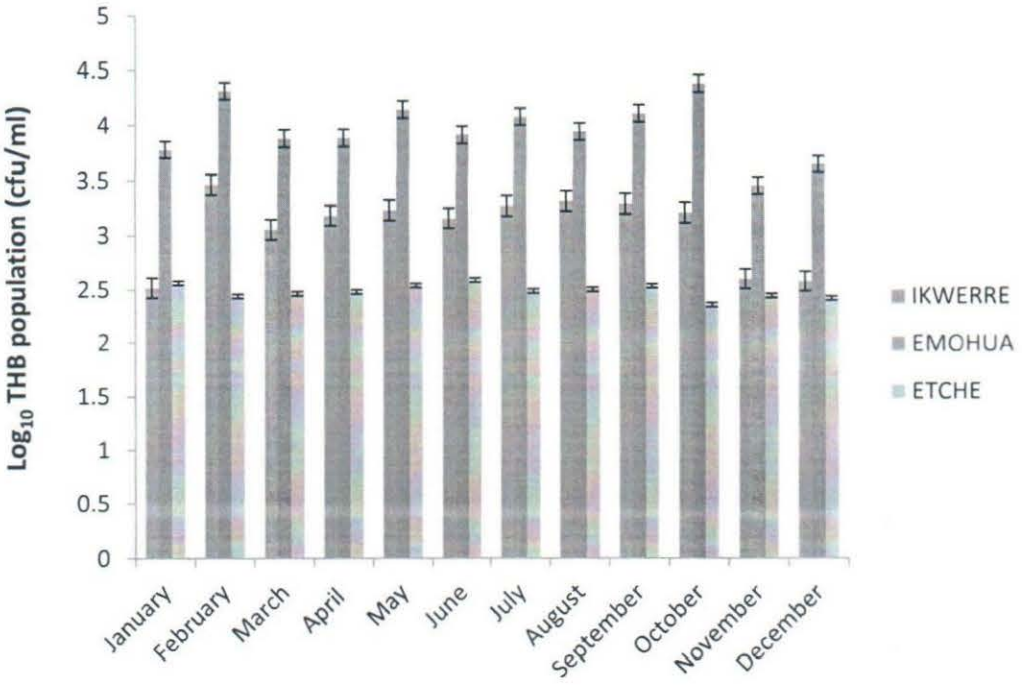


FIG. 5: Mean heterotrophic bacterial count of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 2

Analysis of Variance (ANOVA) of mean heterotrophic bacterial count of water from stream sources.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	17050	1420.83333	586944.7
Emohua	12	127200	10600	39154545
Etche	12	3680	306.666667	2124.242

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	765804716.7	2	382902358	28.9029	3.2849
Within Groups	437179758.3	33	13247871.5		
Total	1202984475	35			

In Table 2 above, the calculated F (*F*= 28.9029) is greater than the tabulated F (*F crit*= 3.2849). There is a significant difference between the total heterotrophic bacterial count of water from streams in Ikwerre, Emohua, and Etche LGA's from the month of January to December.

4.2 Total aerobic heterotrophic fungal (THF) count from well water samples.

The mean total heterotrophic fungal (THF) count of well water samples from Ikwerre, Emohua and Etche LGA's is presented in figure 6. Emohua LGA had a total fungal count ranging from 1.25 x 10^2 cfu/ml in the month of December to 2.25 x 10^4 cfu/ml in June, and Ikwerre LGA had 2.17 x 10^3 in February to 3.48 x 10^3 in September, while in Etche it was 1.52 x 10^2 cfu/ml in January to 2.67 x 10^2 cfu/ml in September. The total mean fungal counts from the three LGA's showed significant difference from the analysis of variance (Table 3).

4.2.1 Mean total aerobic heterotrophic fungal (THF) count from stream water sources

The changes in the mean total aerobic heterotrophic fungal count from stream water sources in Ikwerre, Emohua and Etche LGA's is depicted in figure 7. The mean fungal count of the stream water samples was highest in Emohua LGA with 2.55 x 10^4 cfu/ml in the month of July, followed by Ikwerre LGA which had 4.20 x 10^3 cfu/ml in September and Etche LGA with the least count of 1.80 x 10^2cfu/ml in January. Table 4 indicates that there was significant difference in the fungal counts from the stream water samples in three LGA's.

4.3 Estimation of total coliform count

4.3.1 Mean total coliform bacterial count from well water sources.

The prevalence of coliform bacteria from well water samples from Ikwerre, Emohua and Etche LGA's is presented in figure 8. In Ikwerre LGA, the mean total coliform count ranged from 50 cfu/100ml in the month of May to 52 cfu/100ml in September. For Emohua LGA, the count ranged between 20x10^2 cfu/100ml to 25 cfu/100ml. In Etche LGA, the coliform count was between 20 cfu/100ml and 37 cfu/100ml.

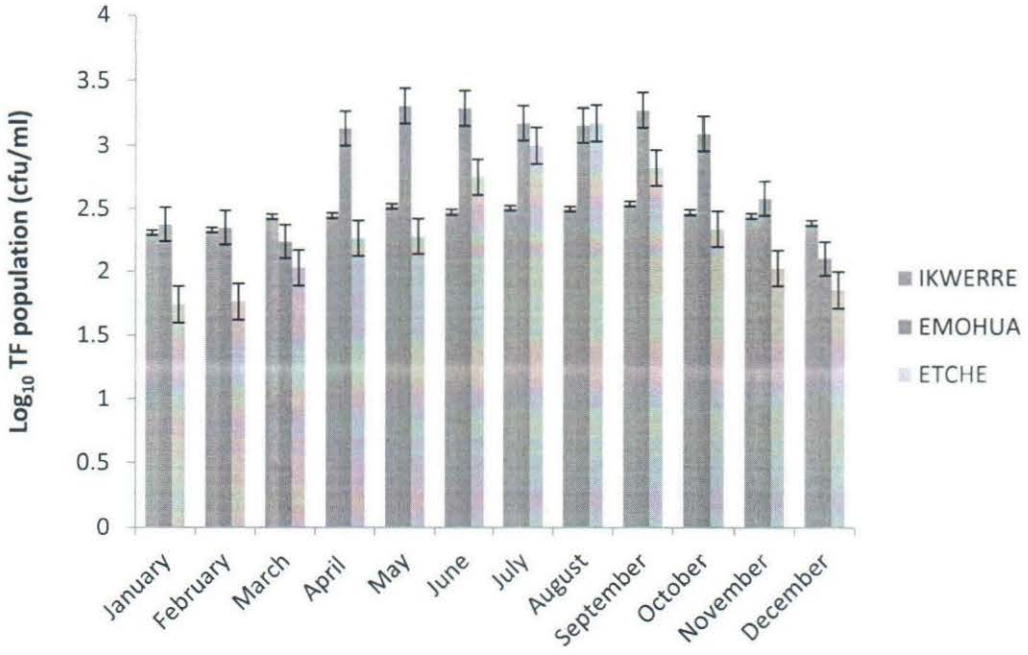


FIG. 6: Mean fungal count of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 3

Analysis of Variance (ANOVA) of mean fungal count of well water sources.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	34400	2866.6668	163939.3
Emohua	12	128733.3	10727.7782	68661379
Etche	12	2456.667	204.7222	1836.786

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	718470910.8	2	359235455.4	15.6582	3.2849
Within Groups	757098704.9	33	22942385		
Total	1475569616	35			

Table 3 shows that the calculated F (*F*= 15.6582) is greater than the tabulated F (*F crit*= 3.2849), meaning that there is a significant difference between the total fungal count of water from wells in Ikwerre, Emohua, and Etche LGA's from the month of January to December.

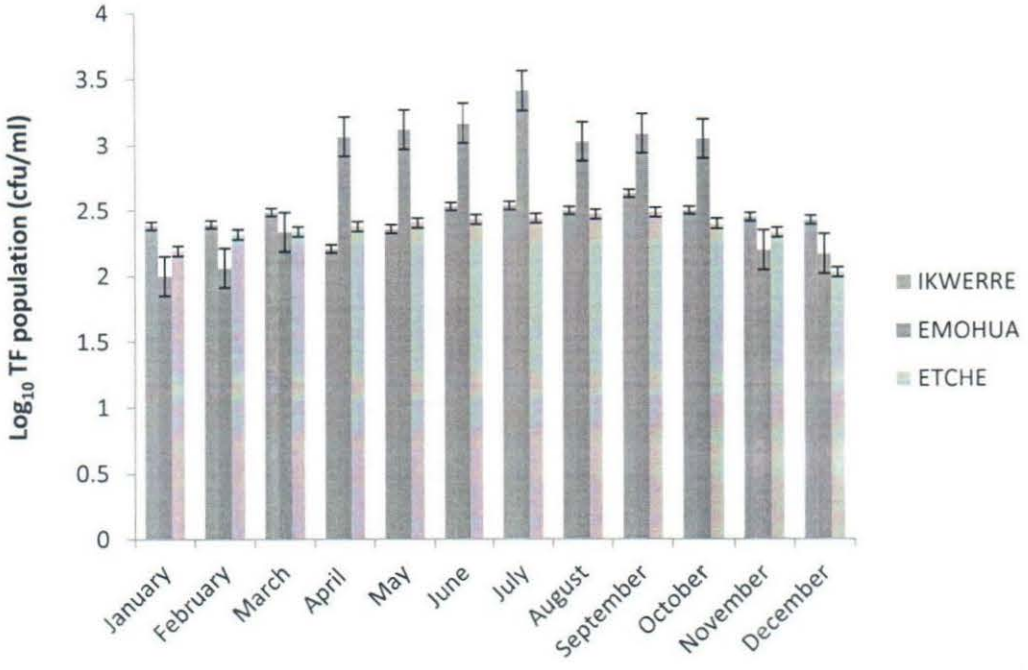


FIG. 7: Mean fungal count of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 4

Analysis of Variance of mean fungal count of stream water samples.

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	3425	285.4167	4452.083
Emohua	12	10530	877.5	567675
Etche	12	2745	228.75	3132.386

ANOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	3098601	2	1549301	8.0797	3.2849
Within Groups	6327854	33	191753.2		
Total	9426456	35			

In Table 4 above, it can be seen that the calculated F ($F = 8.0797$) is greater than the tabulated F ($F\ crit = 3.2849$). There is thus a significant difference between the total fungal count of water from streams in Ikwerre, Emohua, and Etche LGA from January to December.

4.3.2 Mean total coliform count from stream water samples

Figure 9 shows the mean total coliform bacterial count from stream water sources in Ikwerre, Emohua and Etche LGA's. Ikwerre LGA had coliform counts between 1 cfu/100ml and 11 cfu/100ml, while in Emohua LGA, the counts ranged from 1 cfu/ml to 9cfu/100ml, whereas Etche LGA got counts of 1cfu/100ml and 4 cfu/100ml.

4.3.3 Comparison of mean total Coliform bacterial count based on the LGA's, water sources and season.

Figure 10 shows that the combined mean total coliform count for the wells and stream water samples in Etche LGA was 0.80±2 2.16 cfu/100ml, whereas that of Ikwerre LGA was found to be 1.56 ± 3.16 cfu/100ml and Emohua had 0.93±2.10 cfu/100ml. The ANOVA results showed that there is no significant difference in the mean total coliform count based on the LGA's ($F_{2, 285} = 2.51$, $p > 0.05$). But, based on source of water, i.e whether stream or well, the ANOVA result showed that there was significant difference in the mean total coliform count ($F_{1, 286} = 8.296$ $P >< 0.05$). The total coliform count was higher in the stream than in the well water source. Comparing the seasons, ANOVA results from table indicates that there was significant difference in coliform count between the dry and wet seasons ($F_{1, 282} = 40.230$, $P < 0.05$).

4.4 Mean Total *Escherichia coli* count from the water sources.

4.4.1 Mean Total *E. coli* count from well water sources

The mean *Escherichia coli* count is shown in figure 11. The value for Ikwerre LGA ranged from $0.2x10^2$ cfu/100ml in January to $1.0x10^2$ cfu/100ml in August. While in Emohua LGA, the mean *E. coli* count is between $0.3x10^2$ cfu/100ml in August and $1.2x10^2$ cfu/100ml in October for Etche LGA, the *E. coli* count occurred only in the month of September ($1.5x10^2$ cfu/100ml) and October ($1.0x10^2$ cfu/100ml).

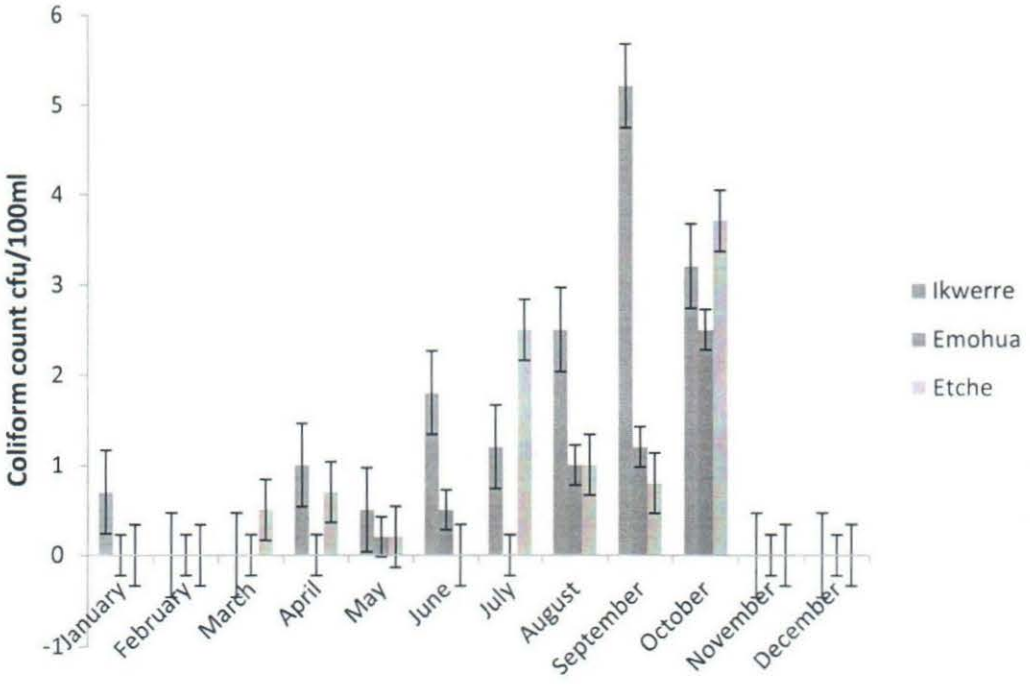


FIG. 8: Mean coliform count of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

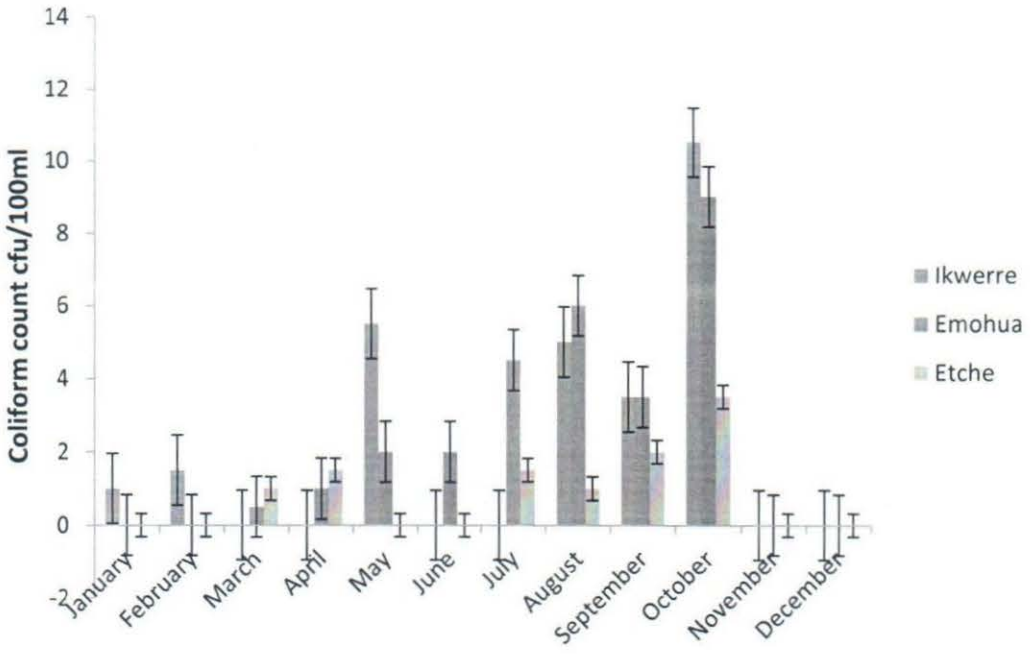


FIG. 9: Mean coliform count of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

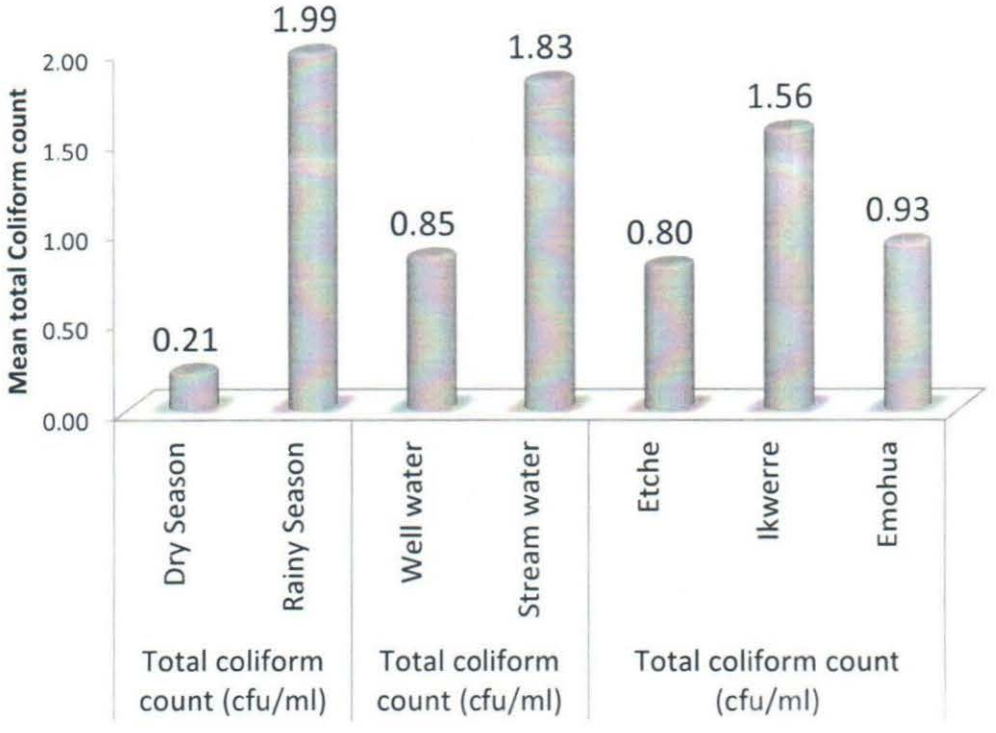


FIG.10: Comparison of mean total coliform count based on the LGA's, water sources and season.

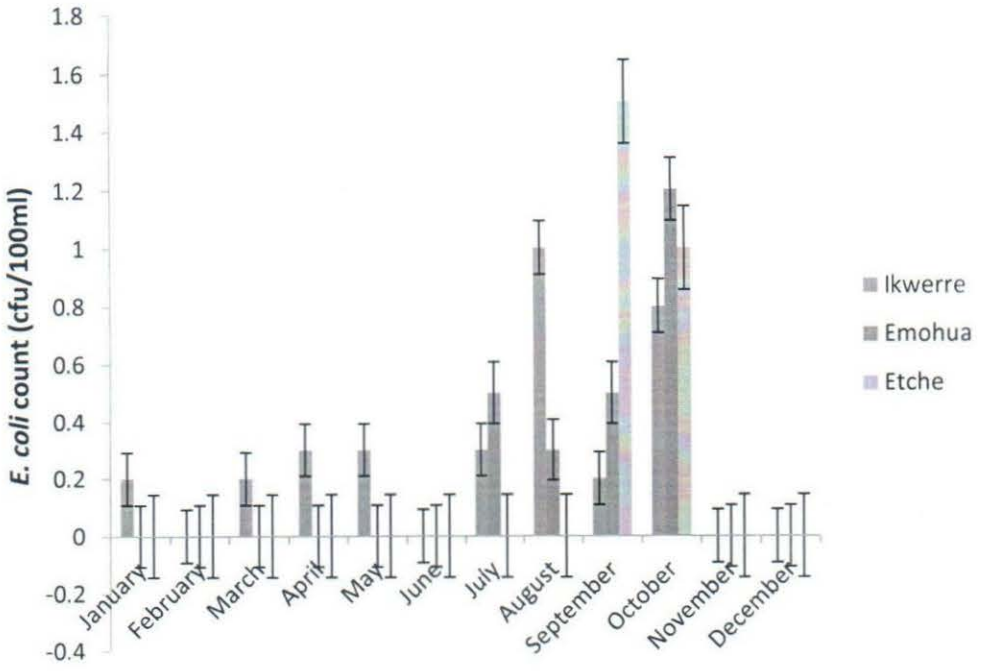


FIG. 11: Mean *Escherichia coli* count of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 5

ANOVA of Coliform count based on LGA's, water type and seasons

TABLE 5 (a)

ANOVA of Coliform count based on LGA's.

		N	Mean	Std. Deviation		Sum of Squares	df	Mean Square	F	Sig.
Coliform	Etche	96	0.80	2.16	Between Groups	31.92	2.00	15.96	2.51	0.08
	Ikwerre	96	1.56	3.16	Within Groups	1813.35	285.00	6.36		
	Emohua	96	0.93	2.11	Total	1845.28	287.00			
	Total	288	1.10	2.54						

TABLE 5 (b)

ANOVA of Coliform count based on water type

		N	Mean	Std. Deviation		Sum of Squares	Df	Mean Square	F	Sig.
Coliform	Well water	216	0.85	2.3	Between Groups	52.02	1	52.02	8.3	0
	Stream water	72	1.83	3.03	Within Groups	1793.26	286	6.27		
	Total	288	1.1	2.54	Total	1845.28	287			

TABLE 5 (c)

ANOVA of Coliform count based on seasons

		N	Mean	Std. Deviation		Sum of Squares	Df	Mean Square	F	Sig.
	Dry Season	144	0.21	0.74	Between Groups	227.56	1	227.56	40.23	0.00
	Rainy Season	144	1.99	3.28	Within Groups	1617.72	286	5.66		
Coliform	Total	288	1.1	2.54	Total	1845.28	287			

4.4.2 Mean total *E. coli* count from stream water sources.

Figure 12 reveals the prevalence of *E. coli* in stream water samples from Ikwerre, Emohua and Etche LGA's respectively. The count in Ikwerre LGA is between $0.5x10^3$ cfu/100ml in the month of July and $3.0x10^3$ cfu/100ml in September. For Emohua LGA, the range is from $0.5 x10^3$ cfu/100ml to 3.0, while in Etche LGA the mean *E. coli* count fell between $0.5x10^3$ cfu/100ml in July and $1.5x10^3$cfu/100ml in October.

4.4.3 Comparison of mean *E. coli* count based on LGA's water sources and seasons

From figure 13, comparison between the mean total *E. coli* count from the three LGA's showed that Emohua LGA had 0.33 ± 0.89 cfu/100ml, while Etche LGA got 0.20 ± 0.87 cfu/100ml and Ikwerre LGA had 0.34± 0.89 cfu/100ml. ANOVA result showed no statistical significant difference in the occurrence of *E.coli* between the three LGA's ($F2, 285 = p. 815, p> 0.05$). Based on water source, the mean total *E. coli* count from well water was 0.23±0.82 cfu/100ml, whereas the stream water samples had 0.47± 1.03 cfu/100ml. There was significant difference in the mean *E. coli* based on source of water ($F1, 286 = 4.0.62, p<0.05$).The mean total E. coli count of well and stream water samples during the dry season was found to be 0.09 ± 1.13cfu/100ml. The ANOVA result shows there was significant difference between the *E. coli* count of well and stream water samples based on seasons ($F1, 286 = 815, p <0.05$) as can be seen on table 6.

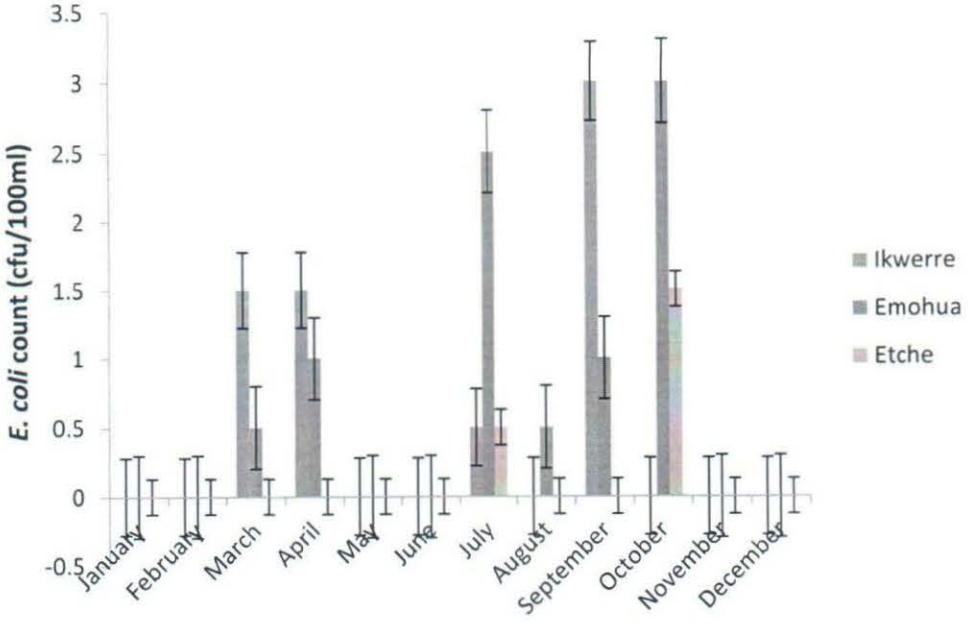


FIG 12: Mean *Escherichia coli* count of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

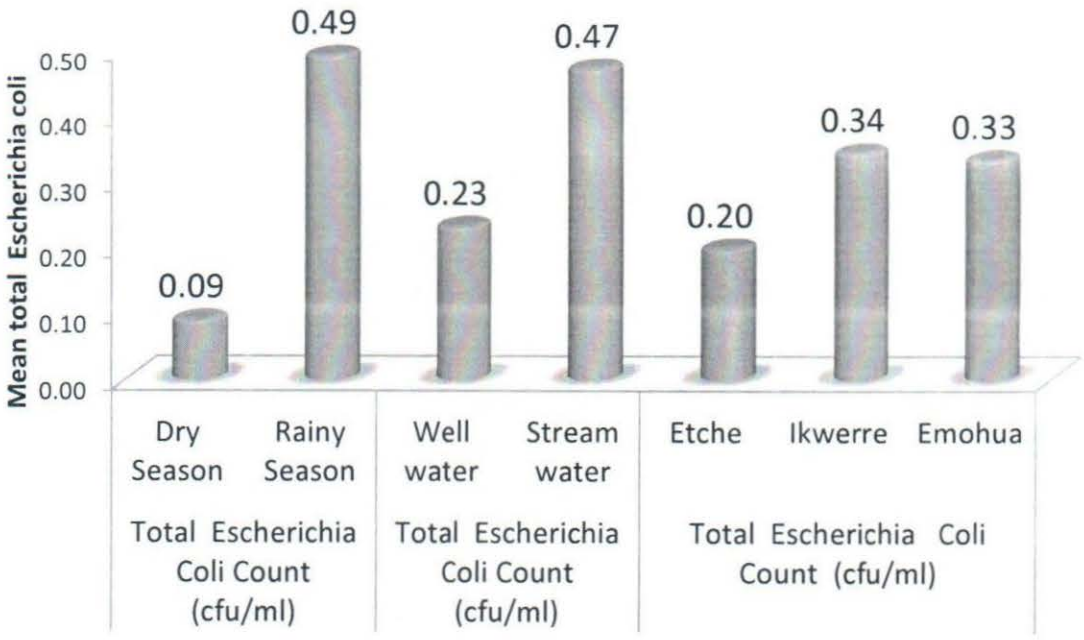


FIG. 13: Comparison of mean total *Escherichia coli* count (cfu/100ml) of water samples versus season, water-source and LGA

TABLE 6

ANOVA of *Escherichia* sp count based on LGA's, water type and seasons

TABLE 6(a)

ANOVA of *Escherichia* sp count based on LGA's

		N	Mean	Std. Deviation		Sum of Squares	Df	Mean Square	F	Sig.
	Ikwerre	96	0.25	0.68	Within Groups	123.73	285.00	0.43		
	Emohua	96	0.18	0.73	Total	124.61	287.00			
	Total	288	0.18	0.66						
Escherichia sp	Etche	96	0.20	0.87	Between Groups	1.27	2.00	0.64	0.82	0.44

TABLE 6 (b)

ANOVA of *Escherichia* sp count based on water type

		N	Mean	Std. Deviation		Sum of Squares	Df	Mean Square	F	Sig.
Escherichia sp	Well water	216	0.23	0.82	Between Groups	3.13	1	3.13	4.06	0.05
	Stream water	72	0.47	1.03	Within Groups	220.37	286	0.77		
	Total	288	0.29	0.88	Total	223.5	287			

TABLE 6 ©

ANOVA of *Escherichia* sp count based on seasons

		N	Mean	Std. Deviation		Sum of Squares	Df	Mean Square	F	Sig.
	Dry Season	144	0.09	0.44	Between Groups	11.68	1	11.68	15.77	0.00
	Rainy Season	144	0.49	1.13	Within Groups	211.82	286	0.74		
Escherichia sp	Total	288	0.29	0.88	Total	223.5	287			

4.5 Total *Salmonella* sp count of stream and well water sources

4.5.1 Mean total *Salmonella* sp count of well water from Ikwerre, Emohua and Etche LGA's.

The mean total *Salmonella* sp count for well water, samples in the three study LGA's is presented in figure 14. For Ikwerre LGA the mean total count was between $0.3x10^2$ cfu/100ml to $0.7x10^2$ cfu/100ml. The months of February, March, April, November and December showed no *Salmonella* count. In Emohua LGA, *Salmonella* sp count occurred only in the month of July ($0.5x10^2$ cfu/100ml) and September ($0.3x10^2$ cfu/100ml), while in Etche LGA counts ranged from $0.3x10^2$ cfu/100ml in September to $0.5x10^2$ cfu/100ml in October. However, mean total count was highest in water samples from Ikwerre LGA.

4.5.2 Mean total *Salmonella sp* count of stream water samples from Ikwerre, Emohua and Etche LGA's.

The total mean *Salmonella* sp count for stream water samples is shown in figure 15. The mean want for Ikwerre LGA ranged from $0.5x10^2$ cfu/100ml to $1.5x10^2$ cfu/100ml for the month of January, April, May, September and October. The other months showed no detectable count. In Emohua LGA, *Salmonella* sp count occurred in only in the months of May ($0.5x10^2$ cfu/100ml), June ($2.5x10^2$ cfu/100ml), August ($10x10^2$ cfu/ml) and October (1.5 cfu/100ml). For Etche LGA, there was count in June ($1.5x10^2$ cfu/100ml) and August ($1.5x10^2$ cfu/100ml) only. The other months showed no presence of *Salmonella* sp.

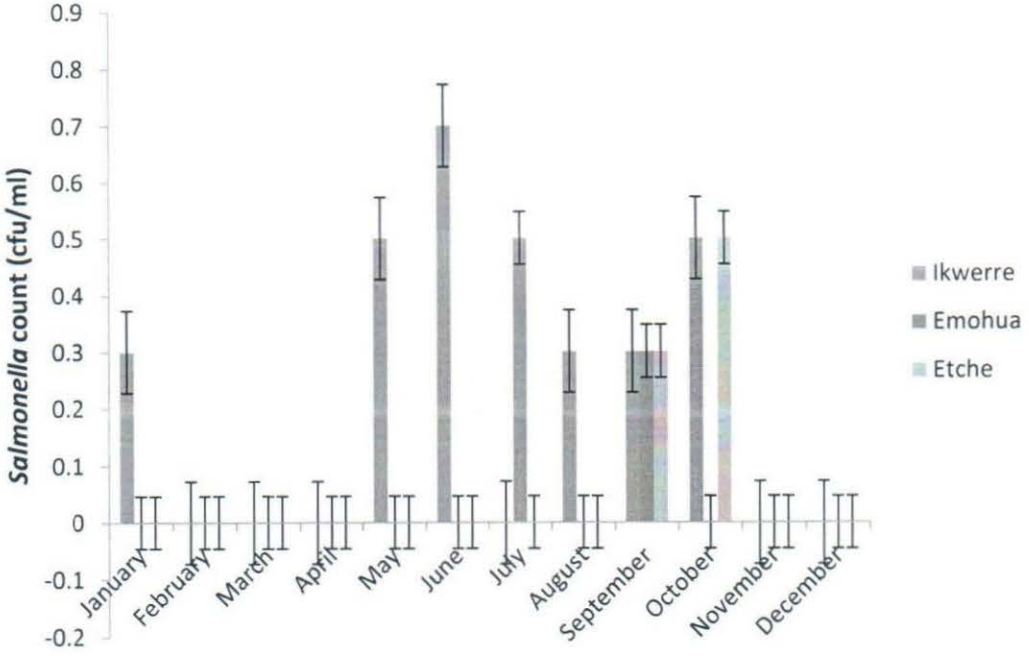


FIG. 14: Mean *Salmonella* sp count of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

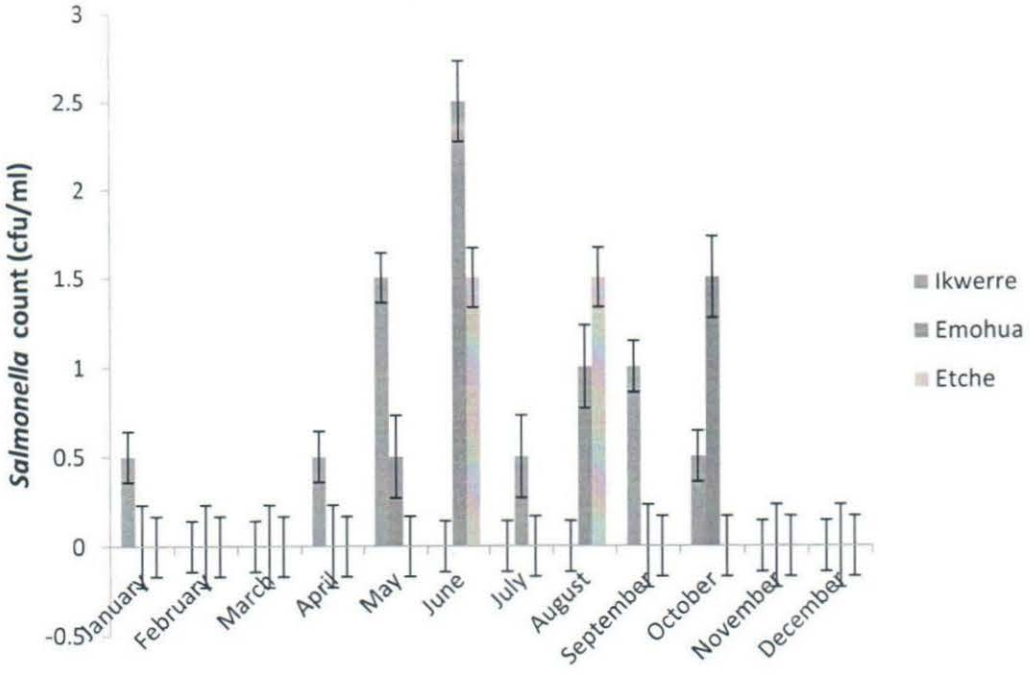


FIG. 15: Mean *Salmonella* sp count of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

4.5.3 Comparison of mean total *Salmonella sp* count by LGA's, source of water and season.

The men total *Salmonella* sp count of well and stream water samples from Ikwerre LGA is 0.25 ± 0.68 cfu/100ml, that of Emohua LGA is 0.18 ± 0.73 cfu/100ml, while in Etche LGA the count is 0.11±0.56 cfu/100ml. Based on LGA's , ANOVA result from table 7a shows there was no significant difference the mean total *Salmonella sp* count between the three local government areas ($F2, 285 = 1.016$, $p>0.05$). Based on water source, the mean total *Salmonella* sp count of well water was 12 ± 0.51 cfu/100ml, while that of stream water was 0.3±0.95 cfu/100ml. The result of ANOVA from table 7b shows that there was significant difference in mean total *Salmonella* sp count based on source of water ($F1, 286 = 7.368,1$) $p <0.05$). Considering seasons, the dry season had mean total *Salmonella* sp count of 0.03± 0.20 cfu/ml whereas the wet season count was 0.33± 0.88 cfu/ml. There was significant difference in the mean total *Salmonella* sp count based on seasons ($F1, 28.6 = 16.308$, $p<0.05$) according to the result of ANOVA from table 7c.

4.6 Total *Vibrio* sp count of well and stream water sources.

4.6.1 Mean total *Vibrio* sp count of well water samples from Ikwerre Emohua and Etche LGA's

The mean total *Vibrio* sp count of well water samples from the three LGA's is presented in figure 17. Total *Vibrio* sp count in Etche LGA was between $0.3x10^1$ cfu/100ml to $1.0x10^1$ cfu/100ml, whereas in Emohua LGA the count was from $0.2x10^1$ cfu/100ml to $0.3x10^1$ cfu/100ml and in Ikwerre LGA it ranged from $0.5x10^1$ cfu/100ml to 0.8 cfu/ml. The highest *Vibrio* sp count occurred in Etche LGA.

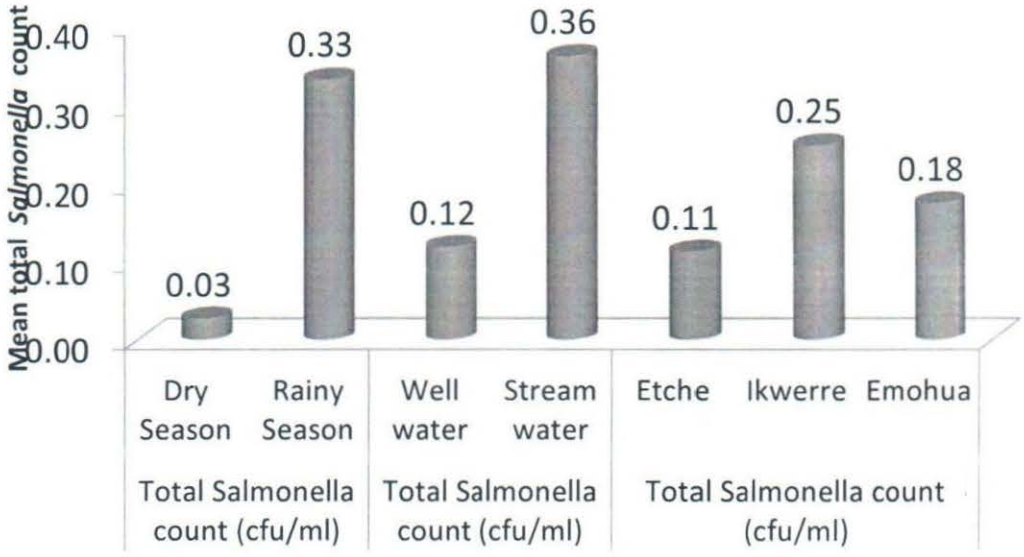


FIG. 16: Comparison of mean total *Salmonella* sp count of water samples based on LGA's, water source and season.

TABLE 7 (a)

ANOVA of *Salmonella* sp count based on LGA's

		N	Mean	Std. Deviation		Sum of Squares	df	Mean Square	F	Sig.
Salmonella sp	Etche	96	0.11	0.56	Between Groups	0.88	2.00	0.44	1.02	0.36
	Ikwerre	96	0.25	0.68	Within Groups	123.73	285.00	0.43		
	Emohua	96	0.18	0.73	Total	124.61	287.00			
	Total	288	0.18	0.66						

TABLE 7 (b)

ANOVA of *Salmonella* sp count based on water type

		N	Mean	Std. Deviation		Sum of Squares	df	Mean Square	F	Sig.
Salmonella sp	Well water	216	0.12	0.51	Between Groups	3.13	1	3.13	7.37	0.01
	Stream water	72	0.36	0.95	Within Groups	121.48	286	0.43		
	Total	288	0.18	0.66	Total	124.61	287			

TABLE 7(c)

ANOVA of *Salmonella* sp count based on season

		N	Mean	Std. Deviation		Sum of Squares	df	Mean Square	F	Sig.
	Dry Season	144	0.03	0.2	Between Groups	6.72	1	6.72	16.31	0.00
	Rainy Season	144	0.33	0.89	Within Groups	117.89	286	0.41		
Salmonella sp	Total	288	0.18	0.66	Total	124.61	287			

4.6.2 Mean total *Vibrio* sp count of stream water samples from Ikwerre, Etche and Emohua LGA's.

Figure 18 shows the mean total *Vibrio* sp count of the stream water samples from the three study LGA's . The mean vibrio sp count from Emohua LGA was high ranging from $0.5x10^1$ cfu100/100ml to $2.0x10^1$ cfu/100ml in the month of September. This was followed by Etche LGA with mean total *Vibrio* count $1.5x10^1$ cfu/100ml and Ikwerre LGA which had $0.5x10^1$ cfu/100ml.

4.6.3 Comparison of mean total *Vibrio* sp count based on the source of water, season and LGA's.

From figure 19, the mean total *Vibrio* sp count for Etche LGA was 0.20 ± 0.95 cfu/100ml Ikwerre LGA 0.14 ± 0.49 cfu/100ml and Emohua LGA 0.13 ± 0.53 cfu/100ml. ANOVA result reveals that there is no significant difference in the mean total *Vibrio* sp count of the water samples based in LGA's. According to water source, the mean total count of well water was 0.14 ± 0.70 cfu/100ml, while the stream water count was 0.18 ± 0.66 cfu/100ml. The result shows there was no significant difference in total *Vibrio* count $F1, 286 = 0.157$, $p>0.05$). The *Vibrio* sp count was observed more in stream than in well water samples.

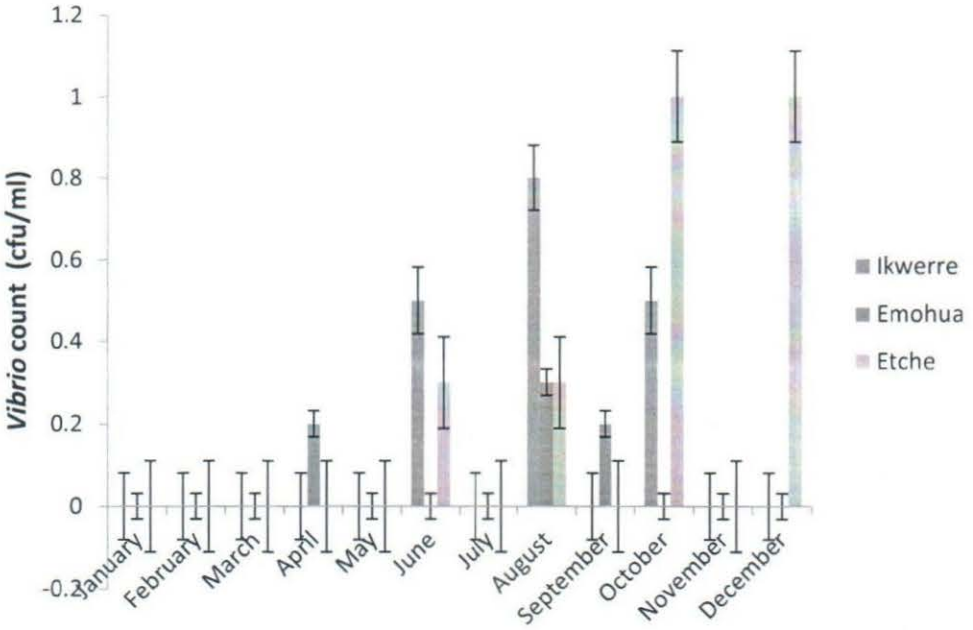


FIG. 17: Mean *Vibrio sp* count of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

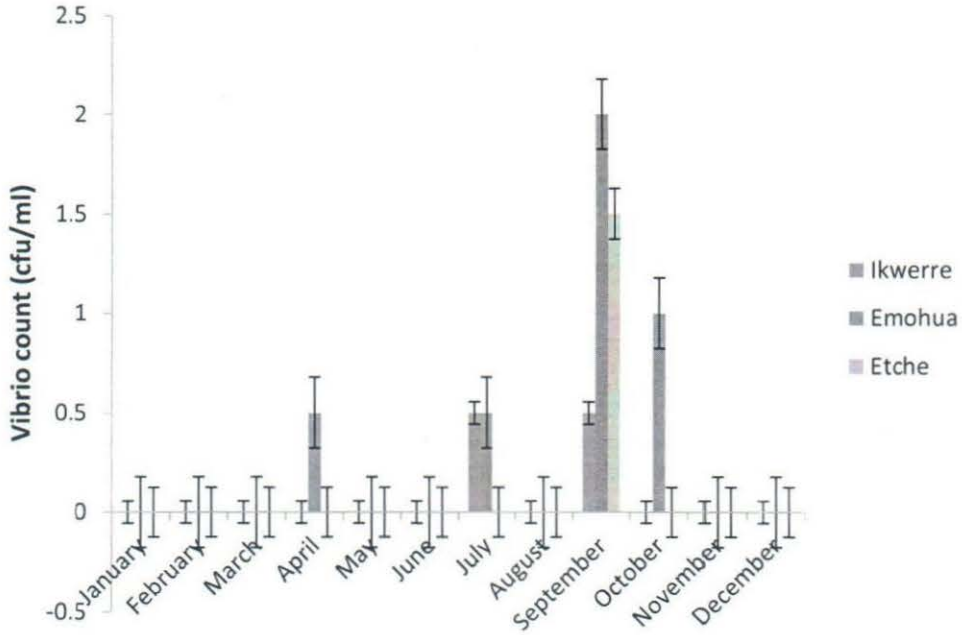


FIG. 18: Mean *Vibrio sp* count of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

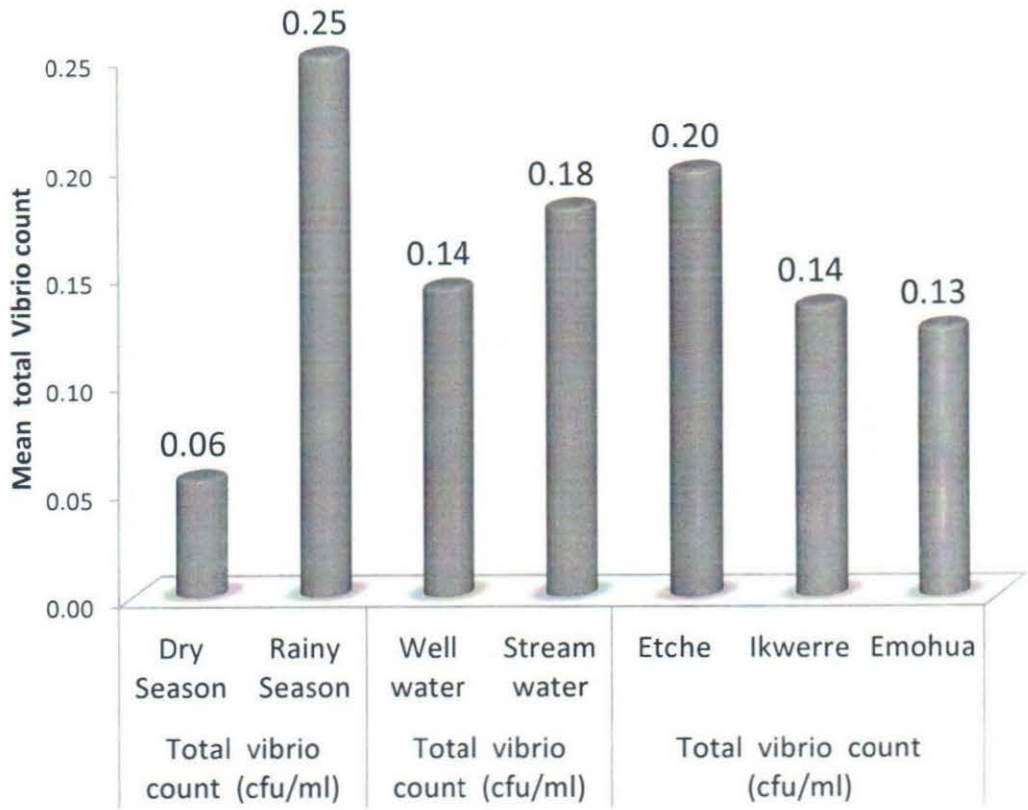


FIG. 19: Comparison of total *Vibrio* count of water samples based on LGA's water source and season

TABLE 8

Biochemical Characterization and Identification of Bacterial isolates in water samples Area, Rivers State

Enzyme Action													Reaction on Kliger iron agar				Fermentation of Sugar					Most Likely Organism Identified
Isolates	Gramstain	Spore	Motility	Coagulase	Catalase	Oxidase	Citrate	Urease	Indole	Methy red	Voges Proskauer	Starch	Slope	Gas productiomn	Hydrogen sulphide		Glucose	Fructose	sucrose	Maltose	Lactose	
1.	-	-	-	-	+	-	-	-	+	+	-	-	Y	+	-		AG	A	A	A	A	*Escherichia coli*
2.	-	-	-	-	+	-	-	-	-	+	+	-	Y	+	-		AG	A	A	A	A	*Klebsiella* sp.
3.	-	-	+	+	-	-	+	+	+	+	-	-	Y	+	-		AG	A	A	A	A	*Enterobacter aerogenes*
4.	+	-	-	+	+	-	+	-	-	-	+	-	Y	+	+		AG	-	A	A	A	*Staphylococcus aureus*
5.	-	-	+	-	+	+	+	-	-	-	-	-	Y	-	-		-	-	AG	-	AG	*Pseudomonas aeruginosa*
6.	-	-	+	-	+	-	+	-	-	+	-	-	Y	+	+		AG	-	AG	AG	AG	*Salmonella* sp.
7.	-	-	+	-	+	+	+	-	+	-	-	+	R	-	-		A	-	AG	-	-	*Vibrio* sp.
8.	-	-	-	-	+	-	-	-	-	+	-	-	R	-	-		A	A	AG	-	-	*Shigella* sp.
9.	+	+	-	-	+	-	+	-	-	-	+	+	Y	-	-		A	A	A	-	A	Bacillus sp

+: Positive Reaction
Red: R
Yellow: Y

-: Negative Reaction
G: Gas Production
A: Acid Production

4.6.4 Molecular Identification of Bacterial isolates

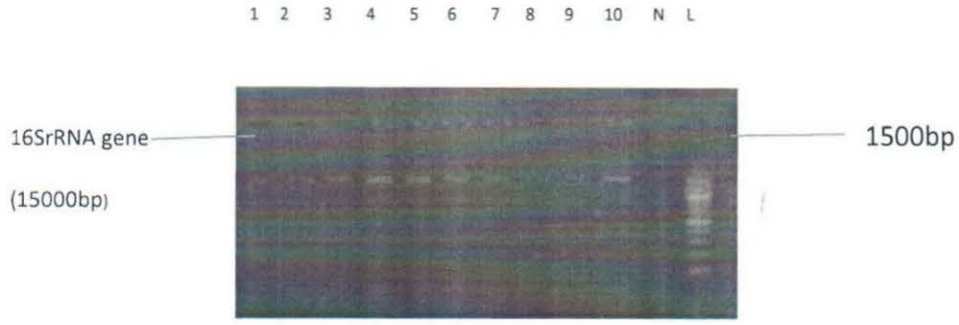


PLATE 13: Agarose gel electrophoresis of the 16S rRNA gene of some selected bacterial isolates. Lanes 1, 3-12 represent the 16SrRNA gene bands (1500bp), Lane 2, failed amplification, Lane N represents the negative control, lane L represents the 100bp molecular ladder.

FIG.20: Phylogenetic tree showing the evolutionary distance between the bacterial isolates.

4.7 Number of reported waterborne disease cases from general hospitals in Ikwerre, Emohua and Etche LGA's of Rivers State.

4.7.1 Reported cases of waterborne disease from selected communities in Ikwerre LGA.

The result of the number of occurrence of waterborne diseases such as amoebic dysentery (amoebiasis), bacillary dysentery (shigellosis), cholera, typhoid or enteric fever and mild / acute diarrhea disease is shown in figure 21 . The mild/acute diarrhea due to *E. coli*was experienced more by residents of the study communities in Ikwerre LGA with a mean value of (152.14). This was followed by typhoid/ enteric fever (92.14), amoebiasis (53.57), cholera (34.18) and bacillary dysentery with a mean of 27.86 respectively. The records showed the study communities Ikwerre LGA presented cases of waterborne disease at varying numbers with mild / acute diarrhea affecting more of the residents.

4.7.2 Reported cases of waterborne diseases from communities in Emohua LGA.

The incidences of waterborne diseases in some communities from Emohua LGA is shown in figure 22. From the figure, mild /acute diarrhea affected greater proportion of the people (178.51), followed by typhoid /enteric fever (80.33), amoebiasis (41.65), bacillary dysentery (32.73) and cholera with the least occurrence rate of 26.78.

4.7.3 Reported cases of waterborne diseases from communities in Etche LGA.

Figure 23 depicts the spread of waterborne disease in selected communities from Etche LGA of Rivers State. Again, cases of the occurrence of mild/acute diarrhea caused by *E. coli* presented more in proportion (112) than typhoid /enteric fever (96) and cholera (56). These was followed by bacillary dysentery and amoebic dysentery each having the same proportion of (47.99)

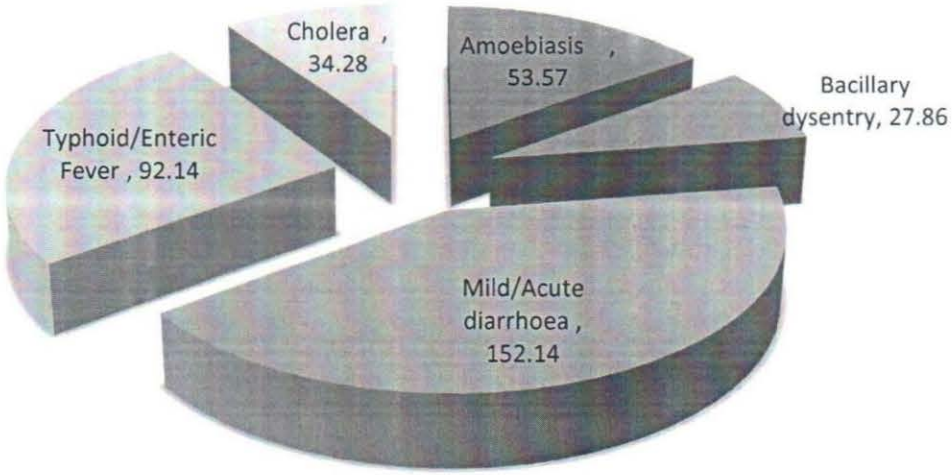


FIG. 21 : Number of reported waterborne disease cases arising from water sources in Ikwerre LGA

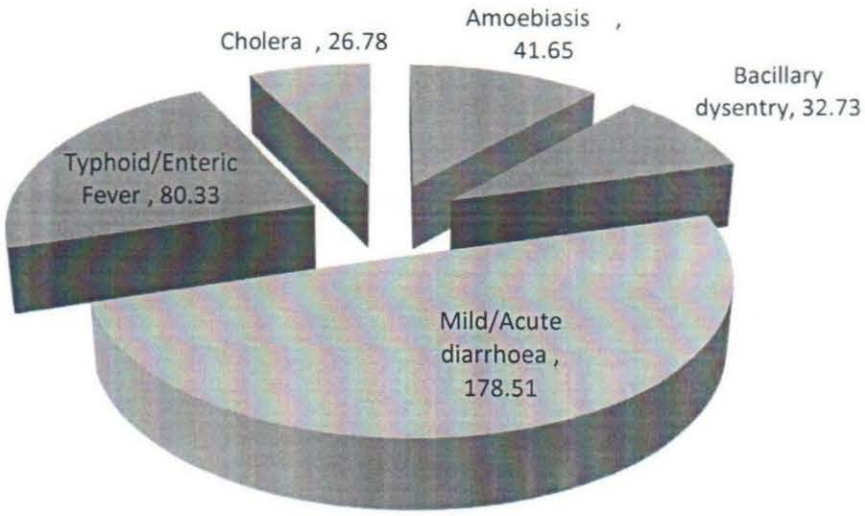


FIG. 22 : Number of reported disease cases arising from water sources in Emohua LGA

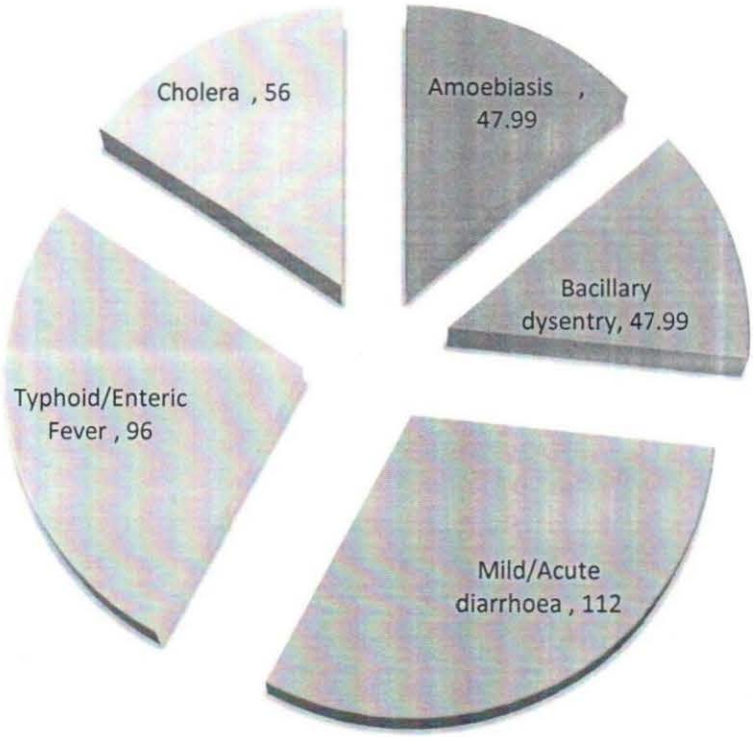


FIG.23: Number of reported disease cases arising from water sources in Etche LGA

4.7.4 Comparison of Percentage of occurrence of disease cases

From table 9, mild/acute diarrhea had the highest percentage of occurrence (49.63%) in Emohua LGA, followed by Ikwerre LGA (42.3%) and Etche LGA with (31.1%). The next in prevalence is bacillary dysentery also with Emohua showingthe highest percentage of 32.7%, Etche LGA 13.3% and Ikwerre LGA 7.7%. Typhoid / enteric fever was observed more in Etche LGA with percentage occurrence of 26.7%, followed by Ikwerre LGA (25.6%) and Emohua LGA (22.7%) respectively. Cholera equally occurred more in Etche LGA (15.5%) , followedby Ikwerre LGA (9.5%,) and Emohua LGA having the least (7.4%)

4.7.5 Correlation of number of diarrhoea cases with *E. coli* count water samples.

The correlation between mean *E. coli* count (cfu/ml) from the well and stream water sources and the reported number of diarrhea cases is shown in table 10. The value of the correlation coefficient (r) is 0.6489 which is approximately equal to +1. This shows that there is a positive correlation between the number of reported diarrhoea cases and the mean *E. coli* count from the well and stream water sources in the LGA's.

4.8 Antibiogram profile of *E. coli* sp, Salmonella *Sp* and *Vibrio* sp.

Tables 11, 12 and 13 shows the antibiogram profiles of the three different test pathogens with selected types of antibiotics. While *E.coli* showed very high sensitivity to Oflaxicin (OFL), Nitroturuntoin and Nalidivic acid (NAL), it was totally resistant to Amoxilillin (AMX) and intermediate to Augumentin (AUG). On the other, *Salmonella* sp showed total resistance to Augmentin (AUG), Tetracycline (TET) and Amoxicillin (AMX) and high sensitivity to NAL, Oflaxicin, Nitrofurantoin and Gentaminin antibiotics. *Vibrio* sp were very resistant to Augmentin, Amoxicillin and Cotrimazole. It was highly sensitive to Nitrofurantoin, Nalidixic acid Oflaxicin, Gentamicin and intermediate to Tetracycline.

TABLE 9

Comparison of percentage occurrence of reported disease cases in Ikwerre, Emohua and Etche LGA.

	Percentage (%) Occurrence of Diseases				
	Amoebiasis	**Bacillary Dysentery**	**Mild/acute Diarrhea**	**Typhoid /Enteric Fever**	**Cholera**
Ikwerre LGA	14.9%	7.7%	42.3%	25.6%	9.5%
Emohua LGA	11.63	32.7%	49.6%	22.33%	7.4%
Etche LGA	13.3%	13.3%	31.1%	26.7%	15.5%

TABLE 10

Correlation of the number of reported mild/acute watery diarrhoea cases with the *E. coli* count in wells and streams water sources

Site	N	X	Y	XY	X^2	Y^2
1	1	4	0.6667	2.6668	16	0.444489
2	1	2	0	0	4	0
3	1	1	0	0	1	0
4	1	1	0.25	0.25	1	0.0625
5	1	1	0	0	1	0
6	1	2	0.3333	0.6666	4	0.111089
7	1	2	0	0	4	0
8	1	1	0.3333	0.3333	1	0.111089
∑	**8**	**14**	**1.5833**	**3.9167**	**32**	**0.729167**

X - number of reported mild/acute watery diarrhoea cases; Y - Mean *E. coli* population (cfu/ml) per site for all the months;

Pearson's Correlation Coefficient, $r = \frac{N(\sum XY) - (\sum X)(\sum Y)}{\sqrt{(N\sum X^2 - (\sum X)^2)}\sqrt{(N\sum Y^2 - (\sum Y)^2)}}$ (Sharma, 2012)

$N(\sum XY)$	=	31.3336
$(\sum X)(\sum Y)$	=	22.1662
$N\sum X^2 - (\sum X)^2$	=	60
$N\sum Y^2 - (\sum Y)^2$	=	3.3265
R	=	**0.6489**

Since r is approximately equal to+1, there is thus a positive correlation between the number of reported mild/acute watery diarrhoea cases and the *E. coli* count in the water source

TABLE 11

Antibiogram of *E. coli* isolates in water samples from Emohua Local Government Area, Rivers State.

Isolate No.	Measurement of Antibiotics Zone of Inhibition (mm)											
	AUG	**TET**	**AMX**	**COT**	**OFL**	**GEN**	**NAL**	**NIT**	**R**	**I**	**S**	**MARI**
WEC1	15I	13R	13R	12I	21S	14I	30S	20S	2(25%)	3(37.5%)	3(37.5%)	0.25
WEC4	16I	17I	11R	21S	19S	131	29S	18S	1(12.5%)	3(37.5%)	3(37.5%)	0.125
WEC 6	161	18I	11R	20S	23S	11R	16I	19S	2(25%)	3(37.5%)	3(37.5%)	0.25
SEC 7	12R	I6I	12R	OR	20S	15S	22S	12R	3(37.5%)	1(12.5%)	1(12.5%)	0.375
SEC8	17I	16I	13R	14I	18S	16S	20S	18S	1(12.5%)	3(37.5%)	4(50%)	0.125

N:B : OFL- Oflaxicin (R:≤12;I:13-15;S≥16) Gen-Gentamicin (R:≤12;I:13-14;S≥15),
Nal-Nalidixic Acid (R:≤13;1:14-19, S:≥19), NIT-Nitrofurantoin(R:≤14, I:15-16; 5:≥17);
Cot-Cotrimazole(R:≤10; I:11-15; S:≥ 16);
Aug- Augumentin (R: :≤13; I:14-17; S:≥18), Amx Amoxicillin (R:≤13; I:14-17;S≥18),
TET – Tetracycline (R:≤ 14; ; I:15; 5: ≥ 19). R = resistant, I= immediate, ; S = sensitive,
WEC: E. coli in well water (no. 1, 2 & 5.)
SEC: Salmonella in stream water sample. (NCCL, 2006)

TABLE 12

Antibiogram of *Salmonella* isolates in water samples from Etche Local Government Area, Rivers State

Isolate No.	Measurement of Antibiotics Zone of Inhibition (mm)											
	AUG	**TET**	**AMX**	**COT**	**OFL**	**GEN**	**NAL**	**NIL**	**R**	**I**	**S**	**MARI**
WSP1	11R	12R	0R	15I	21S	13R	20S	20S	3(37.5%)	2(25%)	3(37.5%)	0.375
WSP6	12R	13R	0R	15I	18S	15S	16I	18S	3(37.5%)	2(25%)	3(37.5%)	0.375
SSP7	13R	12R	15I	10R	20S	16S	16I	17S	3(37.5%)	2(25%)	2(25%)	0.375
SSP8	11R	11R	13R	16S	19S	18S	19S	17S	3(37.5%)	0(0%)	5(62.5%)	0.375

N:B : OFL- Oflaxicin (R:≤12;I:13-15;S≥16) Gen-Gentamicin (R:≤12;I:13-14;S≥15),
Nal-Nalidixic Acid (R:≤13;1:14-19, S:≥19), NIT-Nitrofurantoin(R:≤14, I:15-16; 5:≥17);
Cot-Cotrimazole(R:≤10; I:11-15; S:≥ 16);
Aug- Augumentin (R: :≤13; I:14-17; S:≥18), Amx Amoxicillin (R:≤13; I:14-17;S≥18),
TET – Tetracycline (R:≤ 14; ; I:15; 5: ≥ 19). R = resistant, I= immediate, ; S = sensitive,
WSP: Salmonella isolates from well water samples
SSP: Salmonella isolates from stream water sample.

TABLE 13

Antibiogram of *Vibrio* isolate in water samples from some communities in Ikwerre Local Government Area Rivers State.

Isolate No.	Measurement of antibiotics zone of inhibition (mm)											
	AUG	TET	AMX	COT	OFL	GEN	NAL	NIT	R	I	S	MARI
WVI	12R	161	12R	141	16S	18S	20S	18S	2(25%)	2(25%)	4(50%)	0.25
WV2	13R	181	13R	165	17S	14I	24S	17S	2(25%)	2(25%)	4(50%)	0.25
WV5	11R	151	11R	10R	20S	16S	14I	22S	3(37.5%)	2(25%)	3(37.5%)	0.375
WV6	12R	171	13R	10R	20S	19S	22S	19S	3(37.5%)	1(12.5%)	4(50%)	0.375
SV7	13R	181	10R	9R	18S	14I	19S	20S	3(37.5%)	1(12.5%)	4(50%)	0.375
SV8	11R	161	12R	10R	151	20S	13I	17S	3(37.5%)	3(37.5%)	2(25%)	0.375

N:B : OFL- Oflaxicin (R:≤12;I:13-15;S≥16) Gen-Gentamicin (R:≤12;I:13-14;S≥15),
Nal-Nalidixic Acid (R:≤13;1:14-19, S:≥19), NIT-Nitrofurantoin(R:≤14, I:15-16; 5:≥17);
Cot-Cotrimazole(R:≤10; I:11-15; S:≥ 16),
Aug- Augumentin (R: :≤13; I:14-17; S:≥18), Amx Amoxicillin (R:≤13; I:14-17;S≥18),
TET – Tetracycline (R:≤ 14; ; I:15; 5:≥ 19). R = Resistant, I= Immediate, ; S = Sensitive
WV: Vibrio species in well (no.1,2,5& 6) water samples
SV: Vibrio species in stream (no. 7 & 8) water samples

4.9 Enterotoxicity test of *E. coli*, *Salmonella* sp and *Vibrio* sp from water samples in Ikwere, Emohua and Etche LGA's

The results of enterotoxicity test using rat with some of the isolates of *E. coli*, *Salmonella* sp and *Vibrio* sp from the three local government areas are presented in tables 14, 15 and 16 respectively. The result was positive for *E. coli* (E co7) with gut-to-weight ratio of 0.067, *Salmonella* sp (Sp05) with gut-to-weight ratio of 0071 and *Vibrio* sp (Vp. 07) producing 0.069 gut-to-weight ratio. The result reveals a direct evidence of occurrence of waterborne diseases from water sources in the three LGA's.

4.10 Analysis of physico-chemical parameters of the well and stream water samples.

The results of each of the physico-chemical parameter measured, the ANOVA analysis, and comparison of the mean values based on the three LGA's, water type, season and WHO standard is presented in the accompaning tables and figures below:

4.10.1 Comparison of Mean Temperature Ranges Base on LGA's, Water Source and Seasons

The result shows that the mean temperature (°C) range of well and stream water samples from villages in Etche LGA was found to be 24.65±.58 °C whereas that of Ikwerre sample was 25.31±.74cfu/ml and mean temperature (°C) range of Emohua samples was 25.27±.66cfu/ml. The mean temperature range of Ikwerre was significantly highest among all locations. The result shows that the mean temperature range of well water was 24.92±.68°C whereas the mean temperature (°C) range of stream water was25.56±.63 °C. The mean temperature range of stream water was significantly higher than that of well water (F1, 286=49.50, P<0.05). The result shows that the mean temperature range of well and stream water samples from dry season was found to be 25.26±.75°C whereas that of rainy season was 24.89± °C. The mean temperature range of dry season water was significantly higher than that of rainy season (F1, 286=20.011. P<0.05) as shown on figure 26.

TABLE 14

Enterotoxicity test of *Escherichia coli* isolated from water samples in Emohua Local Government Area, Rivers State.

E. Coli Code	Rat Gut weight(g)	Rat Body Weight (g) minus gut weight	Rat Gut Weight divided by body weight (g)	Remark	Standard gut to weight ratio
Eco 1	0.296	6.790	0.043	-	>0.065
Eco 2	9.310	6.812	0.046	-	
Eco 3	0.308	6.801	0.045	-	
Eco 4	0.320	7.260	0.044	-	
Eco 5	0.330	6.200	0.053	-	
Eco 6	0.328	6.801	0.048	-	
Eco 7	0.336	5.000	**0.067**	+	
Eco 8	0.344	6.141	0.056	-	
Uninoculated	0.431	5.72	0.075	+	
TSB	0.340	5.350	0.063	-	
Con. 09	0.311	5.401	0.057	-	

TSB: Tryptic soy broth

++: Clear toxicity
+: Doubtful toxicity
-: Non-toxicity
EC: Escherichia coli from sample sites 1-8
Con. 9: control E. coli from UPTH
>0.065 (Baselski et al., 1977)

TABLE 15

Enterotoxicity test of *Salmonella* sp isolated from water samples in Emohua Local Government Area, Rivers State

Salmonella Code	Rat Gut weight(g)	Rat Body Weight (g) minus gut weight	Rat Gut Weight divided by body weight (g)	Remark	Standard gut to weight ratio
Sp 01	0.372	6.081	0.061	-	>0.065
Sp 02	0.301	6.020	0.051	-	
Sp 03	0.330	6.550	0.050	-	
Sp 04	0.328	6.250	0.052	-	
Sp 05	0.380	5.382	**0.071**	+	
Sp 06	0.333	6.045	0.055	-	
Sp 07	0.320	6.031	0.053	-	
Sp 08	0.314	6.106	0.051	-	
Uninoculated	0.311	5.401	0.057	-	
TSB	0.340	5.350	0.063	-	
Con. 10	0.331	4.861	0.068	+	

Sp01 – 08: Salmonella Isolates

TSB: Tryptic soy broth
+:Doubtful toxicity
-:Non-toxicity
++: Clear toxicity
Con.10: Control salmonella
>0.065 (Baselski et al., 1977)

TABLE 16

Enterotoxicity test of *Vibrio* sp isolated from water samples in Etche Local Government Area, Rivers State

Vibrio Code	Rat Gut weight(g)	Rat Body Weight (g) minus gut weight	Rat Gut Weight divided by body weight (g)	Remark	Standard gut to weight ratio
Vp .01	0.365	6.063	0.060	-	>0.065
Vp.02	0.310	6.022	0.051	-	
Vp .03	0.351	6.050	0.058	-	
Vp .04	0.360	6.042	0.060	-	
Vp .05	0.300	5.901	0.050	-	
Vp .06	0.362	6.062	0.060	-	
Vp. 07	0.372	5.380	**0.069**	+	
Vp. 08	0.293	4.950	0.059	-	
Uninoculated	0.311	5.401	0.057	-	
TSB	0.340	5.350	0.063	-	
Con. 10	0.327	4.838	0.067	+	

Vp01 – 08: Vibrio Isolates
TSB: Tryptic Soy Broth
+: Doubtful Toxicity
-: Non-toxicity
++: Clear Toxicity
Con.10: Control Vibrio

>0.065 (Baselski et al., 1977)

4.10.2 Comparison of Mean pH Ranges Base on LGA's, Water Source and Seasons

The results from figure 29 shows that the mean pH of well and stream water samples from villages in Etche Local Government Area was found to be 5.97, SD=0.73, whereas that of Ikwerre was 6.08±0.73 and that of Emohua was 6.79±6.33. Thus, the mean pH was highest in Emohua in LGA. The result shows that the mean pH of well water was 5.97±4.24 whereas the mean pH value of stream water was7.24 ±0.38. The ANOVA result (F1, 286=6.477, p< 0.05) shows that there was significant difference in pH based on water type. This indicated that the pH value was higher in the stream water than in the well water.The result shows that the mean pH of well and stream water samples during the dry season was found to be 6.62±5.18, whereas that of rainy season was 5.95±0.81. There was no significant difference in pH based on season (F1, 286=2.307, P>0.05).

4.10.3 Comparison of Mean total hardness of water based on LGA, water source and seasons.

The result from figure 32 shows that the mean total hardness (mg/l) of well and stream water samples from Etche LGA was found to be 11.01 ±7.92 mg/l whereas that of Ikwerre LGA was 10.98±7.98mg/l and mean total hardness of Emohua samples was 128.21±1141.94 mg/l. The total hardness of water was higher in Emohua LGA than in the other two LGA's. The result shows that the mean total hardness of well water was 12.04±9.11mg/lwhereas the mean total hardness of stream water was164.13±1318.91mg/l. There was no significant difference in total hardness of water based on type of water (286=2.892, p>0.05). However, the total hardness was slightly higher in the well water sources than in the stream water. The result shows that the mean total hardness of well and stream water samples from dry season found to be 91.79±932.21mg/l whereas that of rainy season was 8.33±2.46mg/l. ANOVA result shows that there was significant difference based on season (F1,286=1.154, P>0.05).

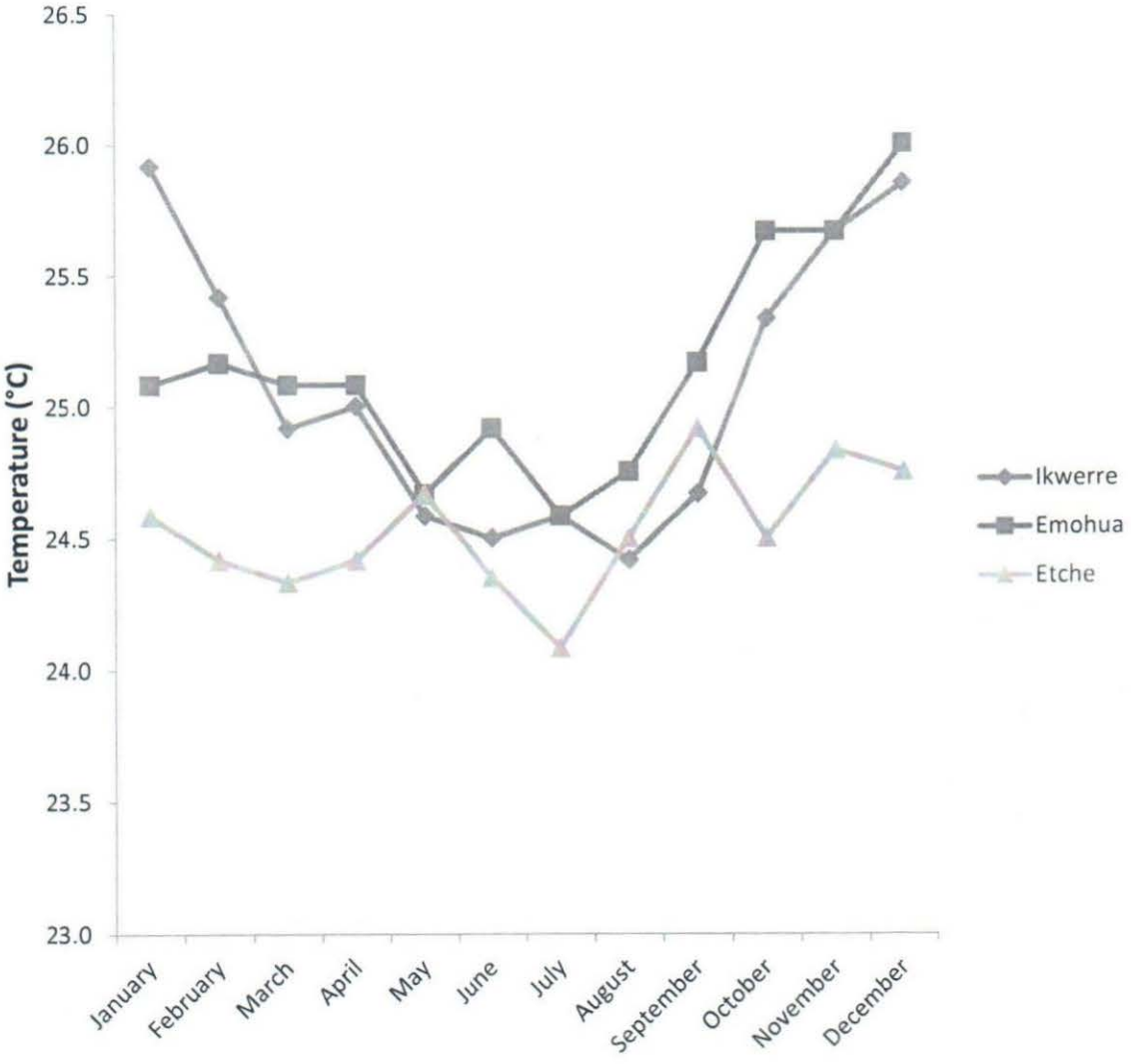


FIG 24 : Mean temperature of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State.

TABLE 17

ANOVA of Temperature ranges from well water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	300.85	25.07083	0.298845
Emohua	12	301.8333	25.15278	0.185396
Etche	12	294.35	24.52917	0.055411

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	2.756037	2	1.378019	7.6606	3.2849
Within Groups	5.936169	33	0.179884		
Total	8.692206	35			

In table 17 above, it can be seen that the calculated F (F= 7.6606) is greater than the tabulated F(F *crit*= 3.2849). There is thus a significant difference between the temperature of water from wells in Ikwerre, Emohua, and Etche LGA,s from January to December.

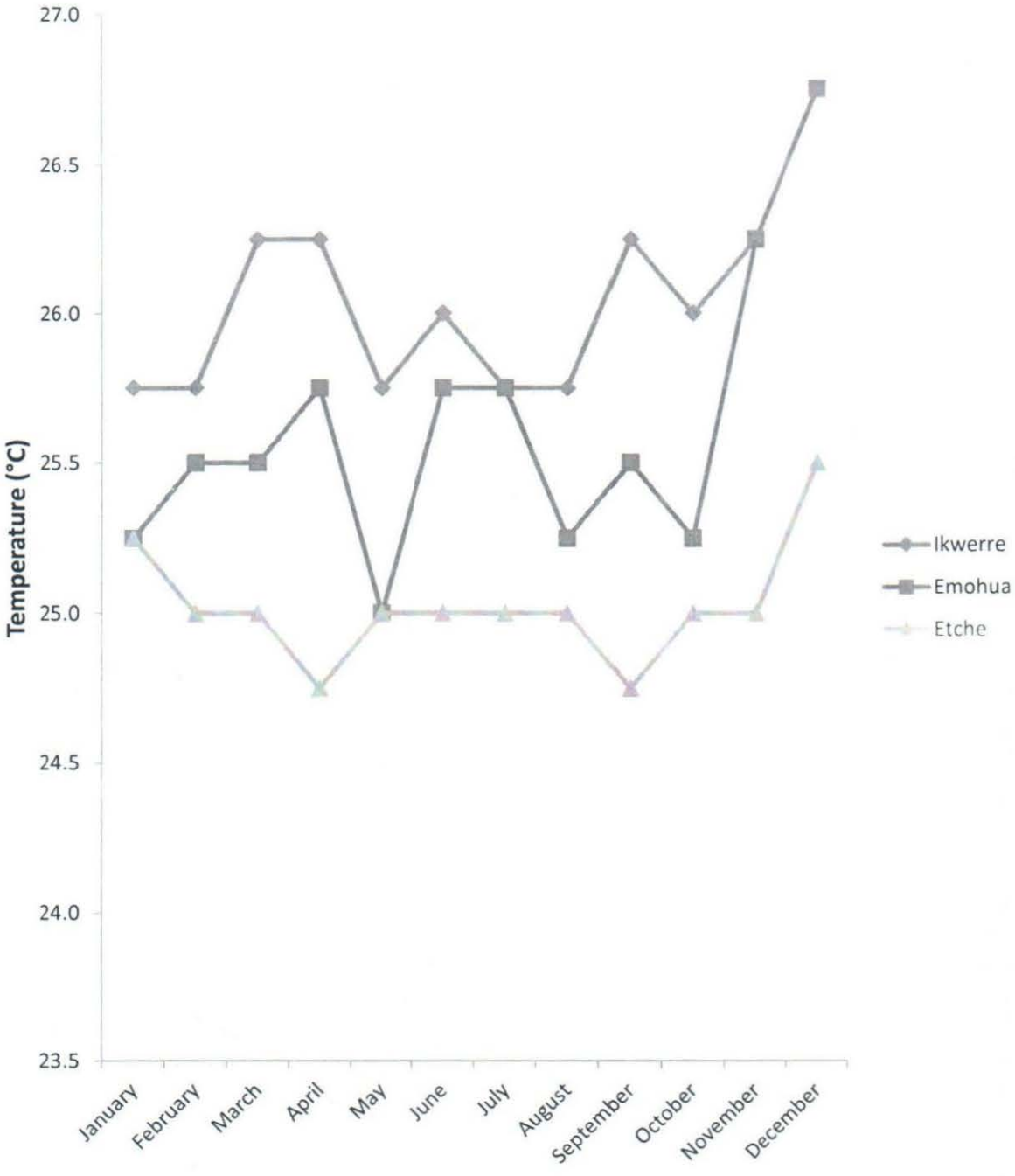


FIG 25: Mean temperature of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 18

ANOVA of Temperature ranges in stream water samples.

SUMMARY

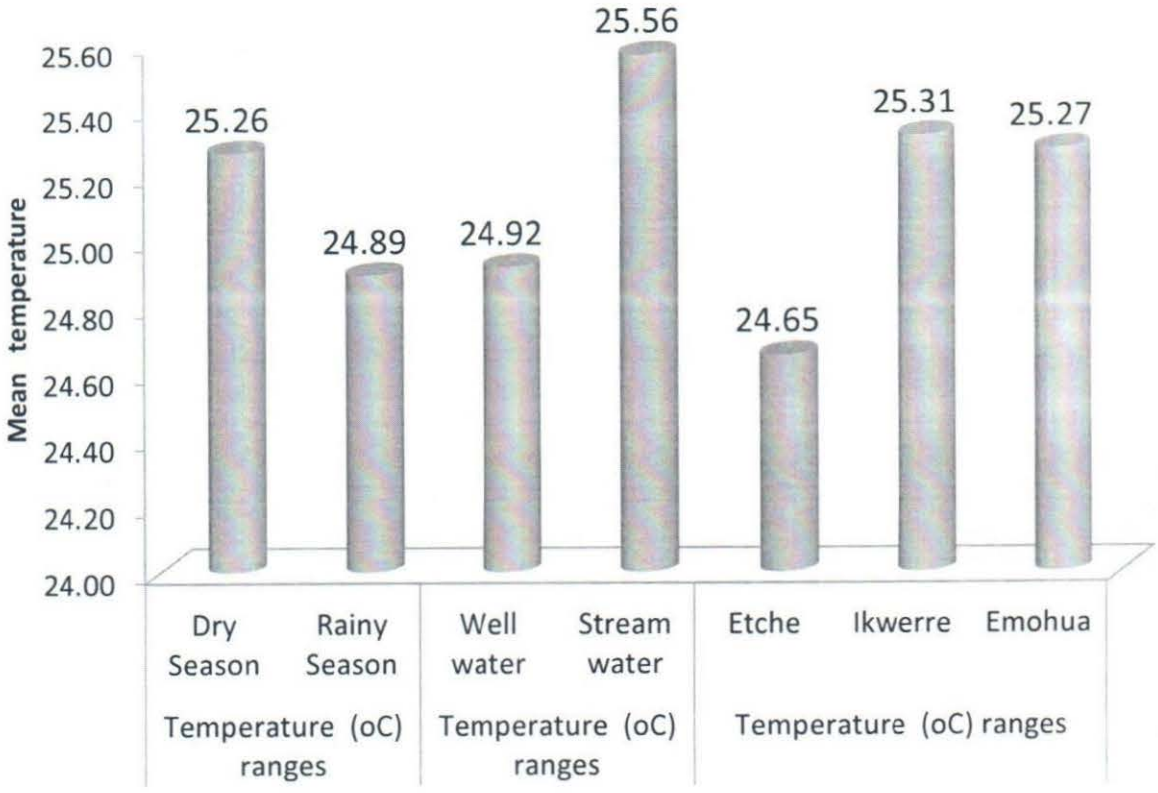
Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	312.5	26.04167	0.100379
Emohua	12	307.5	25.625	0.232955
Etche	12	300.25	25.02083	0.039299

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	6.322917	2	3.161458	25.4524	3.2849
Within Groups	4.098958	33	0.124211		
Total	**10.42188**	**35**			

From table 18, it can be seen that the calculated F (*F*= 25.4524) is greater than the tabulated F(*F crit*= 3.2849). There is thus a significant difference between the temperature of water from streams in Ikwerre, Emohua, and Etche LGA from January to December.

Comparison of mean temperature ranges based on LGA, water source and seasons.



WHO(2003); 30^0C

FIG. 26: Comparison of mean Temperature ranges of water samples based on LGA's, water source and season

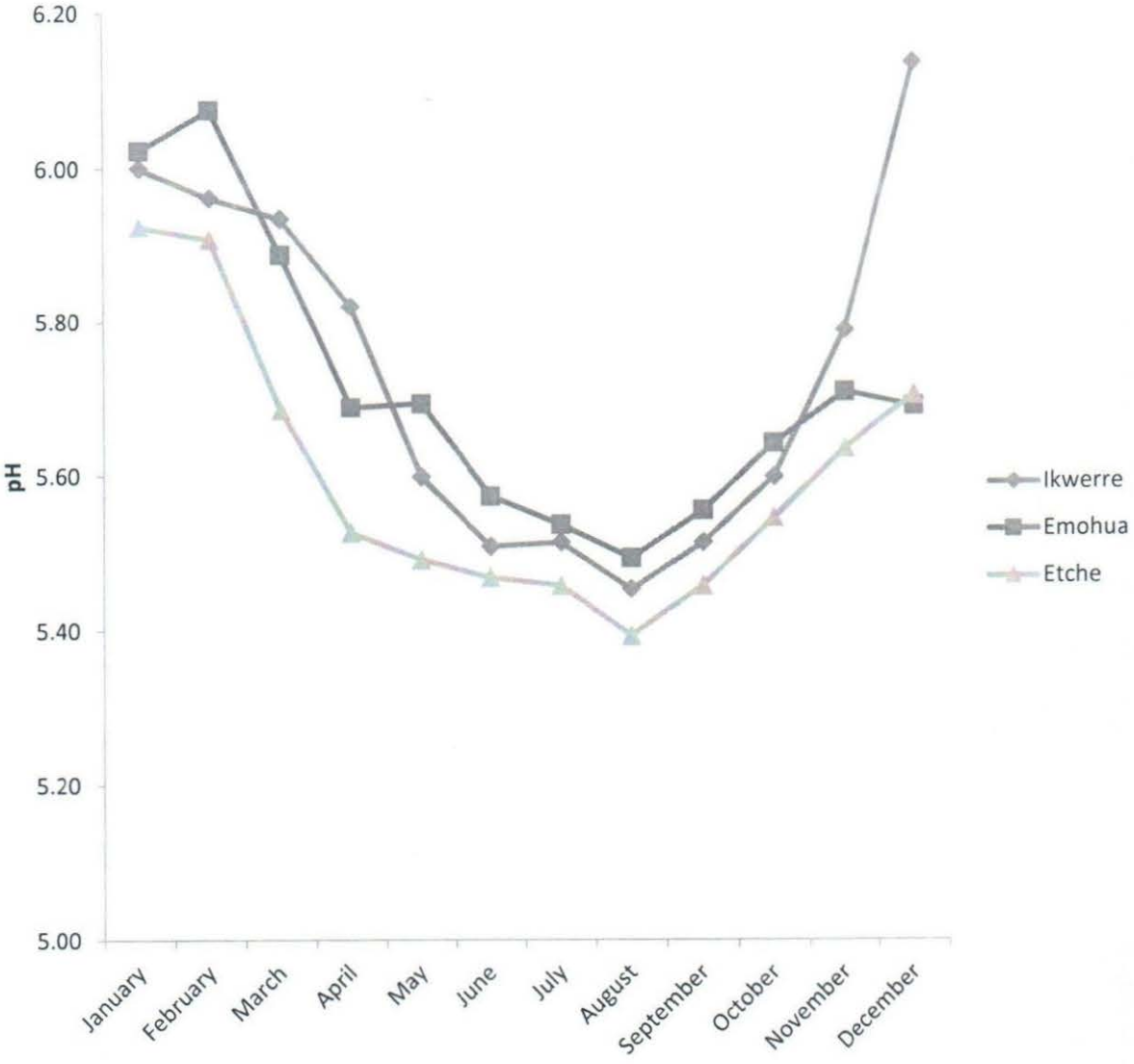


FIG. 27: Mean pH of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 19

ANOVA of pH ranges from well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	68.82333	5.735278	0.054244
Emohua	12	68.56667	5.713889	0.035321
Etche	12	67.2	5.6	0.030954

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	0.126913	2	0.063457	1.5796	3.2849
Within Groups	1.325712	33	0.040173		
Total	1.452625	35			

The Analysis of Variance on Table 19 shows that the calculated F (F= 1.5796) is lesser than the tabulated F(F *crit*= 3.2849). This indicates that there was no significant difference between the pH of water from wells in Ikwerre, Emohua, and Etche LGA'sfrom January to December.

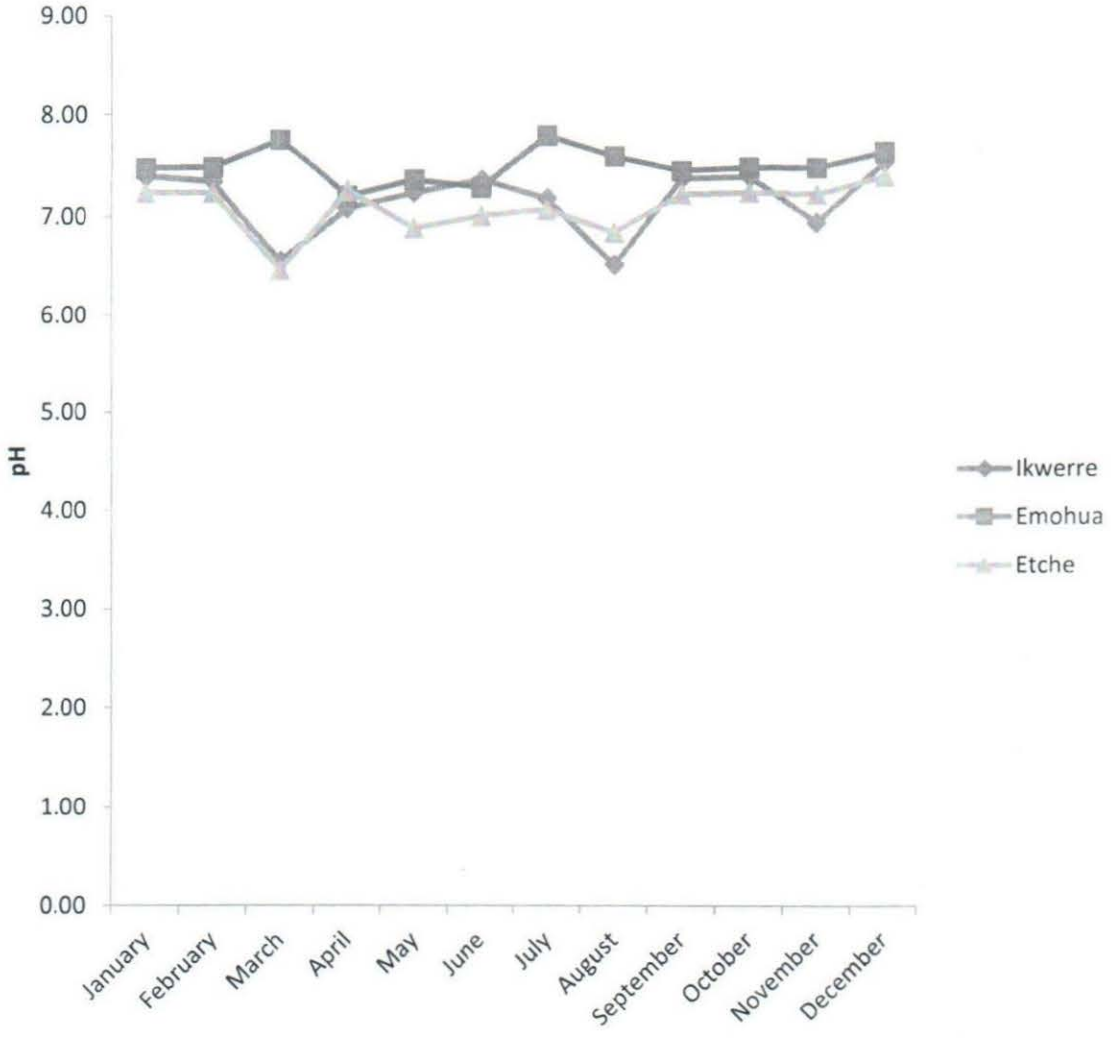


FIG. 28: Mean pH of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 20

ANOVA of pH ranges from stream water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	85.79	7.149167	0.108427
Emohua	12	89.865	7.48875	0.030669
Etche	12	84.945	7.07875	0.063414

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	1.153501	2	0.576751	8.5441	3.2849
Within Groups	2.227604	33	0.067503		
Total	3.381106	35			

From table 20, the calculated F (F= 8.5441) is greater than the tabulated F($F\ crit$= 3.2849). There is a significant difference between the pH of water from streams in Ikwerre, Emohua, and Etche LGA'sfrom January to December.

Comparison of mean pH ranges based on LGA, water source and seasons.

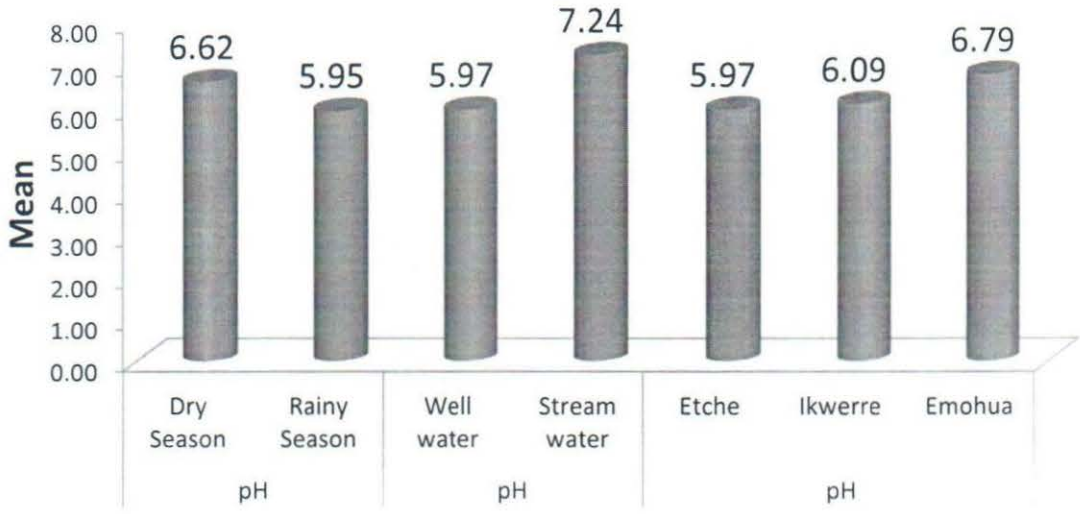


FIG. 29: Comparison of pH value of water samples based on season, water-source and location

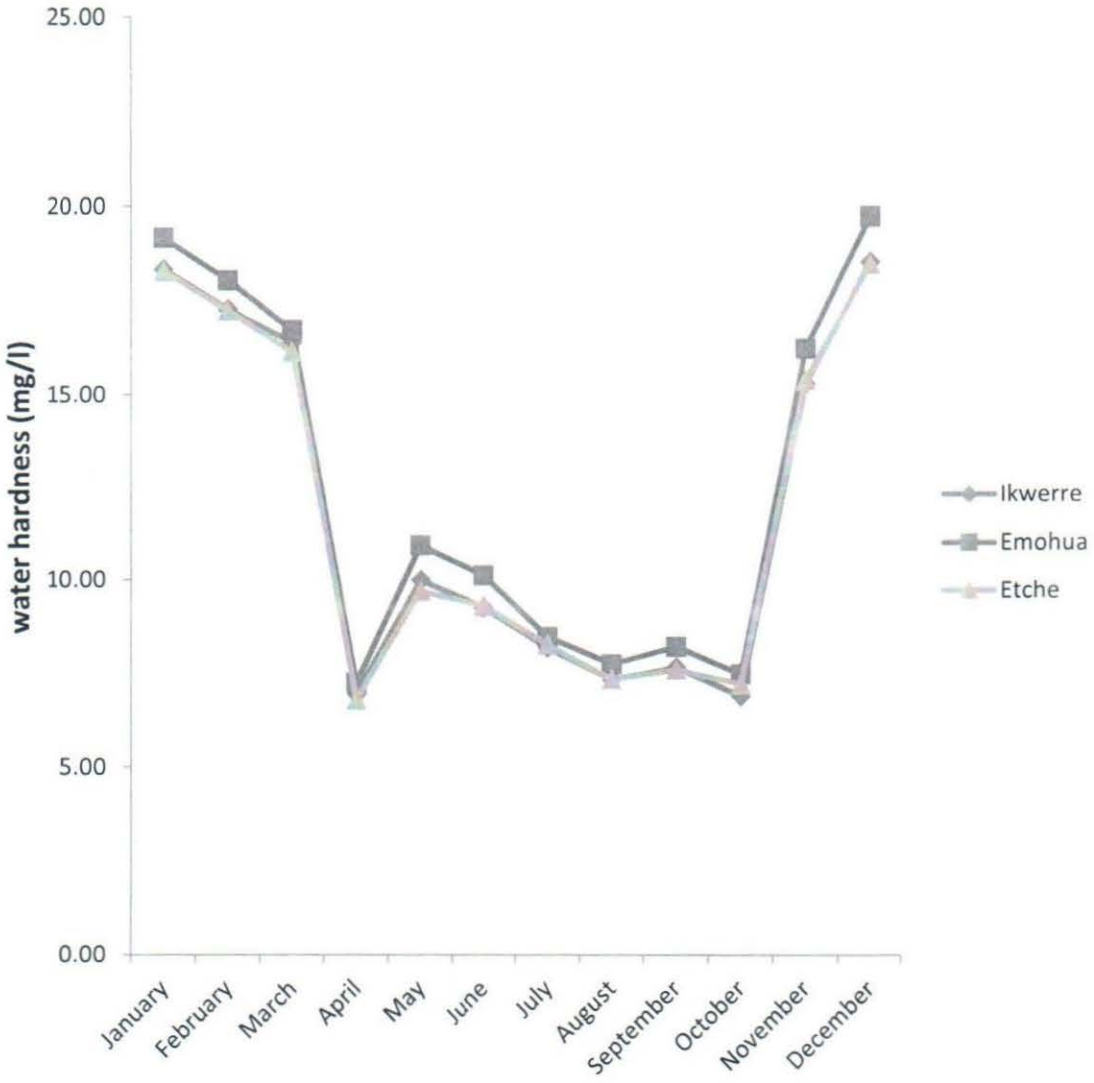


FIG. 30: Mean total hardness of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 21

ANOVA of mean total hardness of water from well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	141.9128	11.82607	23.63961
Emohua	12	149.9282	12.49401	25.28393
Etche	12	141.5968	11.79974	23.24768

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	3.715459	2	1.85773	0.0772	3.2849
Within Groups	793.8834	33	24.05707		
Total	797.5988	35			

Table 21 above, shows that the calculated F (F= 0.0772) is less than the tabulated F(F *crit*= 3.2849). There is no significant difference between the total hardness of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

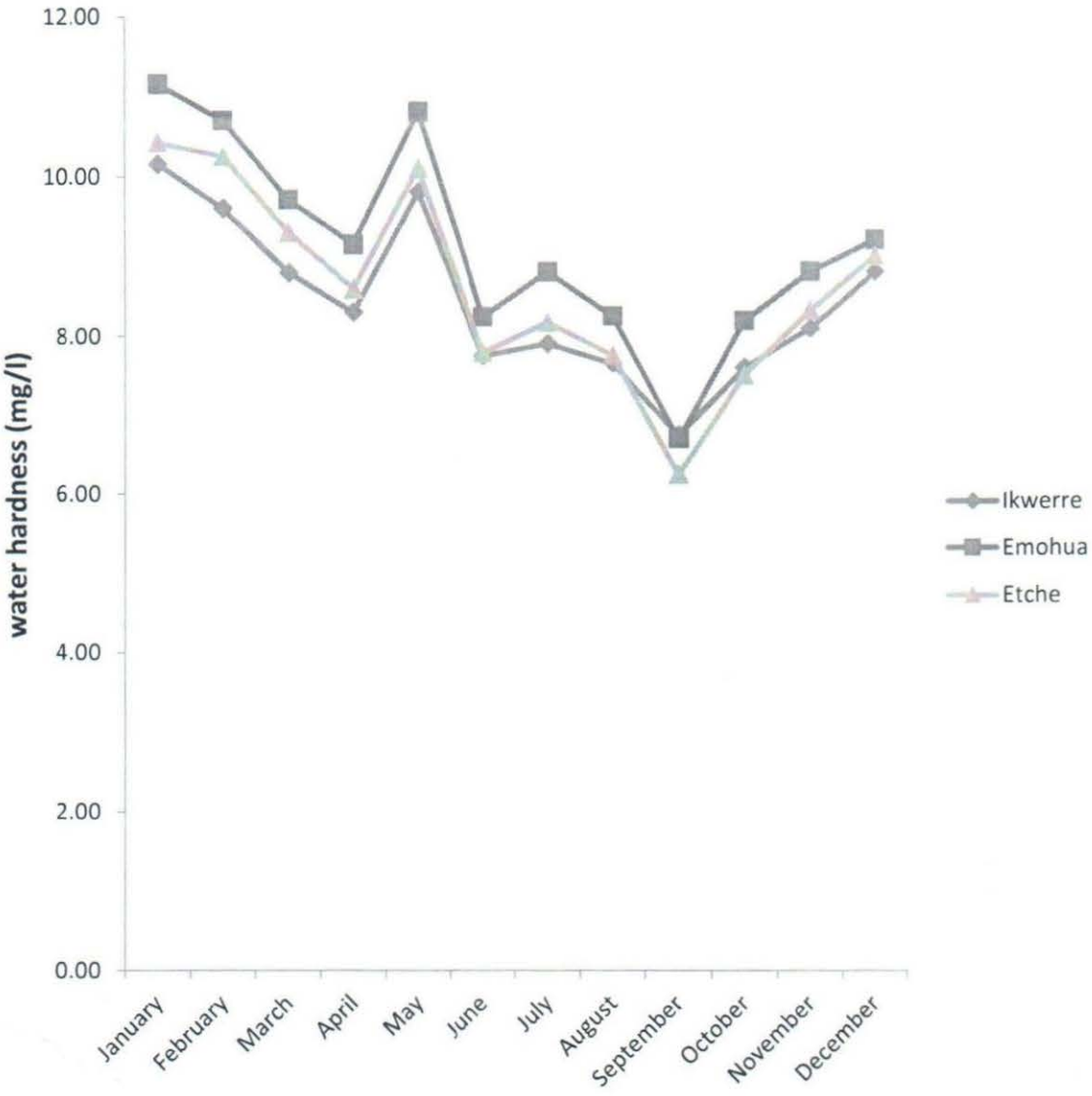


FIG. 31: Mean total hardness of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 22

ANOVA of mean total hardness of water from stream water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	101.2175	8.434792	1.043441
Emohua	12	109.7285	9.144042	1.651787
Etche	12	103.473	8.62275	1.572759

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	3.240436	2	1.620218	1.1389	3.2849
Within Groups	46.94786	33	1.422662		
Total	50.1883	35			

The ANOVA result on shows that the calculated F (*F*= 1.1389) is less than the tabulated F(*F crit*= 3.2849). There is thus no significant difference between the mean total hardness of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December

Comparison of Mean total hardness of water based on LGA, water source and seasons.

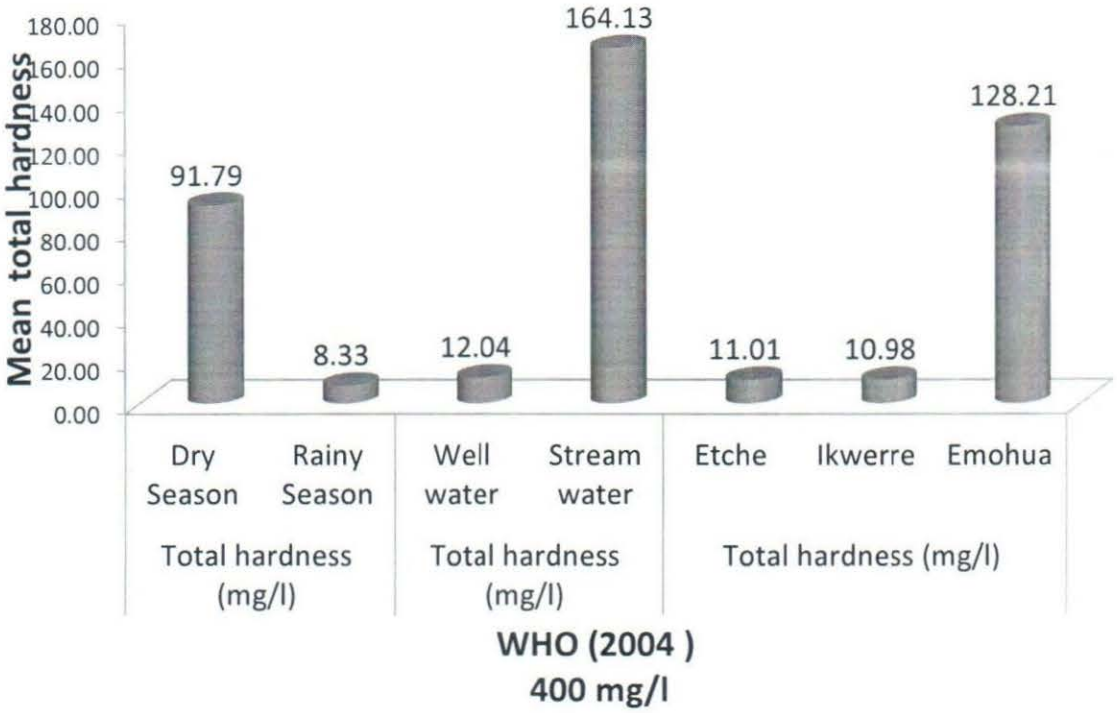


FIG. 32: Comparison of mean total hardness of water samples based on LGA's, water source and season

4.10.4 Comparison of Mean Dissolved Oxygen of water based on LGA's, water source and seasons.

The result of the comparisons on figure 35 shows that the mean dissolved oxygen ranges of well and stream water samples from Etche LGA was found to be 6.46±0.78, whereas that of Ikwerre LGA was 6.97±0.81 and that of Emohua LGA was 7.25±0.85. The result shows that the mean dissolved oxygen ranges of well water was 7.02±0.90 while the mean dissolved oxygen ranges of stream water was6.52±0.65. Based on the type of water, the ANOVA result indicates that the dissolved oxygen ranges was significantly higher in the well water than in the stream water (P1, 286=18.803, P<0.05). The result also shows that the mean dissolved oxygen ranges of well and stream water samples from dry season was found to be 6.68±0.87 whereas that of rainy season was 7.11±0.83. The result of ANOVA reveals a significant difference based on season (F1, 286=18.496, p<0.05).

4.10.5 Comparison of mean Nitrate concentration based on LGA's, water source and seasons

The result of the comparison on figure 38 shows that the mean nitrate concentration (mg/l) of well and stream water samples from villages in Etche LGA was found to be 0.50±0.55mg/l whereas that of Ikwerre sample was 0.51±0.56mg/l and mean nitrate concentration of Emohua samples was 0.52±0.54 mg/l. The result shows that the mean nitrate concentration of well water was 0.60±0.61mg/l whereas the mean nitrateconcentration of stream water was 0.24±0.03mg/l. This indicates that the nitrate concentration was significantly higher in the well water than in the stream water (F1, 286=25.761, P<0.05). The result shows that the mean nitrate concentration (mg/l) of well and stream water samples from dry season was found to be 0.52±0.61mg/l whereas that of rainy season was 0.50±0.49mg/l. The result of ANOVA shows there was no significant different based on season (F1,286=198,P>0.05).

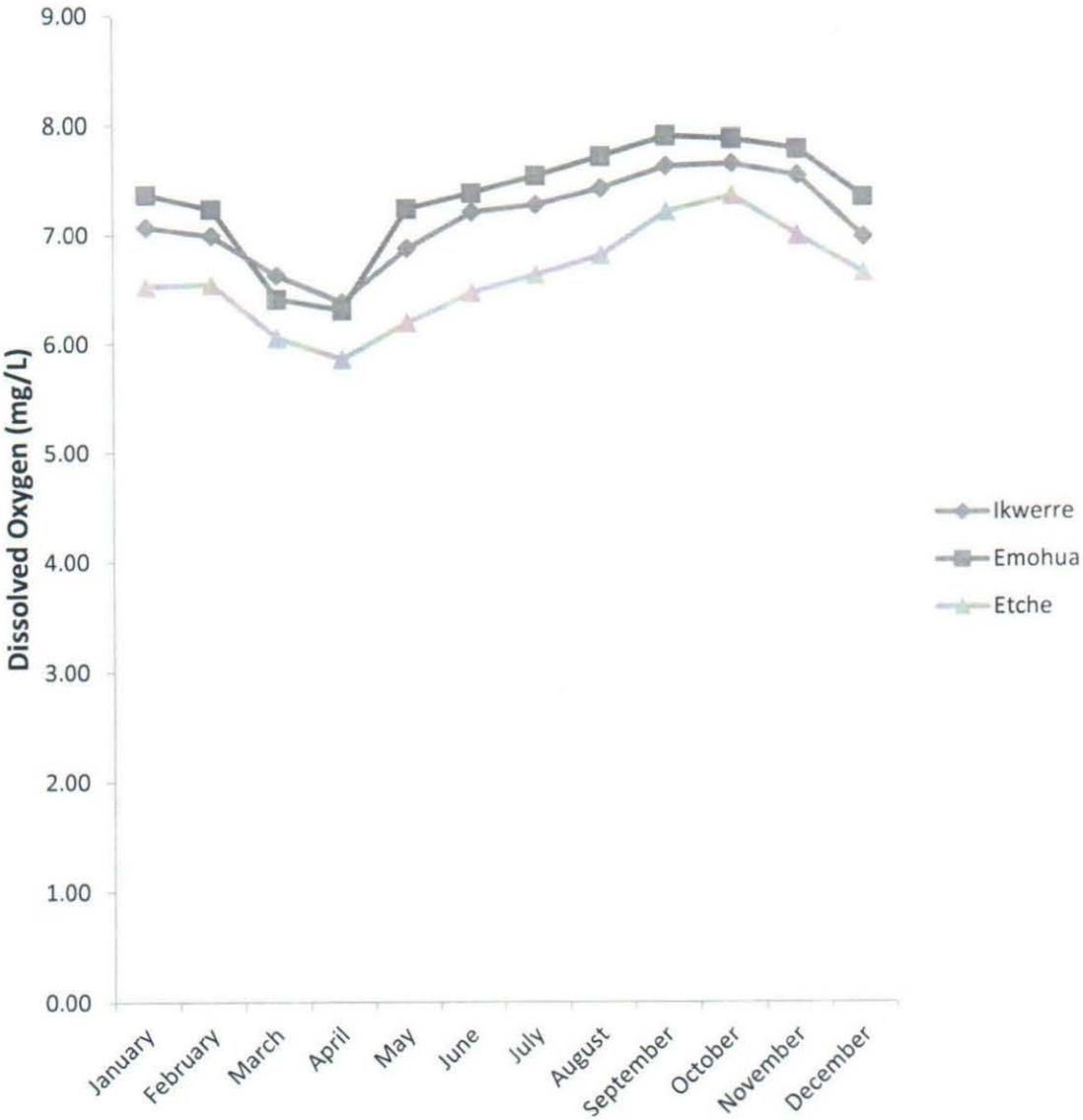


FIG. 33: Mean Dissolved Oxygen of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 23

ANOVA of Mean Dissolved Oxygen from well water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	85.54	7.128333	0.157157
Emohua	12	88.005	7.33375	0.265035
Etche	12	79.16833	6.597361	0.19825

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	3.465584	2	1.732792	8.378502	3.2849
Within Groups	6.824864	33	0.206814		
Total	10.29045	35			

From Table 23, it can be seen that the calculated F is greater than the tabulated F(*F crit*). There is thus a significant difference between the dissolved oxygen of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

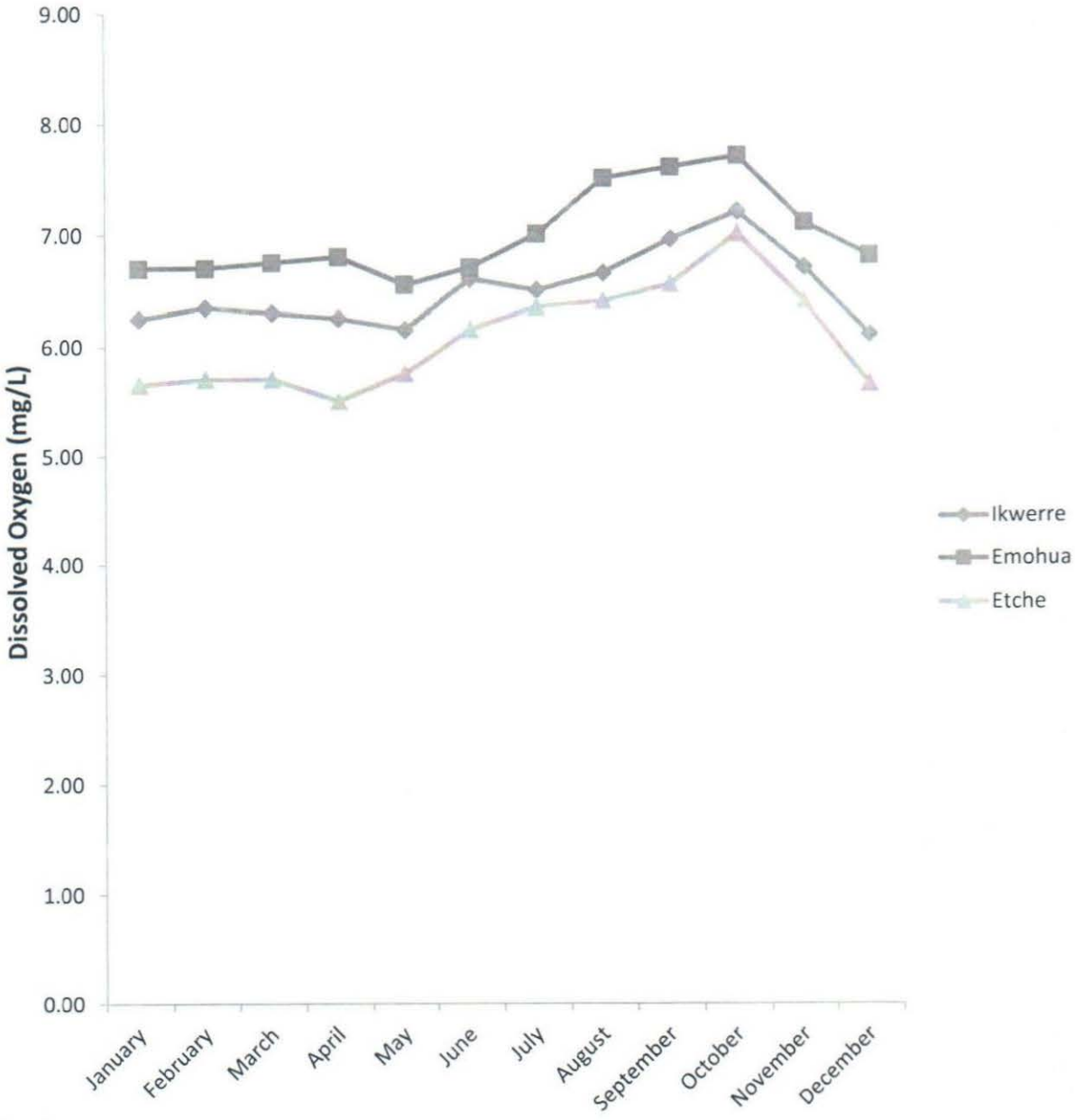


FIG. 34: Mean Dissolved oxygen of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 24

ANOVA of Mean Dissolved Oxygen of water from stream water samples

SUMMARY

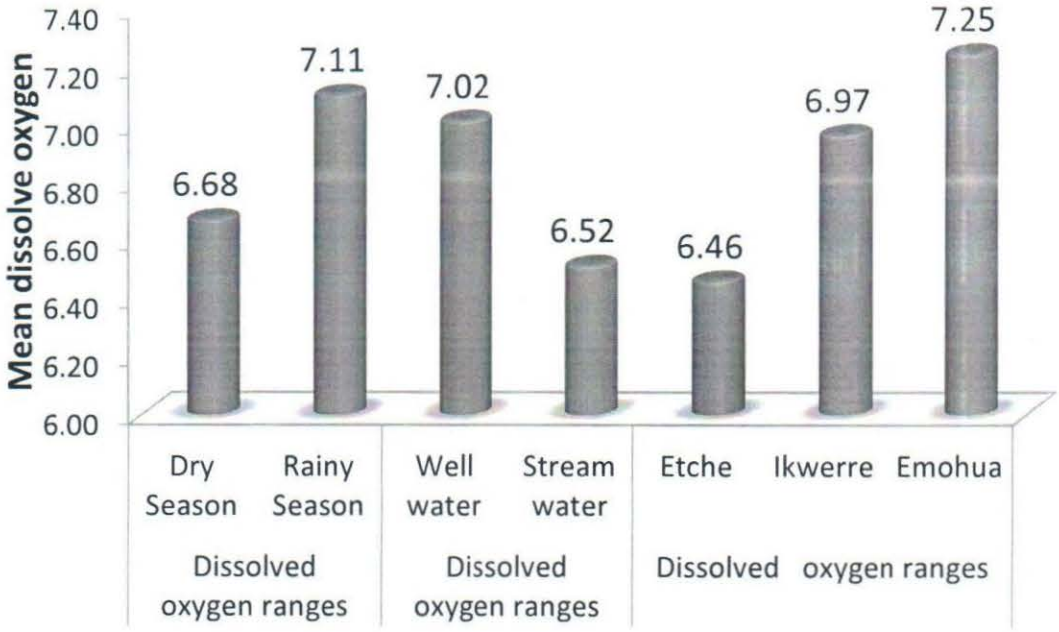
Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	78	6.5	0.112273
Emohua	12	83.9	6.991667	0.156742
Etche	12	72.8	6.066667	0.222879

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	5.140556	2	2.570278	15.6758	3.2849
Within Groups	5.410833	33	0.163965		
Total	10.55139	35			

The ANOVA result on table 24 shows that the calculated F is greater than the tabulated F(*F crit*), indicating a significant difference between the dissolved oxygen of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

i. Comparison of Mean Dissolved Oxygen ranges based on LGA, water source and seasons.



WHO, 2003
7.5mlg/l

FIG. 35: Comparison of mean Dissolved Oxygen ranges of water samples based on LGA's, water source and season

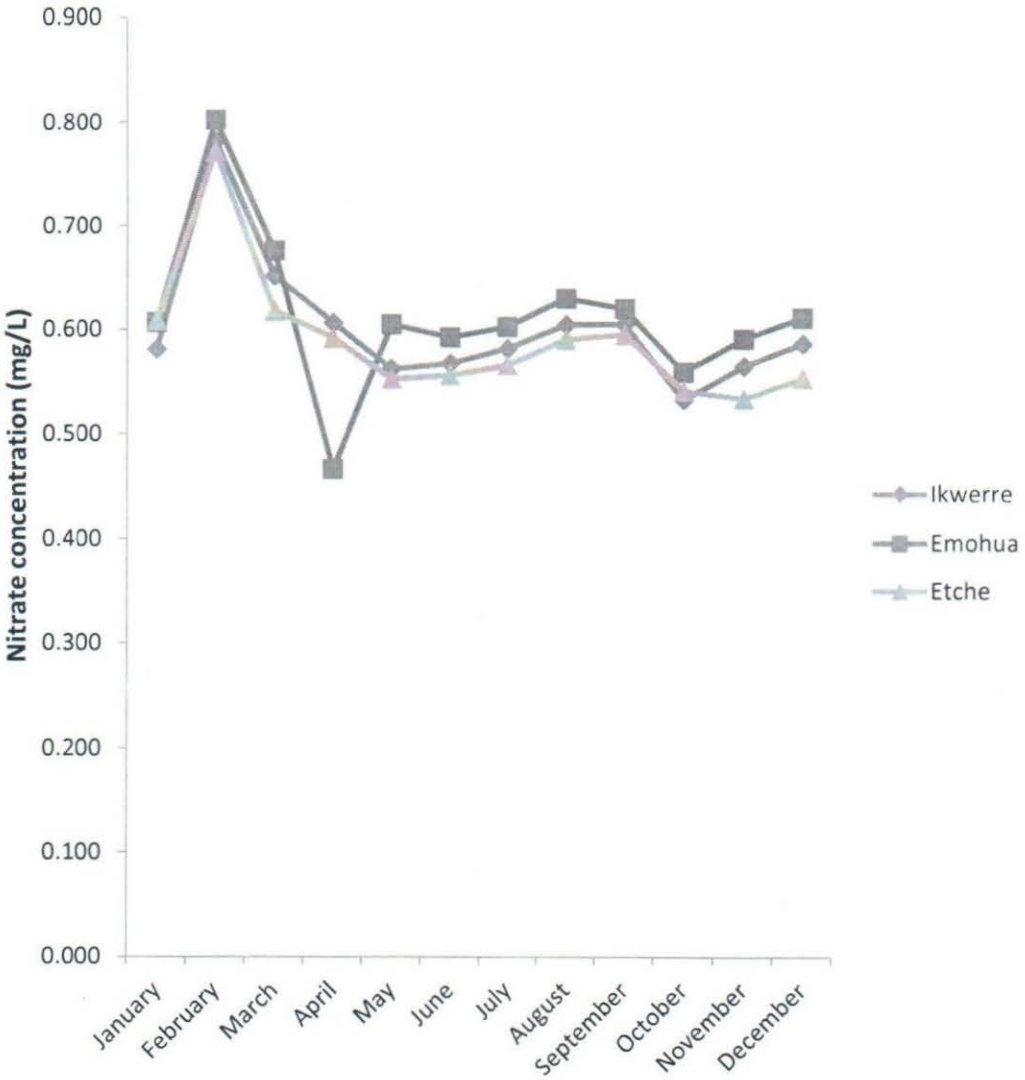


FIG. 36: Mean Nitrate concentration of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 25

ANOVA of Mean Nitrate concentration of water from well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	7.2245	0.602042	0.004098
Emohua	12	7.361633	0.613469	0.005991
Etche	12	7.076667	0.589722	0.004029

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	0.003385	2	0.001693	0.359667	3.2849
Within Groups	0.155297	33	0.004706		
Total	0.158682	35			

From table 25 above, the calculated F (0.359667) is less than the tabulated F (3.2849) (*F crit*). There is thus no significant difference between the nitrate concentration of water from wells in Ikwerre, Emohua, and Etche LGA'sfrom January to December.

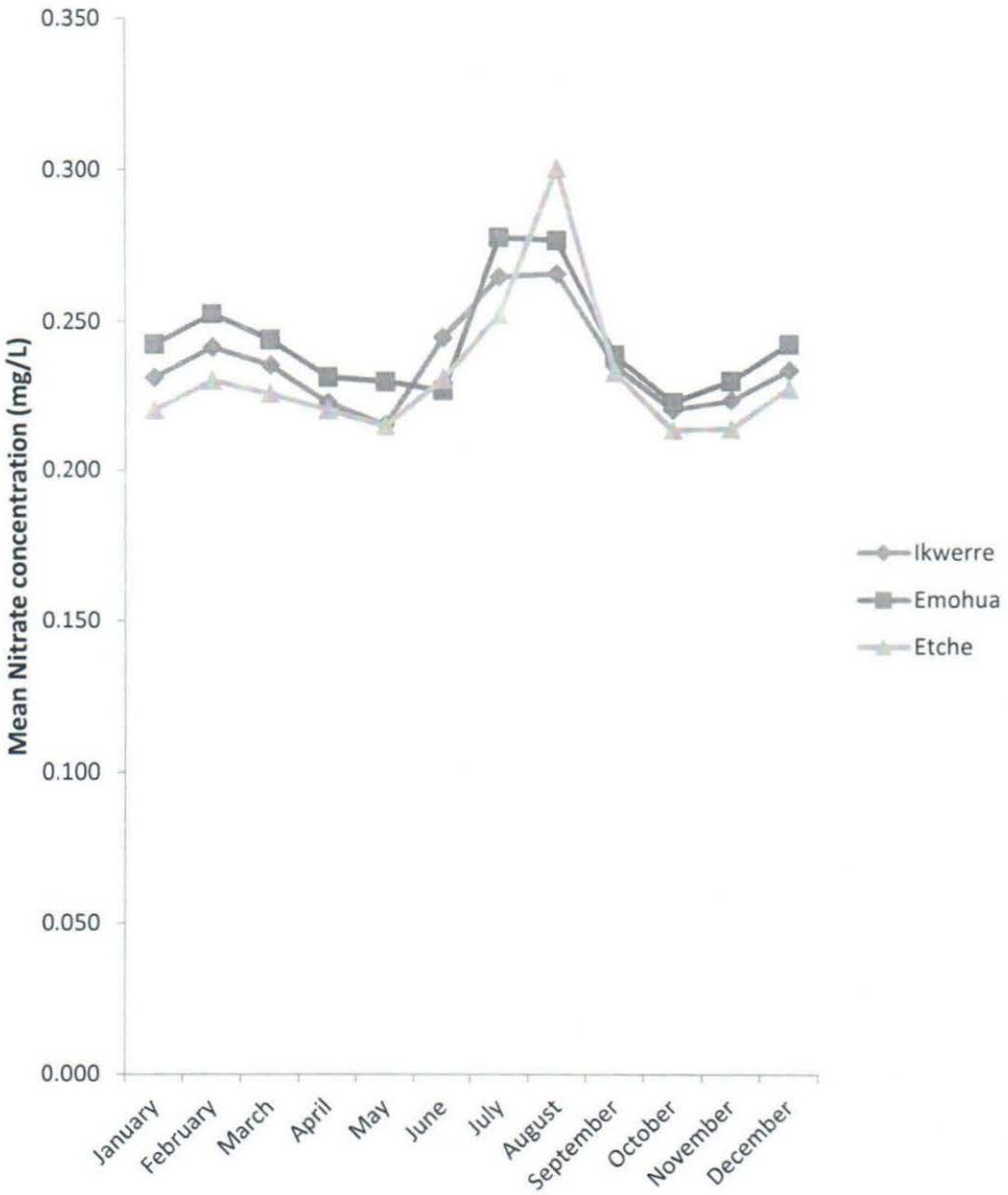


FIG. 37: Mean Nitrate concentration of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 26

ANOVA of Mean Nitrate concentration of water from stream water samples

SUMMARY

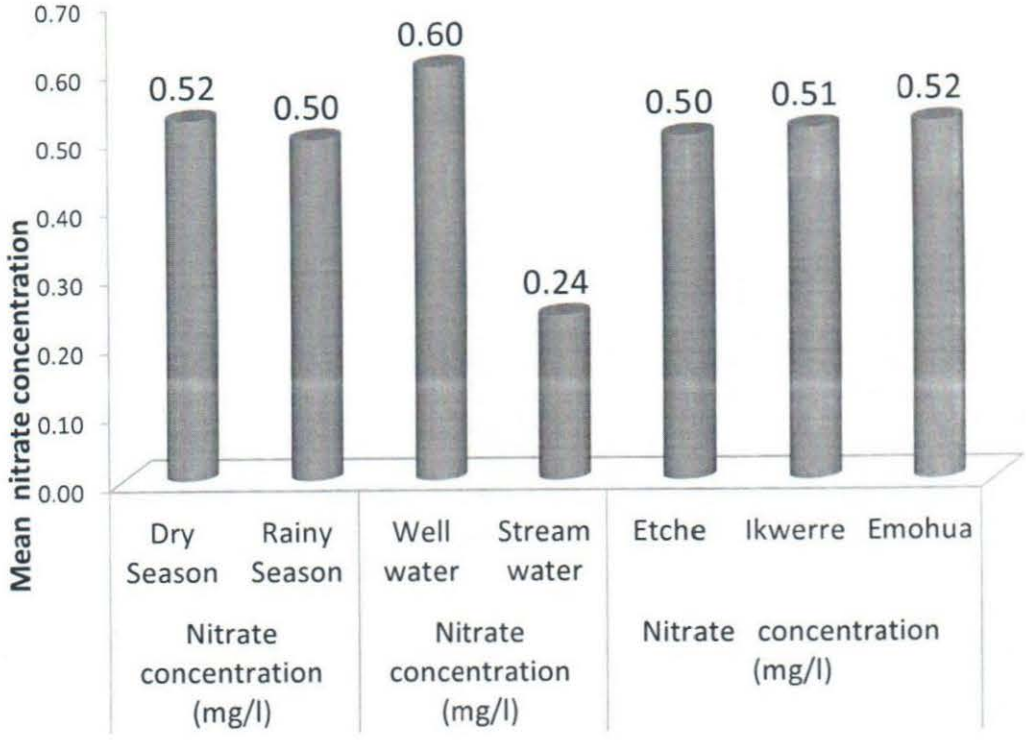
Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	2.834	0.236167	0.000254
Emohua	12	2.915	0.242917	0.000323
Etche	12	2.7835	0.231958	0.000573

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	0.000733	2	0.000367	0.95636	3.2849
Within Groups	0.012654	33	0.000383		
Total	0.013387	35			

The result from table 26 shows that the calculated F is less than the tabulated F(*F crit*), meaning that there is no significant difference between the nitrate concentration of water from streams in Ikwerre, Emohua, and Etche LGA'sfrom January to December.

ii. Comparison of mean Nitrate concentration based on LGA's, water source and seasons



WHO, 2003 50mlg/l

FIG. 38: Comparison of mean Nitrate concentration (mg/l) of water samples based on LGA's, water source and season

4.10.6 Comparison of mean Biological Oxygen Demand based on LGA's, water source and seasons

The result from the comparsion on figure 41 shows that the mean biological oxygen demand (mg/l) of well and stream water samples from Etche LGA was 7.54±2.81 mg/l, Ikwerre LGA was 7.71±2.79 mg/l and that of Emohua LGA was 8.04±2.84 mg/l. The mean biological oxygen demand was higher in the water samples from Emohua LGA. Based on the LGA's,the result shows that the mean biological oxygen demand for well water was 7.98±2.85 mg/lwhereas the mean biological oxygen demand of stream water was7.12±2.62 mg/l. ANOVA result reveals that there was significant difference based on water type ($F1, 286=5.09$, $P<0.05$). This indicates that the biological oxygen demand was slightly higher in the well water than in the stream water. The result shows that the mean biological oxygen demand (mg/l) of well and stream water samples from dry season was found to be 6.06±2.81mg/l while that of rainy season was 9.47±1.46 mg/l. The result of ANOVA indicates there was significant difference of mean biological oxygen demand based on season ($F1, 286=167.511$, $p<0.05$).

4.10.7 Comparison of Mean Salinity concentration based on LGA's, water source and seasons

Based on the LGA's, the result shows that the mean salinity (mg/l) of well and stream water samples from Etche LGA was found to be 18.97±13.22mg/l, whereas that of Ikwerre LGAwas 19.69±14.07mg/l and Emohua LGA was 20.81±14.89mg/l. The result shows that the mean salinity of well water was 20.10±15.29mg/l whereas the mean salinity of stream water was18.97±9.39mg/l. The ANOVA result revealed that there was significant difference in mean salinity based on the type of water ($F1, 286=0.349$, $p>0.05$). This indicates that the salinity was slightly higher in the well water sources than the stream water. The result shows that the mean salinity (mg/l) of well and stream water samples from dry season was found to be 22.53±15.26mg/l whereas that of rainy season was 17.11±12.17mg/l. The result of ANOVA shows that there was significant difference in mean salinity based on season ($F1,286=11.125$, $p<0.05$) according to the results shown on figure 44.

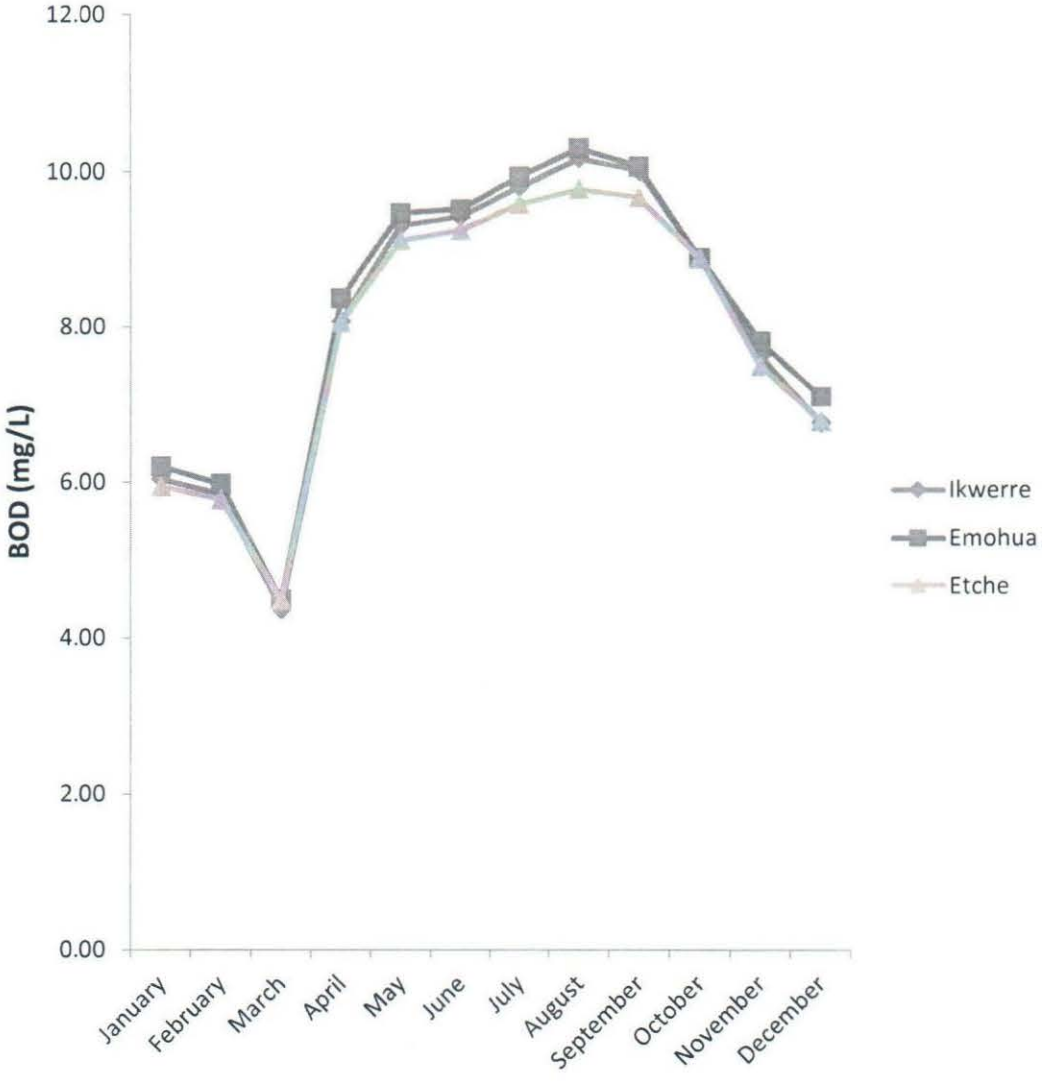


FIG. 39: Mean Biochemical Oxygen Demand (BOD_5) of water from wells in Ikwerre, Emohua and Etche LGA's of Rivers State.

TABLE 27

ANOVA of Mean Biochemical Oxygen Demand (BOD_5) of well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	96.19667	8.016389	3.611425
Emohua	12	98.02167	8.168472	3.515874
Etche	12	94.691	7.890917	3.18436

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	0.463639	2	0.231819	0.067444	3.284918
Within Groups	113.4282	33	3.43722		
Total	113.8919	35			

The result of ANOVAon table 27 shows that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the BOD_5 of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

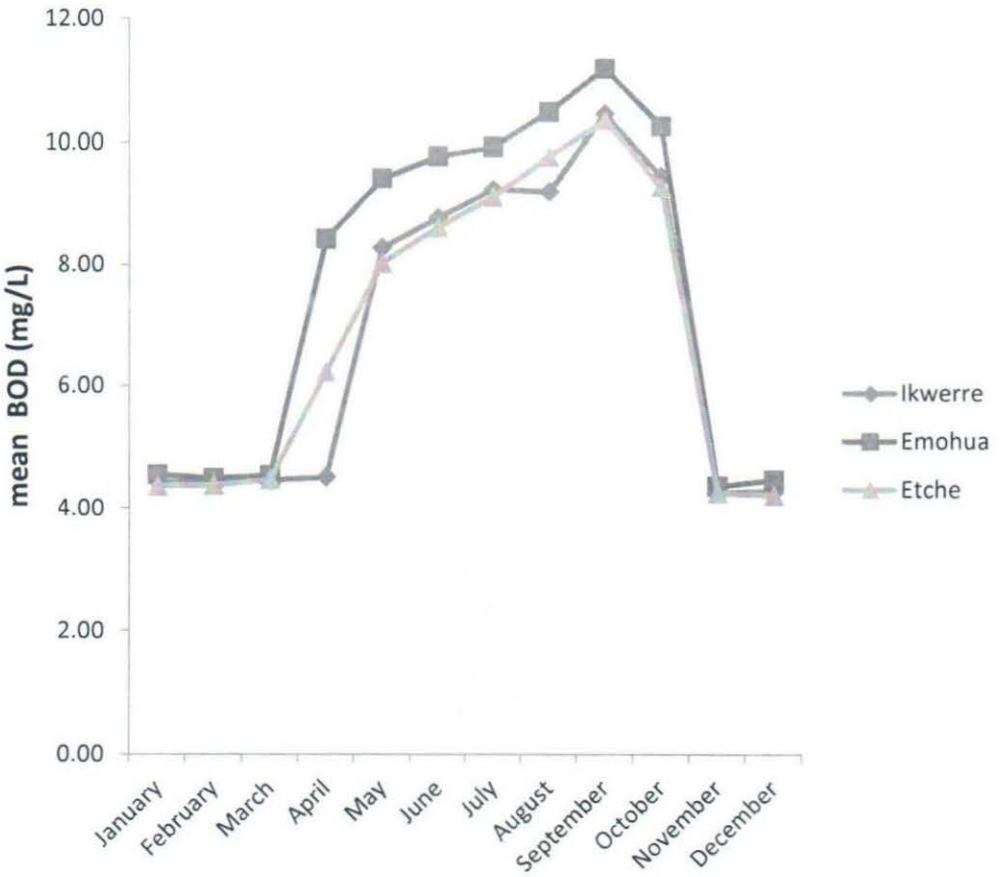


FIG.40: Mean BOD_5 of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 28

ANOVA of Mean BOD_5 of stream water samples

SUMMARY

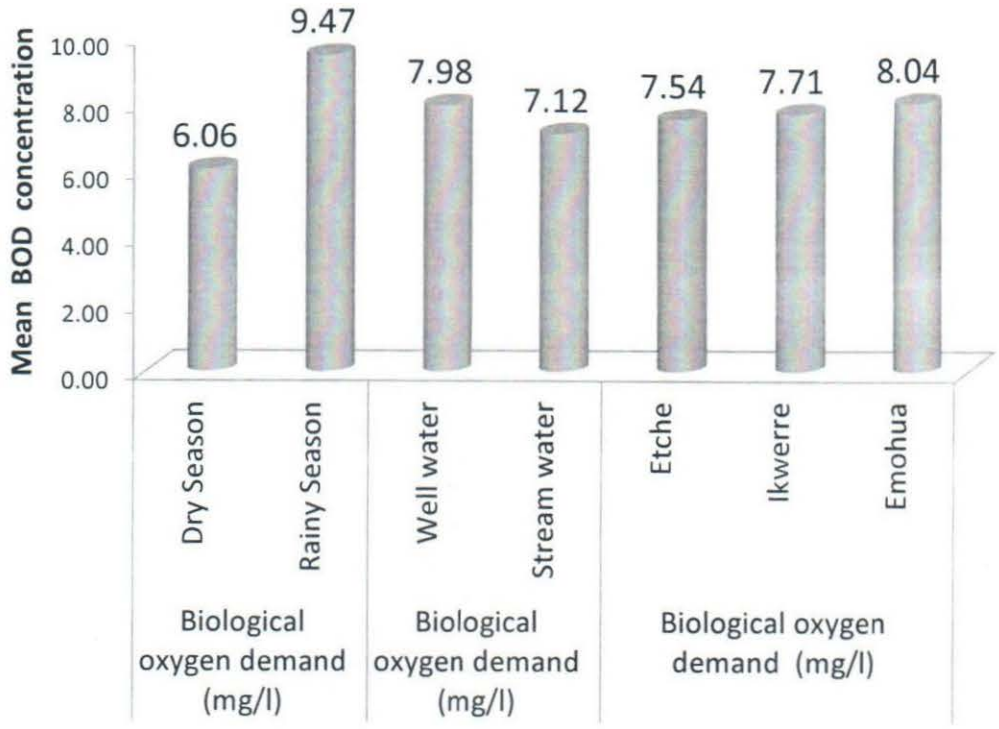
Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	81.655	6.804583	6.612325
Emohua	12	91.805	7.650417	8.242852
Etche	12	82.965	6.91375	6.18021

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	5.080117	2	2.540058	0.362255	3.2849
Within Groups	231.3893	33	7.011796		
Total	236.4694	35			

It can be seen from the ANOVA result on table 28 above that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the mean BOD_5 of water samples from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

Comparison of Mean Biochemical Oxygen Demand based on LGA's, water source and seasons



WHO, 2004 30mlg/l

FIG. 41: Comparison of mean 5-Day Biochemical Oxygen Demand (mg/l) of water samples based on LGA's, water source and season

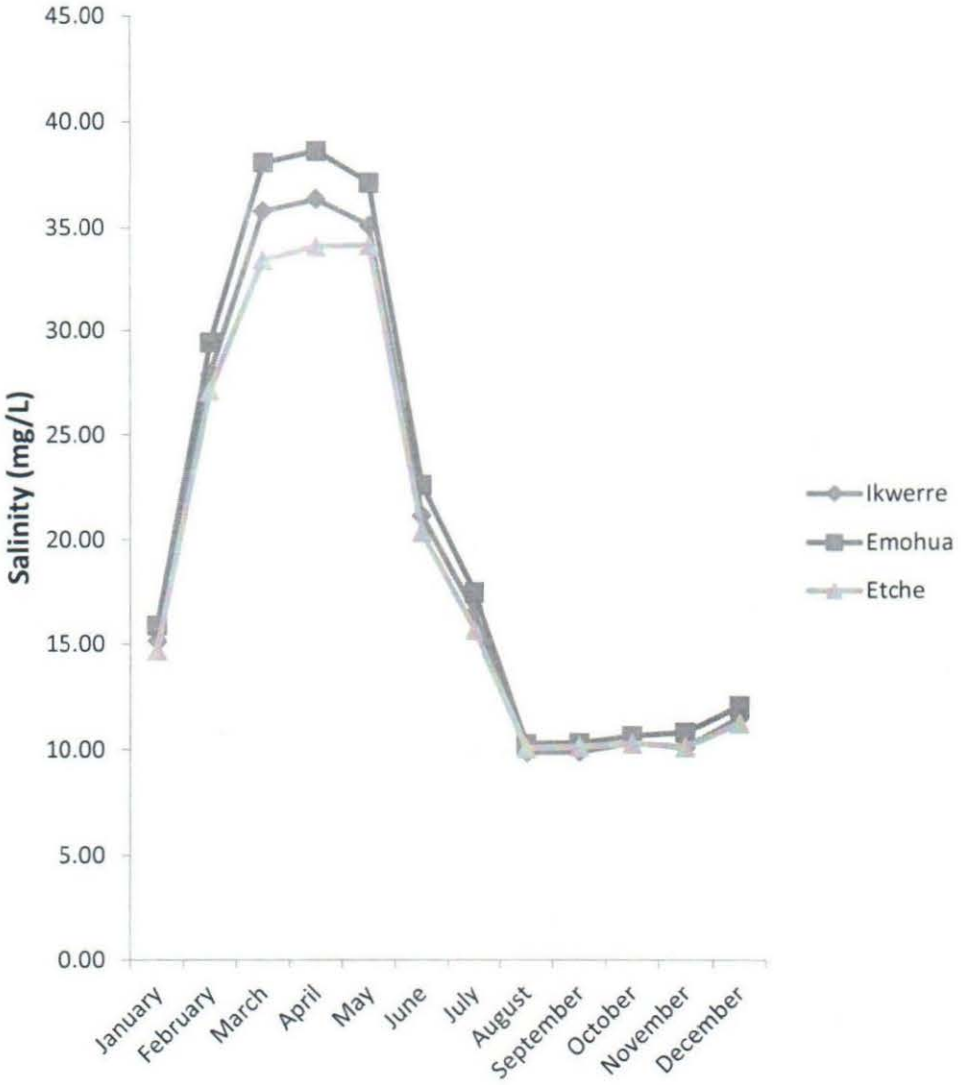


FIG. 42: Mean salinity of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 29

ANOVA of Mean Salinity of well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	239.4767	19.95639	119.2166
Emohua	12	253.125	21.09375	135.6738
Etche	12	231.1433	19.26194	103.0792

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	20.52542	2	10.26271	0.086008	3.284918
Within Groups	3937.666	33	119.3232		
Total	3958.191	35			

From the result on table 29, the calculated F value (0.086008) is less than the tabulated F(*F crit*) (3.284918). There is thus no significant difference between the salinity of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

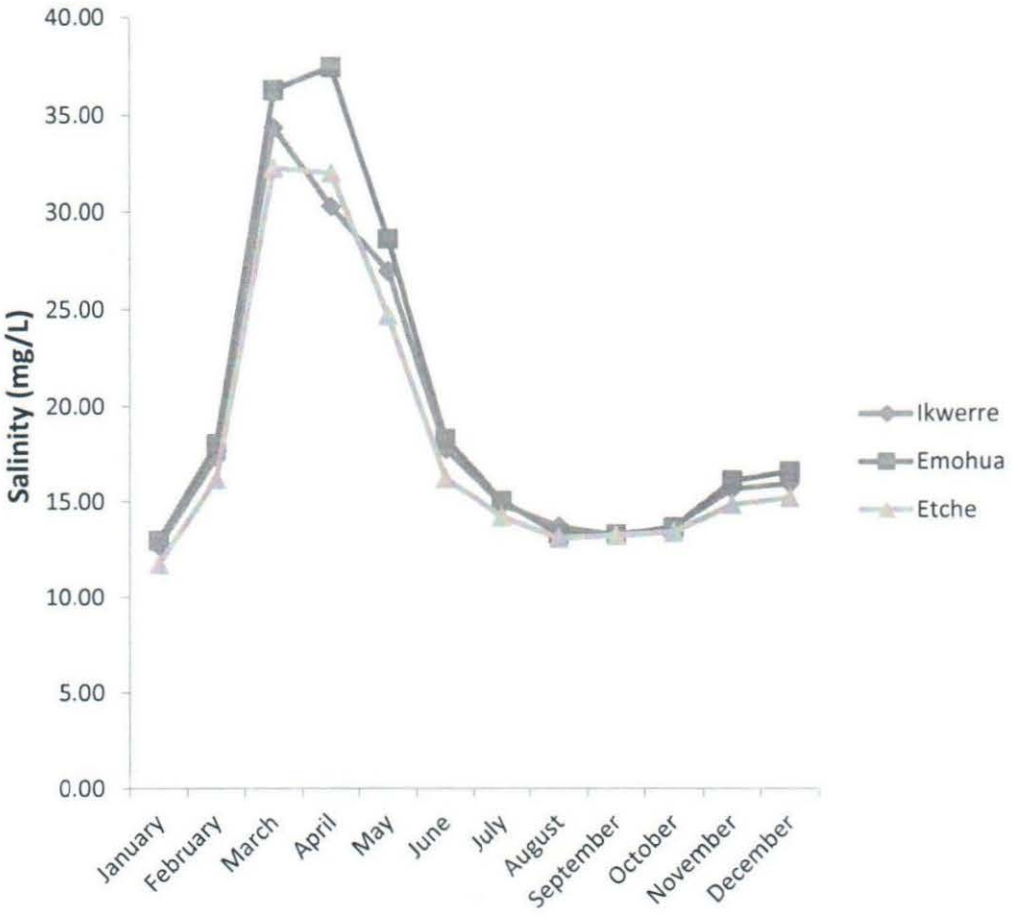


FIG. 43: Mean salinity of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 30

ANOVA of Mean Salinity of stream water samples.

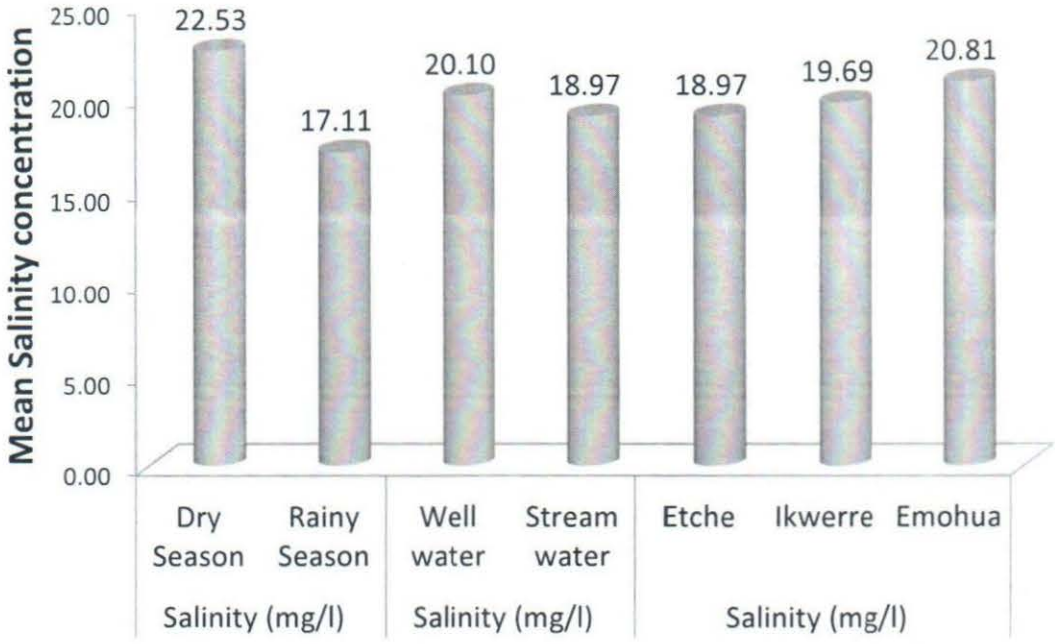
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	226.465	18.87208	54.30189
Emohua	12	239.495	19.95792	79.87832
Etche	12	217.085	18.09042	53.5733

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	21.11037	2	10.55519	0.168655	3.2849
Within Groups	2065.289	33	62.5845		
Total	2086.399	35			

The ANOVA result on table 30 shows that the calculated F (0.168655) is less than the tabulated F(*F crii*) 3.2849. There is thus no significant difference between the salinity of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.



WHO, 2004 250mlg/l

FIG. 44: Comparison of Mean Salinity concentration based on LGA's, water source and seasons

4.10.7 Comparison of mean chloride concentration based on LGA's, water source and seasons

The result of the mean comparison on figure 47 shows that the mean chloride content (mg/l) of well and stream water samples from Etche LGA was found to be 8.68±7.03 mg/l, Ikwerre LGA 9.29±7.68 mg/l and Emohua LGA was 9.94±7.69 mg/l. The result shows that the mean chloride content of well water was 10.32±8.46 mg/lwhereas the mean chloride content of stream water was6.24±3.09mg/l. The result of ANOVA shows there was significant difference based on water source ($F1, 286=16.017$, $p<0.05$). This indicates that the chloride content was significantly higher in the well water than in the stream water. The result shows that the mean chloride content of well and stream water samples from dry season was found to be 10.81±8.26mg/l whereas that of rainy season was 7.80±6.78 mg/l. The result of ANOVA shows there was significant difference based on season ($F1, 286=11.381$, $p>0.05$).

4.10.8 Comparison of Mean Iron concentration of water samples based on season, water-source and location

The result on figure 50 shows that the mean iron concentration (mg/l) of well and stream water samples from Etche LGA was found to be 0.32±0.40mg/l, that of Ikwerre LGA 0.34±0.44mg/l and Emohua LGA was 0.34±0.43 mg/l. The result shows that the mean iron concentration of well water was 0.39±0.47mg/l whereas the mean iron concentration of stream water was0.17±0.13mg/l. This indicates that the iron concentration was significantly higher in the well water than in the stream water. The result shows that the mean iron concentration (mg/l) of well and stream water samples from dry season was found to be 0.40±0.52mg/l whereas that of rainy season was 0.27±0.29 mg/l. Iron concentration was slightly higher during the dry season than in the wet season.

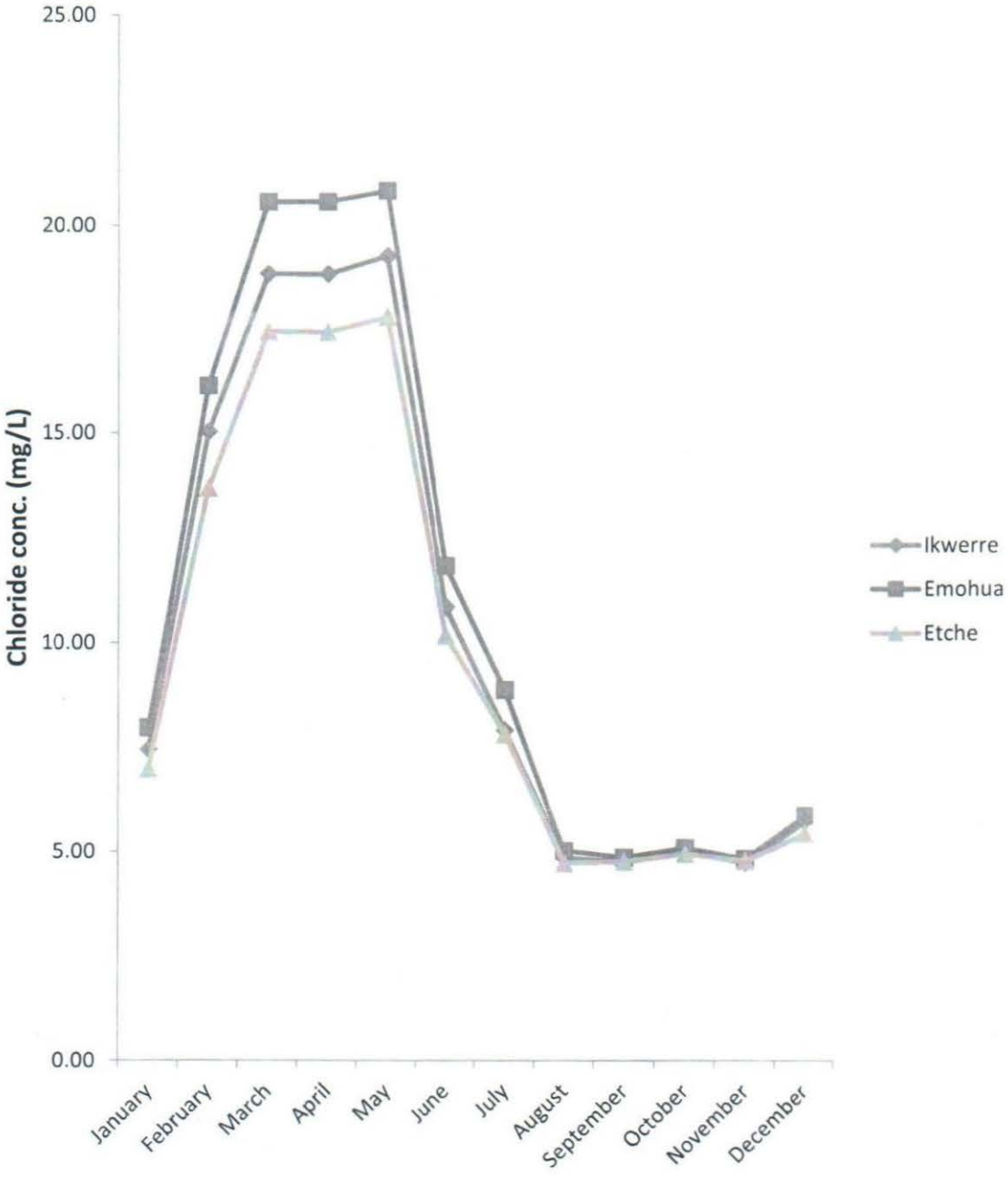


FIG.45: Mean chloride concentration of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 31

ANOVA of Mean Chloride concentration of well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	123.195	10.26625	36.48152
Emohua	12	132.4933	11.04111	44.78527
Etche	12	115.9833	9.665278	29.57518

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	11.41798	2	5.708989	0.154517	3.284918
Within Groups	1219.262	33	36.94732		
Total	1230.68	35			

From table 31, the ANOVA result shows that the calculated F (0.154517) is less than the tabulated F(*F crit*) 3.284918. There is thus no significant difference between the chloride concentration of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

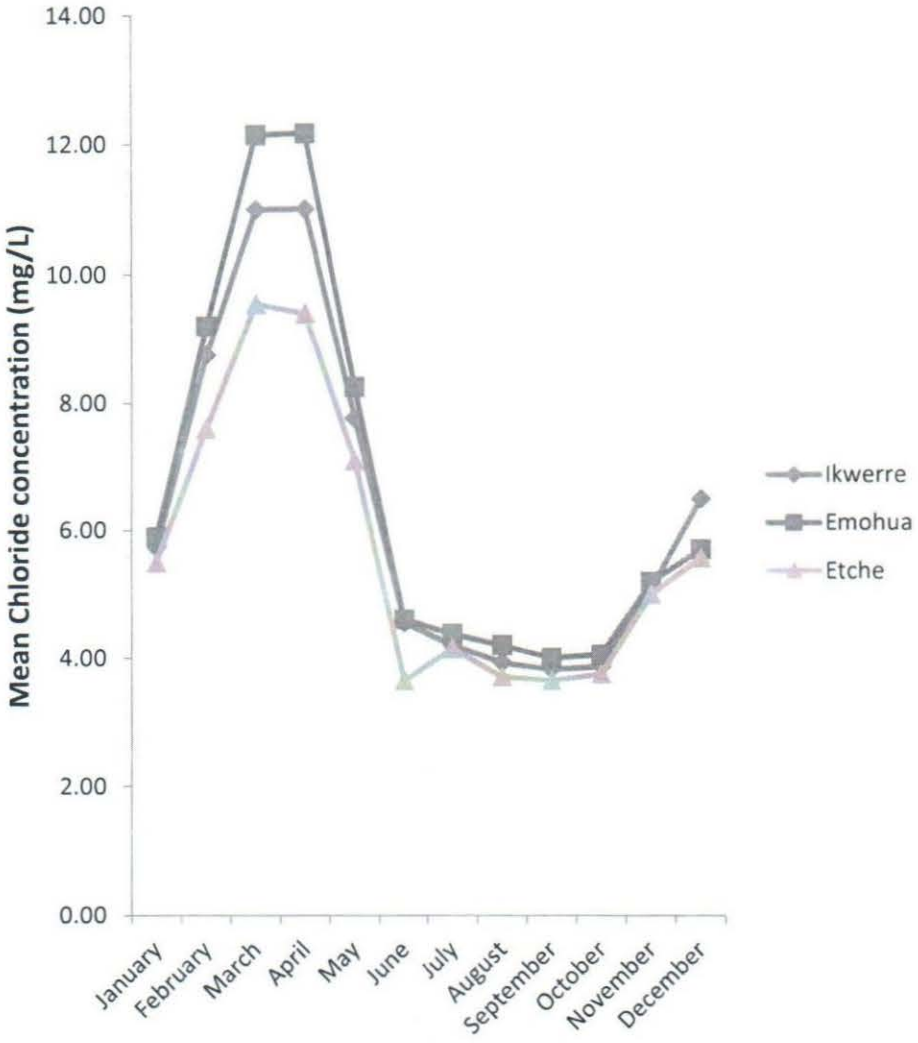


FIG. 46: Mean chloride concentration of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 32

ANOVA of Mean Chloride concentration from stream water samples

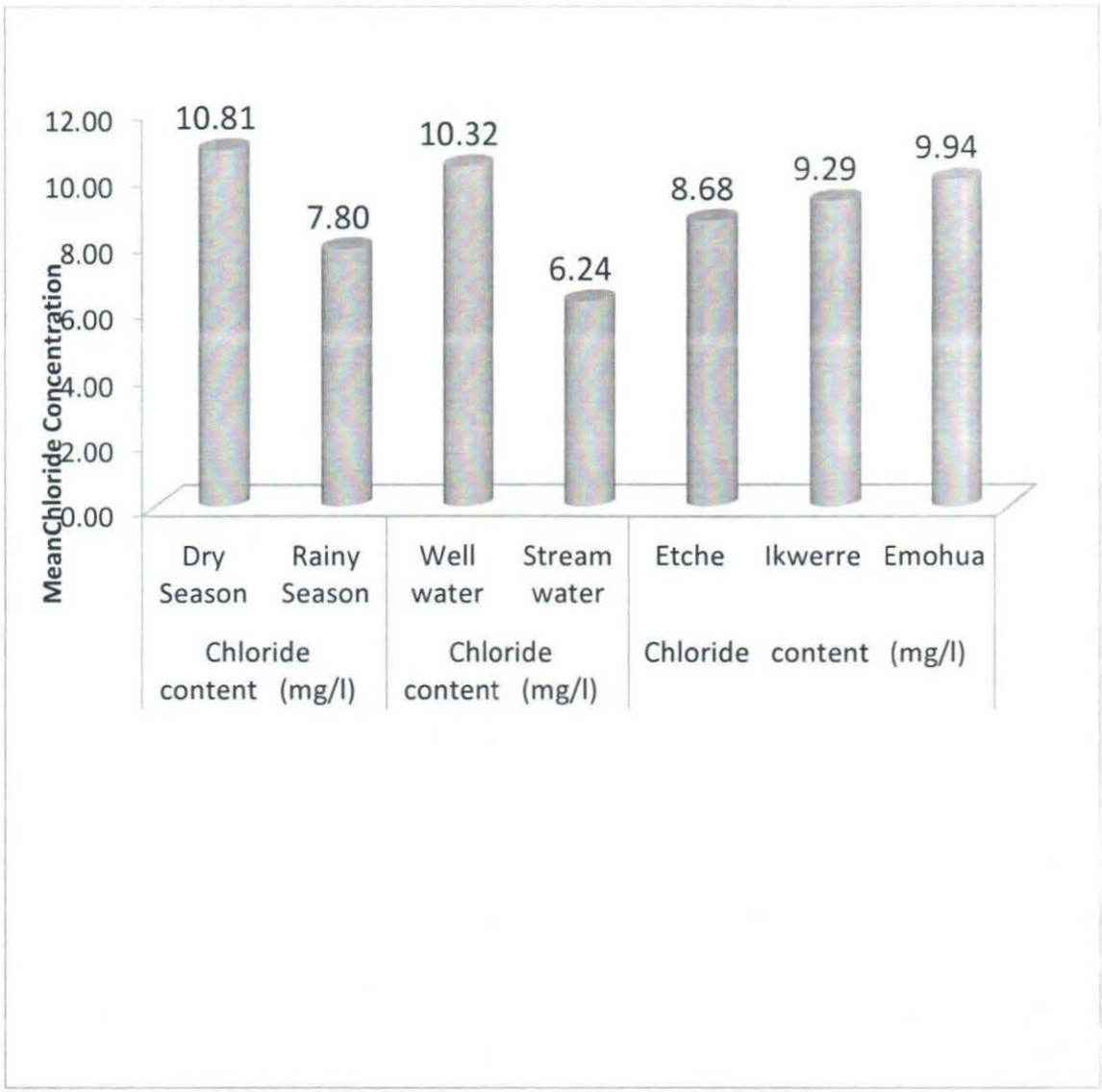
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	76.23	6.3525	7.20903
Emohua	12	79.825	6.652083	9.319257
Etche	12	68.64	5.72	4.844445

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	5.434343	2	2.717172	0.381398	3.2849
Within Groups	235.1	33	7.124244		
Total	240.5344	35			

The ANOVA result on table 32 shows that the calculated F (0.381398) is less than the tabulated F (*F crit*) 3.2849. There is thus no significant difference between the chloride concentration of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.



WHO, 2004 250mlg/l

FIG. 47: Comparison of mean chloride concentration (mg/l) of water samples based on LGA's water source and season.

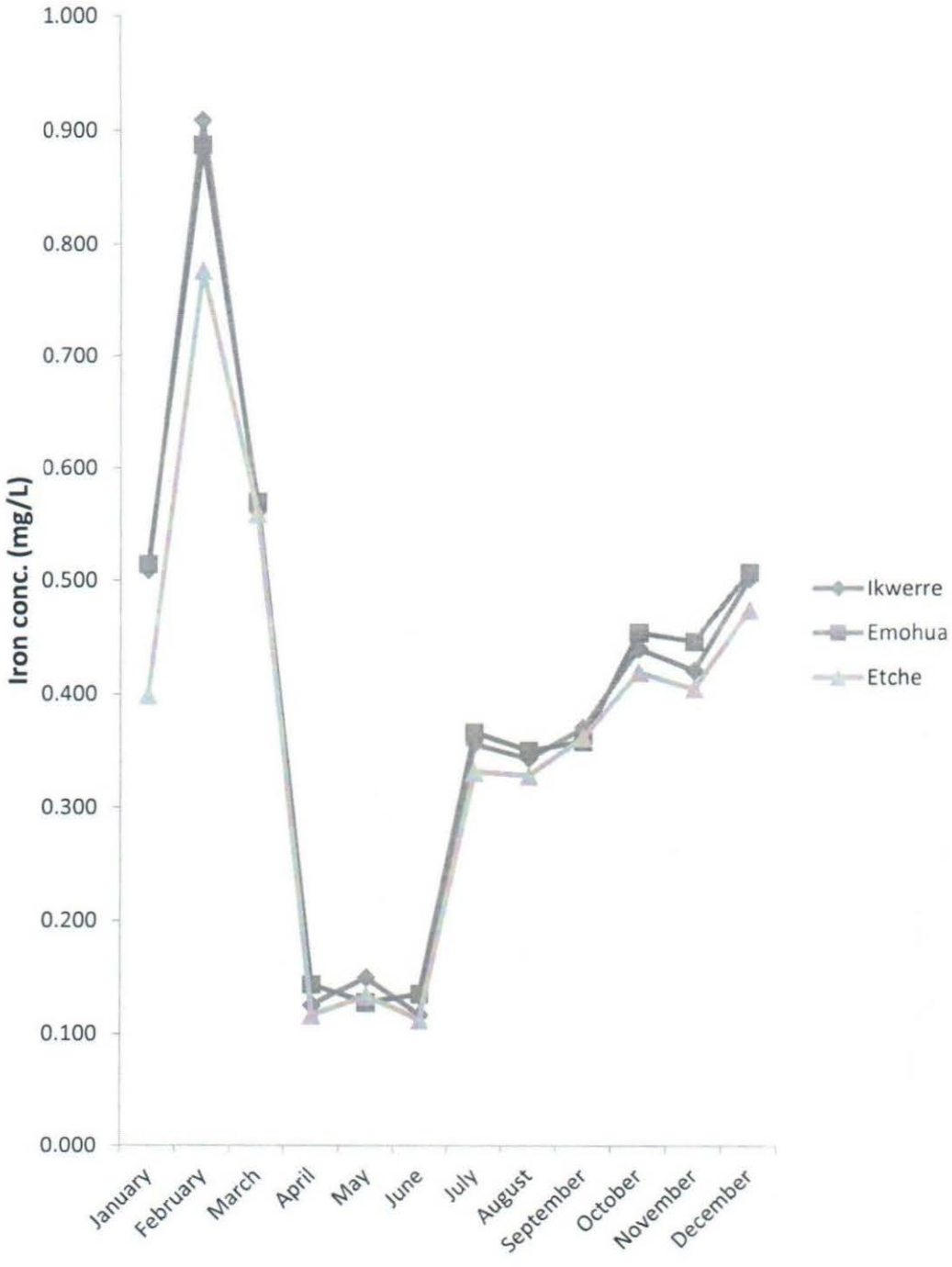


FIG. 48: Mean Iron concentration of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 33

ANOVA of Mean Iron concentration from well water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	4.801833	0.400153	0.048479
Emohua	12	4.860667	0.405056	0.046448
Etche	12	4.4162	0.368017	0.03689

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	0.009715	2	0.004857	0.110546	3.284918
Within Groups	1.449992	33	0.043939		
Total	1.459707	35			

The ANOVA result on table 33 shows that the calculated F (0.110546) is less than the tabulated F(*F crit*) 3.284918. There is thus no significant difference between the iron concentration of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

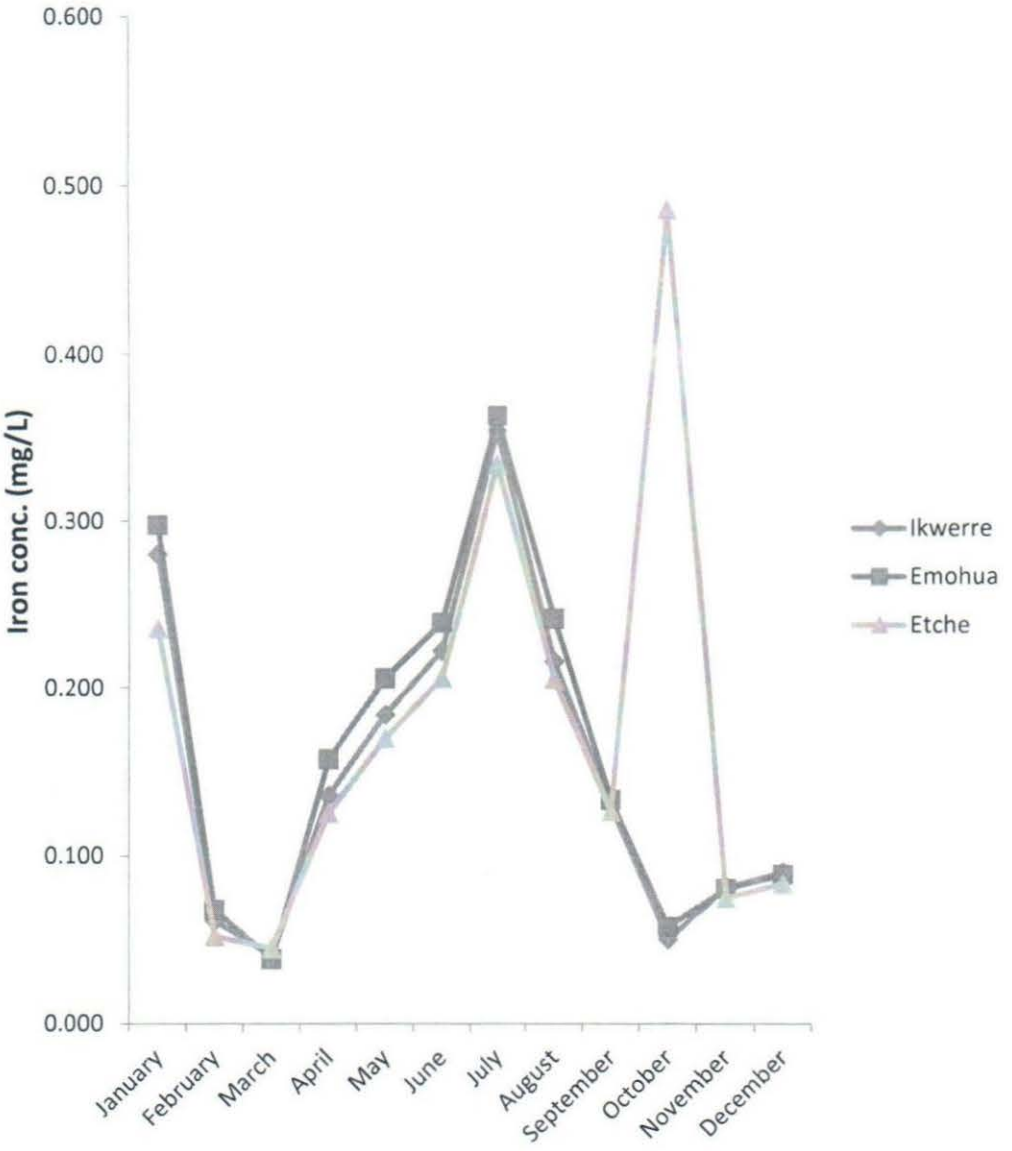


FIG. 49: Mean Iron concentration of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 34

ANOVA of Mean Total Iron concentration from stream water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	1.8465	0.153875	0.009793
Emohua	12	1.972	0.164333	0.010977
Etche	12	2.143	0.178583	0.016543

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	0.003692	2	0.001846	0.14841	3.2849
Within Groups	0.410445	33	0.012438		
Total	0.414137	35			

From table 34, the calculated F (0.14841) is less than the tabulated F(*F crit*) 3.2849. There is no significant difference between the iron concentration of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

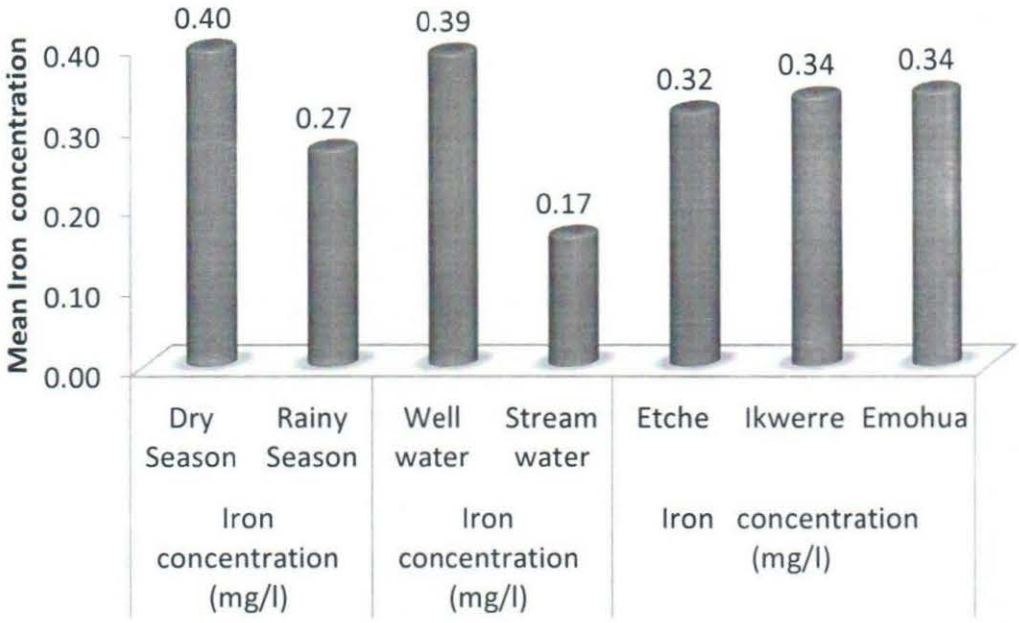


FIG. 50: Comparison of Mean Iron concentration of water samples based on season, water-source and location

4.10.9 Comparison of mean turbidity of water samples based on season, water-source and location

The result from figure 57 shows that the mean turbidity range (NTU) of well and stream water samples from Etche LGA was found to be 16.14±17.46 mg/l whereas that of Ikwerre LGA was 16.80±18.39 mg/l and mean turbidity range of Emohua samples was 17.46±18.98 mg/l. There was no significant difference in the turbidity ranges of the samples based on the LGA's. Based on type of water, the mean turbidity ranges NTU of well water was 17.70±20.90 NTU whereas the mean turbidity ranges of stream water was14.09±3.29 NTU. There is significant difference between the mean ranges (F1, 286=2.123, p>0.05). However, the turbidity ranges was slightly higher in the well water than in the stream water. The result shows that the mean turbidity range (NTU) of well and stream water samples from dry season was found to be 13.98±13.52mg/l whereas that of rainy season was 19.62±21.64mg/l. The result of ANOVA shows there was significant difference turbidity of the water samples based on season (F1, 286=7.049, p<0.05).

4.10.10 Comparison of Mean Calcium concentration (mg/l) of water samples based on LGA's, water source and season.

The result of the comparion on figure 60, shows that the mean calcium concentration (mg/l) of well and stream water samples from Etche LGA was found to be 11.63±25.86mg/l whereas that of Ikwerre LGA was 11.85±26.21mg/l and mean calcium concentration of Emohua LGA was 12.25±27.38 mg/l. There was significant difference in calcium concentration from the three LGA's (F2, 285=0.014, p>0.05).The mean calcium concentration of well water was 3.77±2.04mg/lwhile that of the stream water was36.35±44.70 mg/l.The calcium concentration was significantly higher in the stream water than in the well water. The result shows that the mean calcium concentration (mg/l) of well and stream water samples from dry season was found to be 15.35±34.13mg/l whereas that of rainy season was 8.48±14.50mg/l. There was significant difference of calcium concentration based on season (F1, 286=4.942, p<0.05).

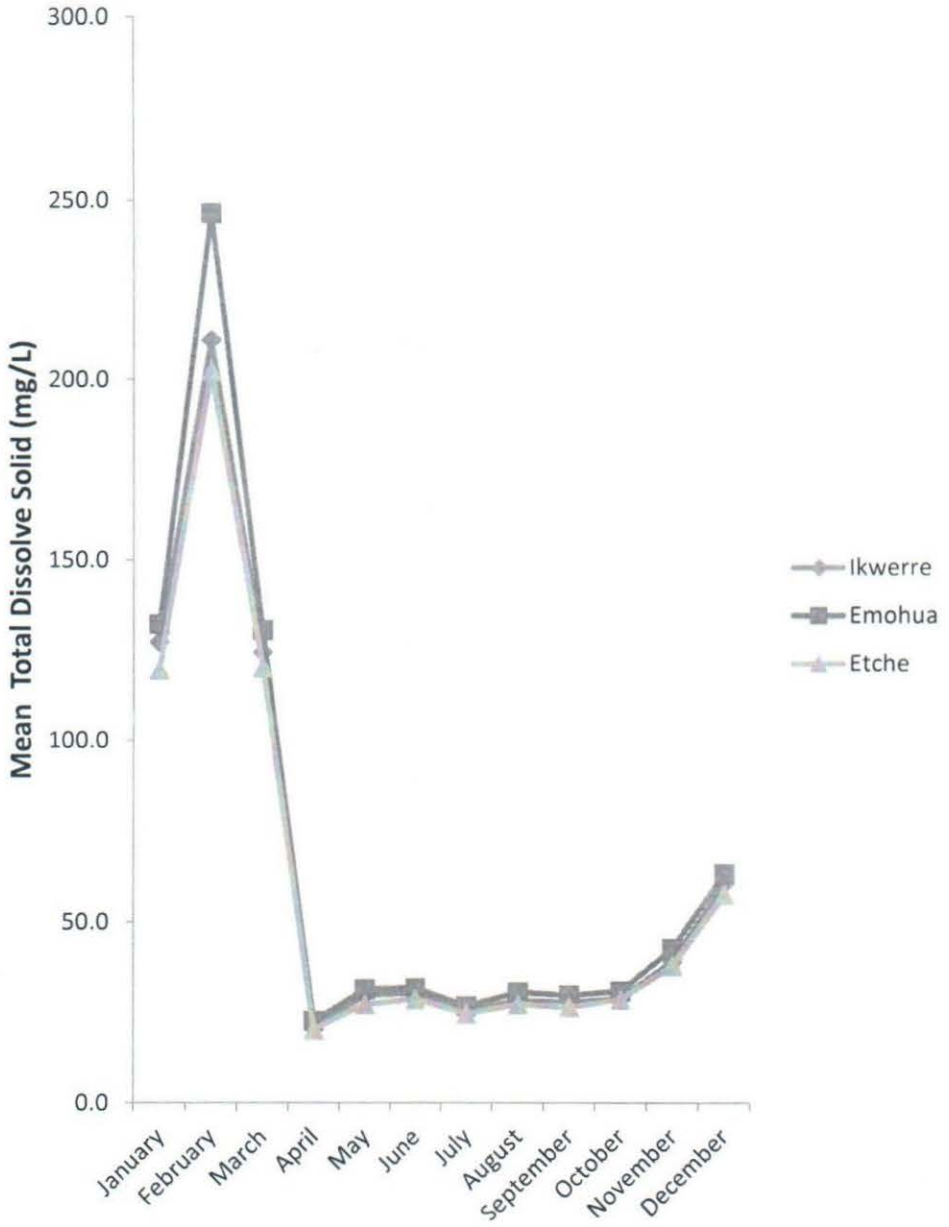


FIG. 51: Mean Total Dissolved Solids (TDS) of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 35

ANOVA of Mean Total Dissolved Solids (TDS) from well water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	754.5	62.875	3567.061
Emohua	12	819.3333	68.27778	4650.875
Etche	12	721.1667	60.09722	3267.336

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	415.3102	2	207.6551	0.05424	3.284918
Within Groups	126338	33	3828.424		
Total	126753.3	35			

The ANOVA result on table 35 shows that the calculated F (0.05424) is less than the tabulated F(*F crit*) 3.248918. There is thus no significant difference between the TDS in water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

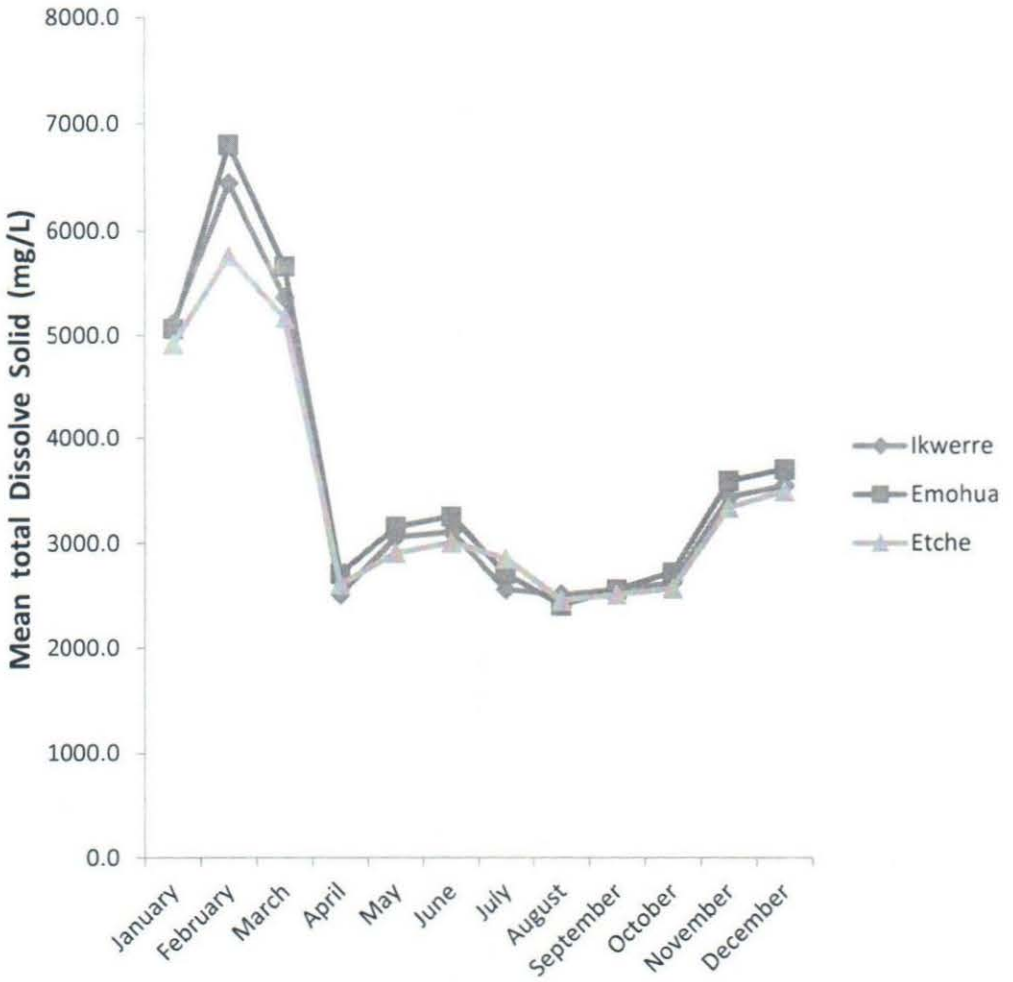


FIG.52: MeanTotal Dissolved Solids (TDS) of water samples from streams of Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 36

ANOVA of Mean Total Dissolved Solids (TDS) from stream water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	1.8465	0.153875	0.009793
Emohua	12	1.972	0.164333	0.010977
Etche	12	2.143	0.178583	0.016543

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	0.003692	2	0.001846	0.14841	3.2849
Within Groups	0.410445	33	0.012438		
Total	0.414137	35			

From table 36, the calculated F (0.14841) is less than the tabulated F(*F crit*). There is thus no significant difference between the iron concentration of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

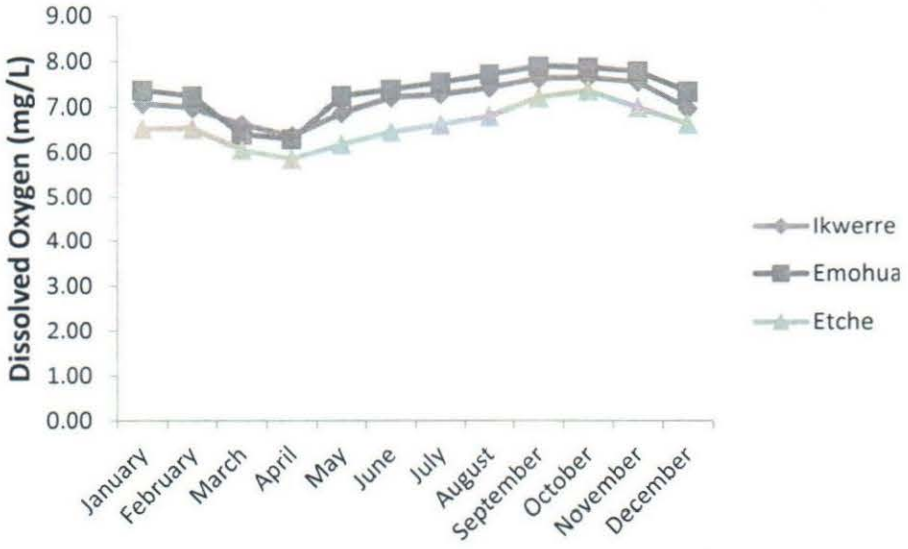


FIG. 53: Mean Dissolved Oxygen of water samples from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 37

ANOVA of Mean Dissolved Oxygen from well water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	85.54	7.128333	0.157157
Emohua	12	88.005	7.33375	0.265035
Etche	12	79.16833	6.597361	0.19825

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	3.465584	2	1.732792	8.378502	3.2849
Within Groups	6.824864	33	0.206814		
Total	10.29045	35			

From table 37, it can be seen that the calculated F is greater than the tabulated F (*F crit*). There is thus a significant difference between the dissolved oxygen of water from wells in Ikwerre, Emohua, and Etche LGA from January to December.

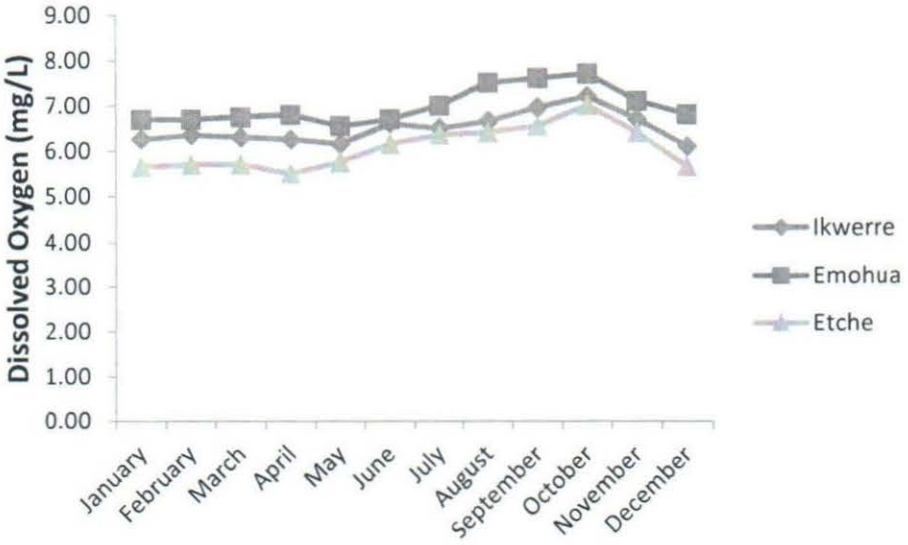


FIG. 54: Mean Dissolved Oxygen of water samples from streams in Ikwerre, Emohua, and Etche LGA of Rivers State.

TABLE 38

ANOVA of Mean Dissolved Oxygen concentration from stream water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	78	6.5	0.112273
Emohua	12	83.9	6.991667	0.156742
Etche	12	72.8	6.066667	0.222879

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	5.140556	2	2.570278	15.6758	3.2849
Within Groups	5.410833	33	0.163965		
Total	10.55139	35			

In Table 38 it can be seen that the calculated F is greater than the tabulated F (*F crit*). There is thus a significant difference between the dissolved oxygen of water from streams in Ikwerre, Emohua, and Etche LGA from January to December.

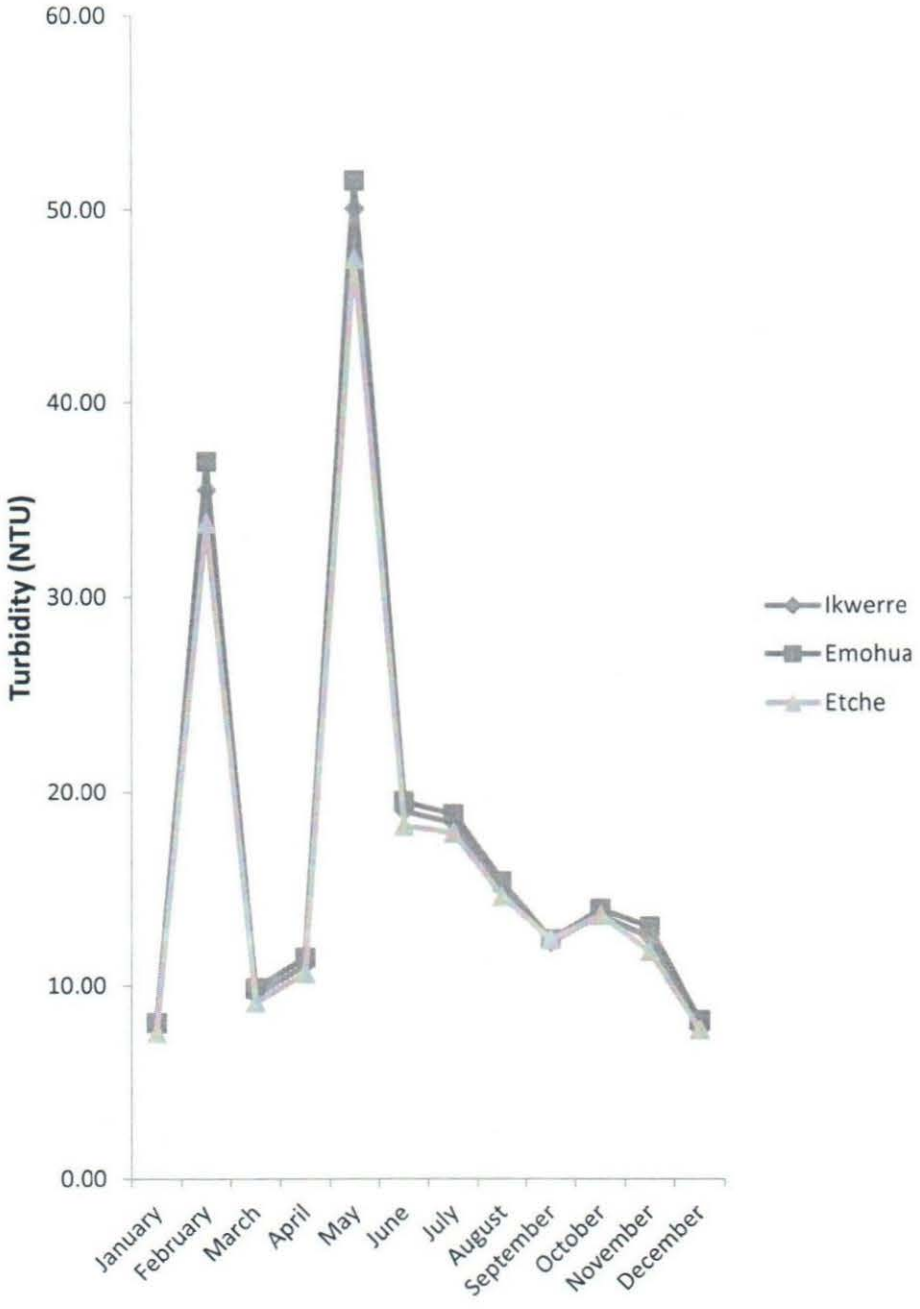


FIG. 55: Mean Turbidity of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 39

ANOVA of Mean Turbidity concentration from well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	212.7647	17.73039	159.0174
Emohua	12	219.472	18.28933	169.3774
Etche	12	205.0243	17.08536	140.9212

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	8.712115	2	4.356058	0.027845	3.284918
Within Groups	5162.477	33	156.4387		
Total	5171.189	35			

From the ANOVA result on table 39 it can be seen that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the turbidity of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

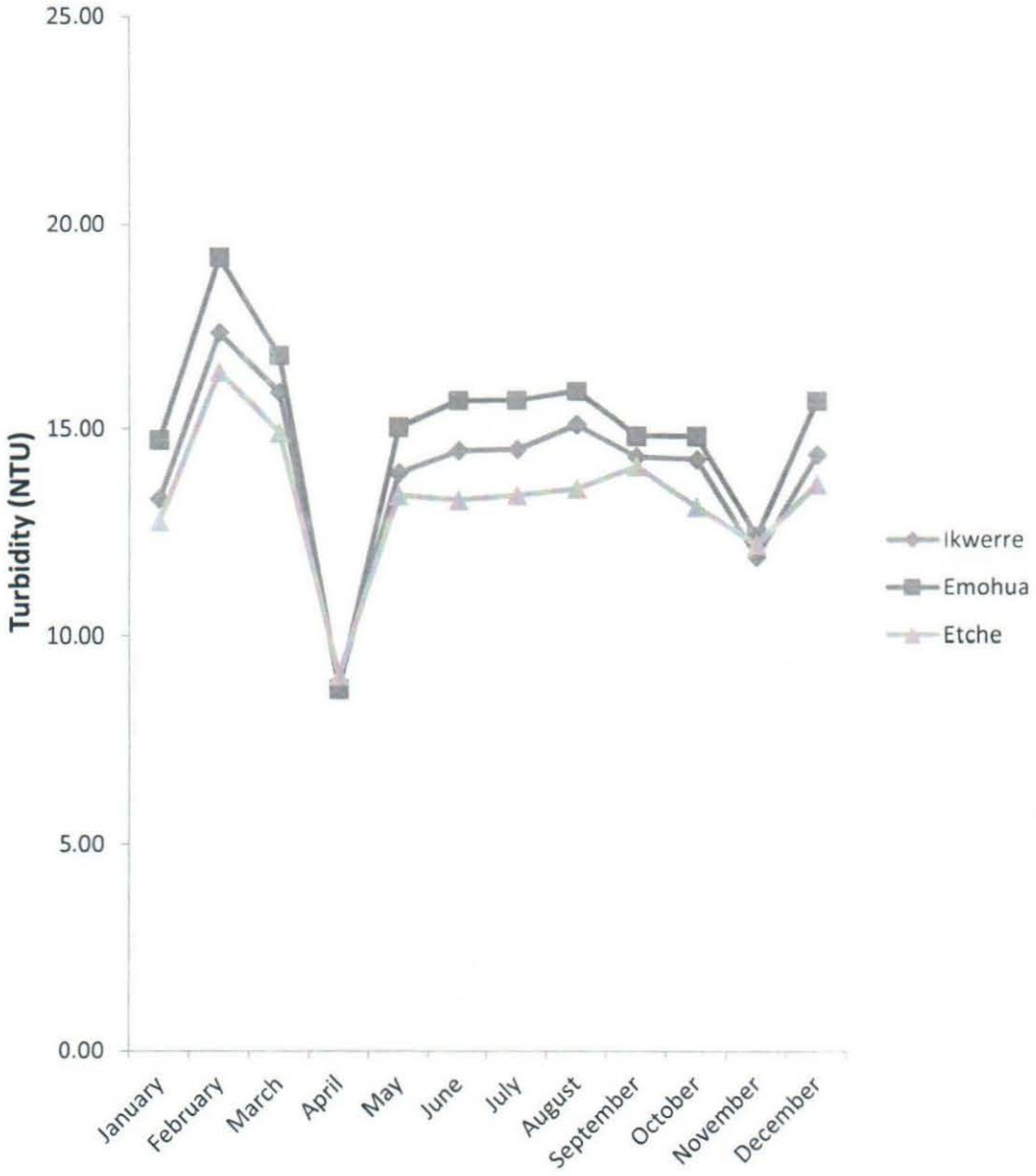


FIG. 56: Mean Turbidity of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 40

ANOVA of Mean Turbidity concentration from stream water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	168.18	14.015	4.388123
Emohua	12	179.455	14.95458	6.310429
Etche	12	159.745	13.31208	2.959766

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	16.29886	2	8.14943	1.789993	3.2849
Within Groups	150.2415	33	4.552773		
Total	166.5404	35			

The result of ANOVA on table 40 it can be seen that the calculated F is lesser than the tabulated F(*F crit*). There is thus no significant difference between the turbidity of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

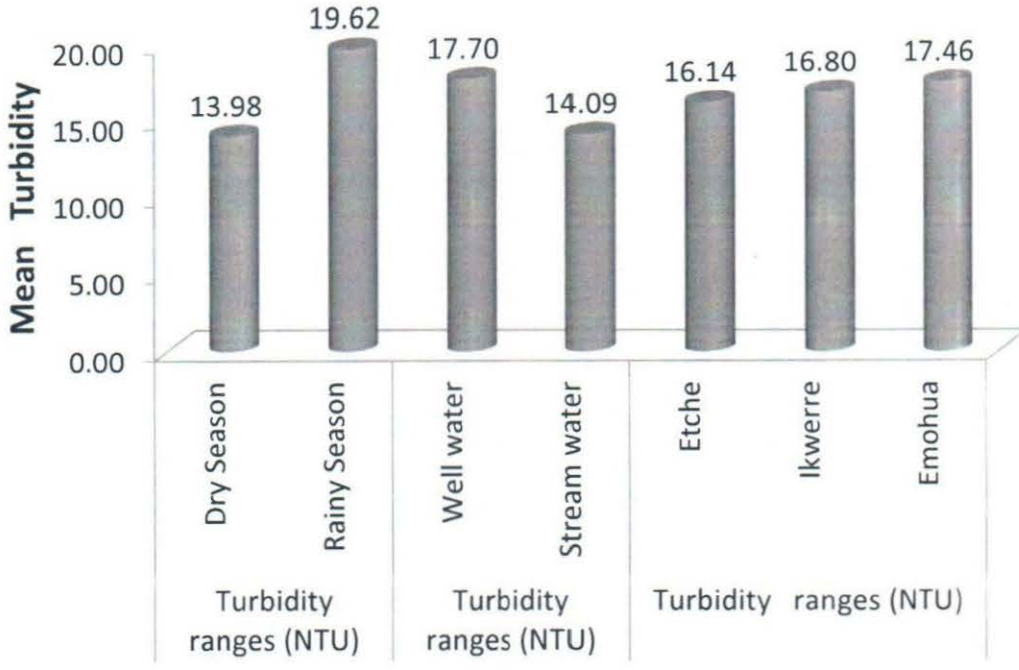


FIG. 57: Comparison of Mean Turbidity ranges (NTU) of water samples based on LGA's water source and season

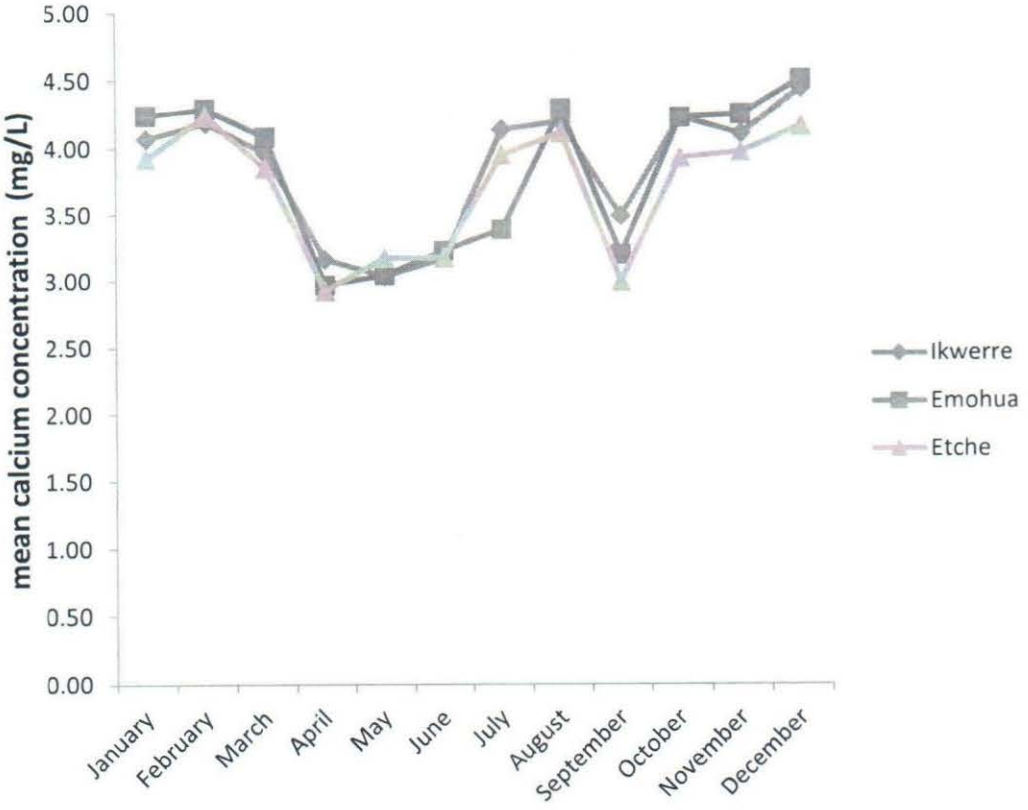


FIG. 58: Mean Calcium concentration of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 41

ANOVA of Mean Calcium concentration from well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	46.13917	3.844931	0.241364
Emohua	12	45.6687	3.805725	0.341416
Etche	12	44.35033	3.695861	0.23518

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	0.143315	2	0.071658	0.262816	3.284918
Within Groups	8.997562	33	0.272653		
Total	9.140878	35			

From the ANOVA result on table 41, it can be seen that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the calcium concentration of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

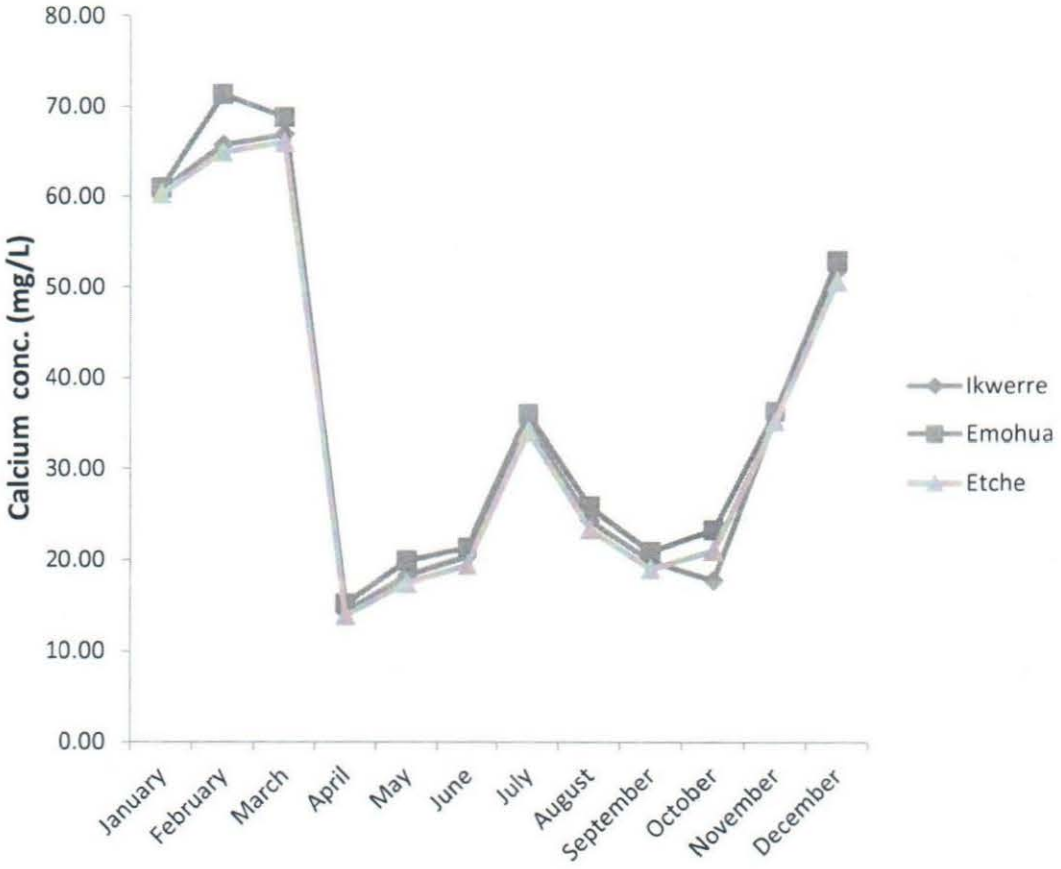


FIG. 59: Mean Calcium concentration of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 42

ANOVA of Mean Calcium concentration from stream water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	430.5495	35.87913	404.22
Emohua	12	452.793	37.73275	417.3616
Etche	12	425.078	35.42317	392.0434

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	35.912	2	17.956	0.044386	3.2849
Within Groups	13349.87	33	404.5417		
Total	13385.79	35			

From table 42, the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the calcium concentration of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

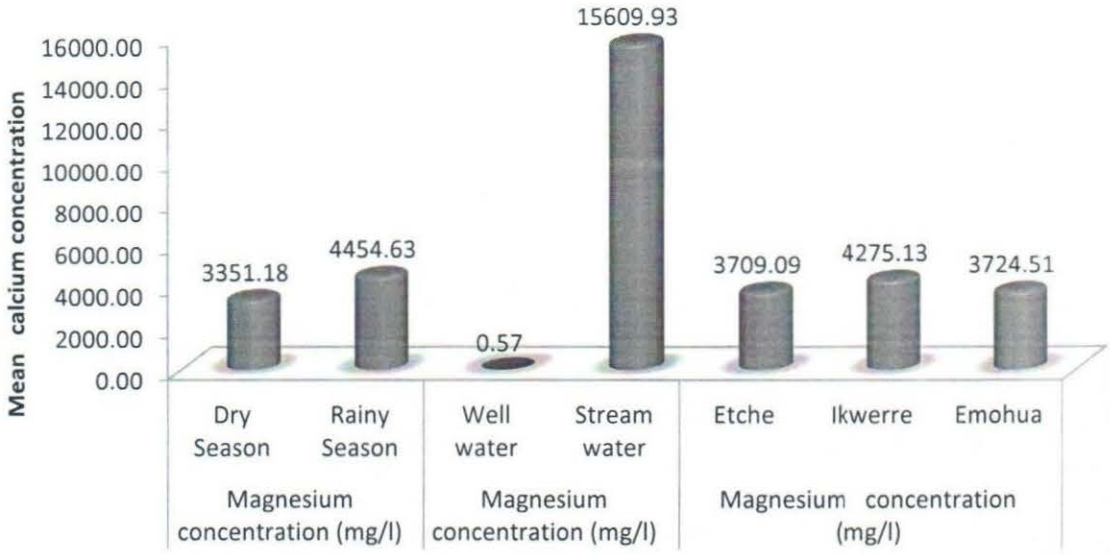


FIG. 60: Comparison of Mean Calcium concentration (mg/l) of water samples based on LGA's, water source and season.

4.10.11 Comparison of Mean Magnesium concentration (mg/l) of water samples based on LGA's, water source and season.

The result of the comparison on figure 63 shows that the mean magnesium concentration (mg/l) of well and stream water samples from Etche LGA was 3709.09±10700.83 mg/l, Ikwerre LGA was 4275.13±11737.64 mg/l and Emohua LGA was 3724.51±11362.08 mg/l. The result shows that the mean magnesium concentration of well water was 0.57±0.44mg/l whereas the mean magnesium concentration of stream water was15609.93±18035.00mg/l. This indicates that the magnesium concentration was significantly higher in the stream water than in the well water ($F1, 286=162.944, p<0.05$). The result shows that the mean magnesium concentration (mg/l) of well and stream water samples from dry season was found to be 3351.18±9224.30 mg/l, whereas that of rainy reason was 4454.63±12953.81mg/l. There was no significant difference in magnesium concentration based on season ($F1, 286=.693, p>0.05$).

4.10.12 Comparison of mean conductivity concentration (mg/l) of water samples based on LGA's, water source and season.

The result of the comparison on figure 66 shows that the mean conductivity of well and stream water samples from Etche Local Government Area, was found to be 1075.12±3089.072µs/cm, Ikwerre LGA was 1112.12±3200.80µs/cm and that of Emohua LGA was 1118.28±3269.81µs/cm. The result shows that the mean conductivity of well water was 32.89±15.94µs/cm whereas the mean conductivity of stream water was 4308.68±5184.37µs/cm. This indicates that the conductivity was higher in the stream water than in the well water. The result shows that the mean conductivity of well and stream water samples in dry season was found to be 1447.43±4025.09µs/cm whereas that of rainy season was 756.24±1951.22µs/cm. The conductivity was higher during the dry season than in the wet season.

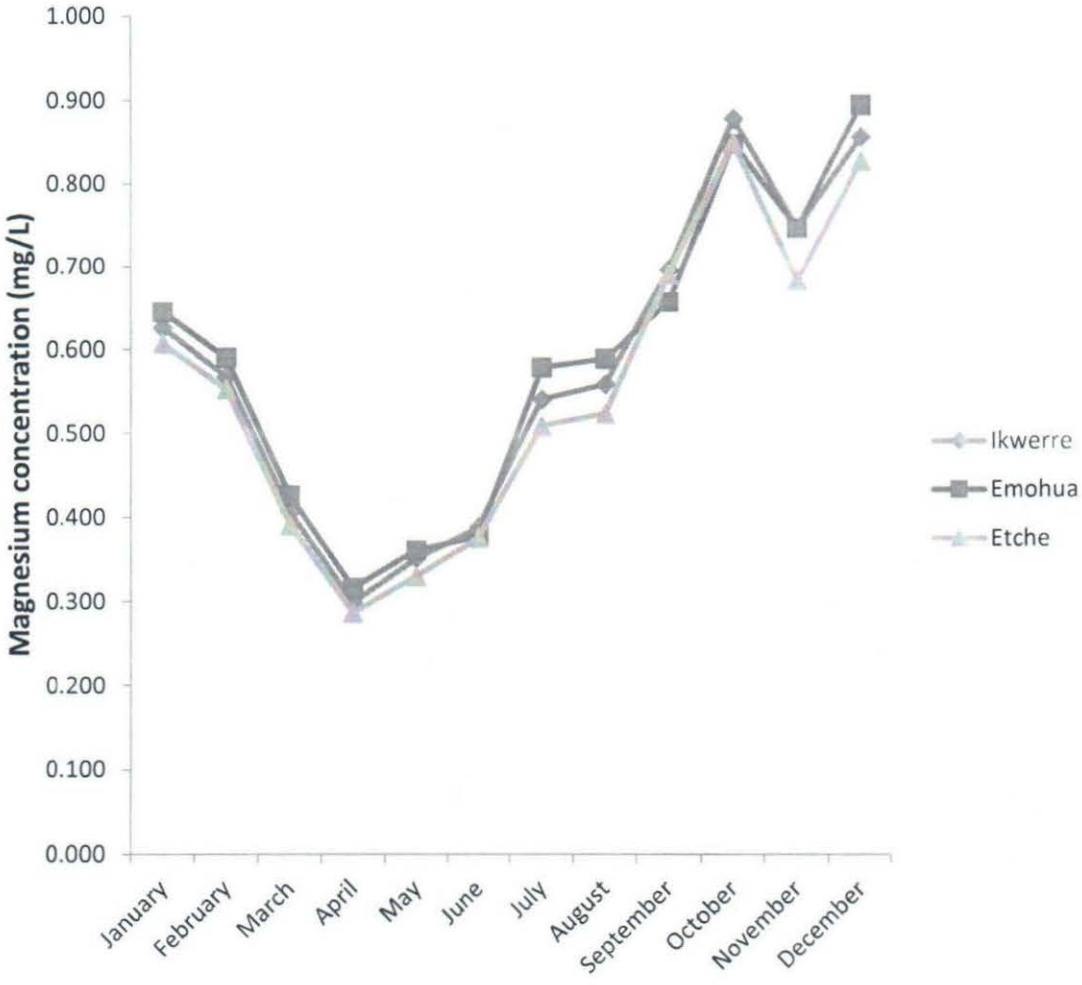


FIG. 61: Mean Magnesium concentration of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 43

ANOVA of Mean Magnesium concentration from well water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	6.914167	0.576181	0.037093
Emohua	12	7.029233	0.585769	0.03543
Etche	12	6.624833	0.552069	0.034676

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	0.007236	2	0.003618	0.10125	3.284918
Within Groups	1.179192	33	0.035733		
Total	1.186428	35			

From table 43, it can be seen that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the magnesium concentration of water from wells in Ikwerre, Emohua, and Etche LGA's from January to December.

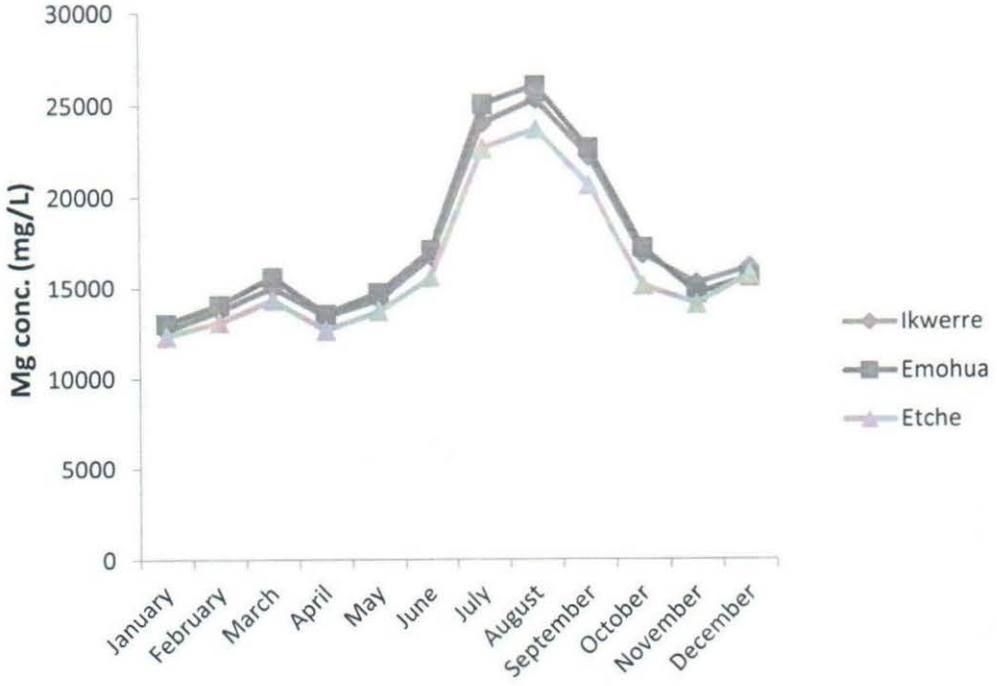


FIG. 62: Mean Magnesium concentration of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 44

ANOVA of Mean Magnesium concentration from stream water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	205185.4	17098.78	18393221
Emohua	12	208930.5	17410.87	20576773
Etche	12	193076.2	16089.68	15499239

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	11444950.81	2	5722475	0.315177	3.2849
Within Groups	599161563.5	33	18156411		
Total	610606514.3	35			

The ANOVA result on table 44 shows that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the magnesium concentration of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

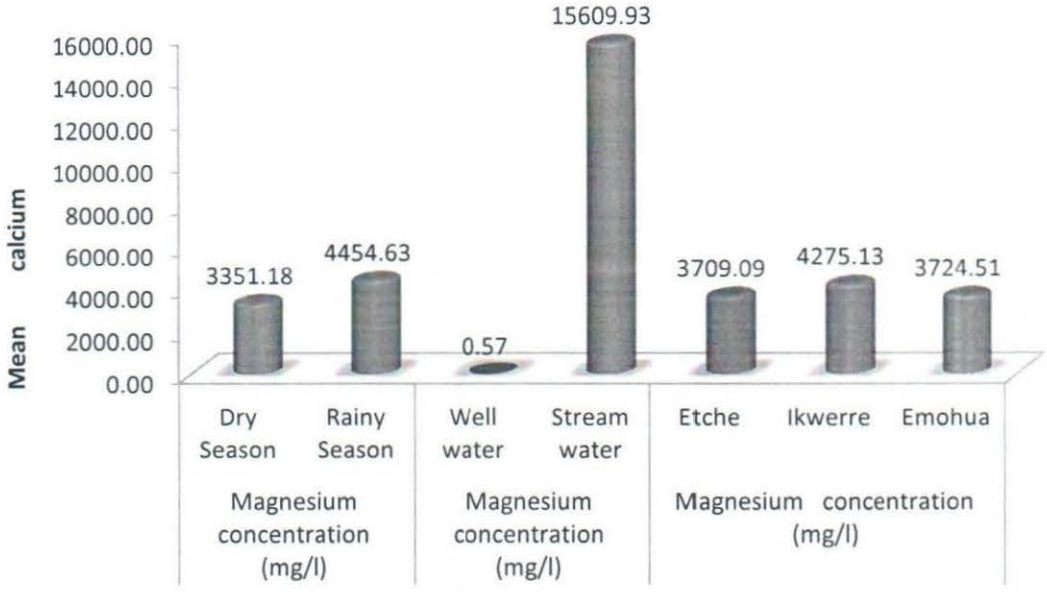


FIG. 63: Comparison of Mean Magnesium concentration (mg/l) of water samples based on LGA's, water source and season

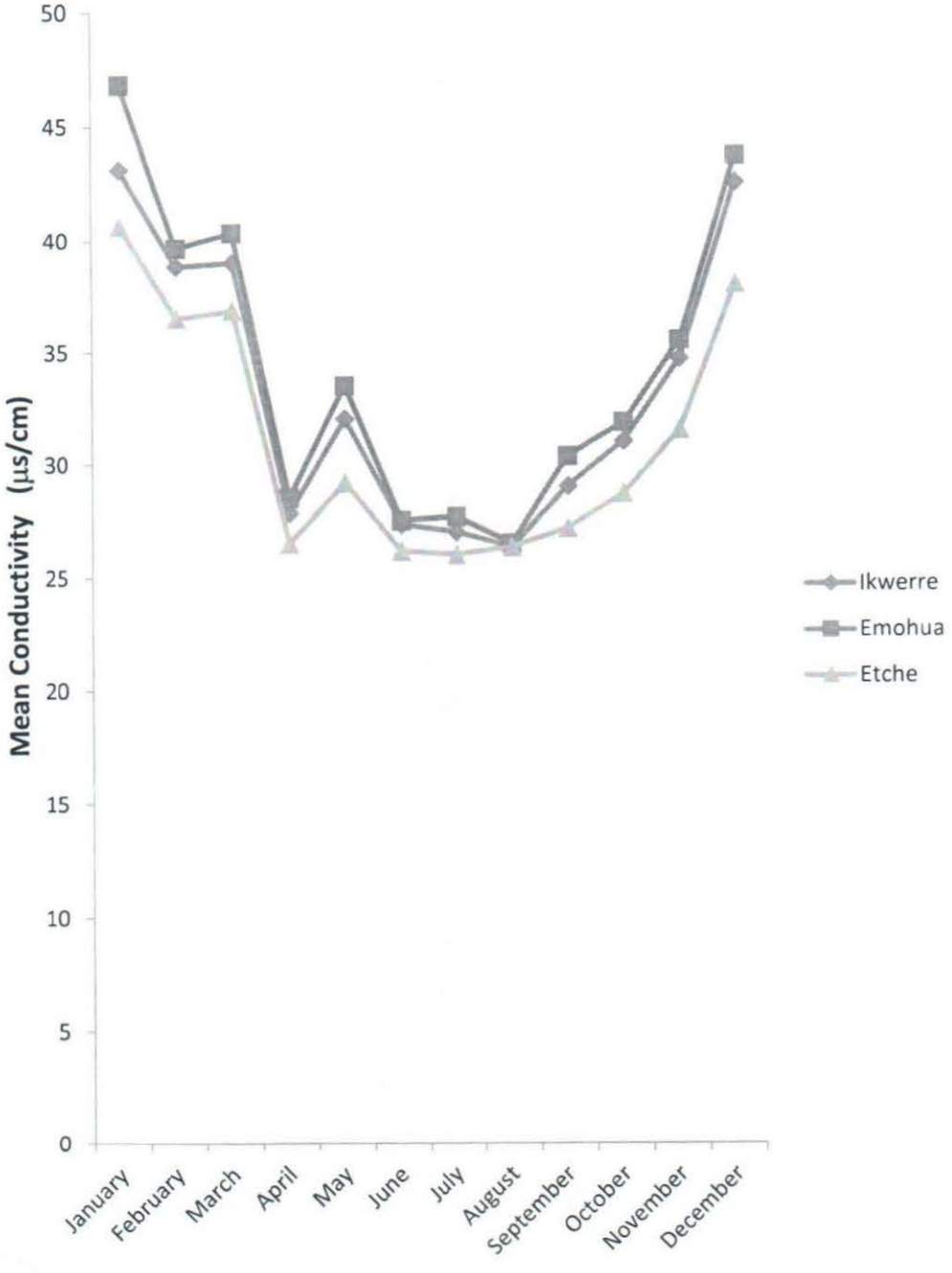


FIG. 64: Mean Conductivity of water from wells in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 45

ANOVA of Mean Conductivity from well water samples

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	398.6667	33.22222	38.73401
Emohua	12	411.8333	34.31944	47.14878
Etche	12	373.5	31.125	29.15215

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	63.22685	2	31.61343	0.824448	3.284918
Within Groups	1265.384	33	38.34498		
Total	**1328.611**	**35**			

From table 45, the ANOVA result shows that the calculated F is less than the tabulated F(*F crit*). There is no significant difference between the conductivity of water from wells in Ikwerre, Emohua, and Etche LGA'sfrom January to December.

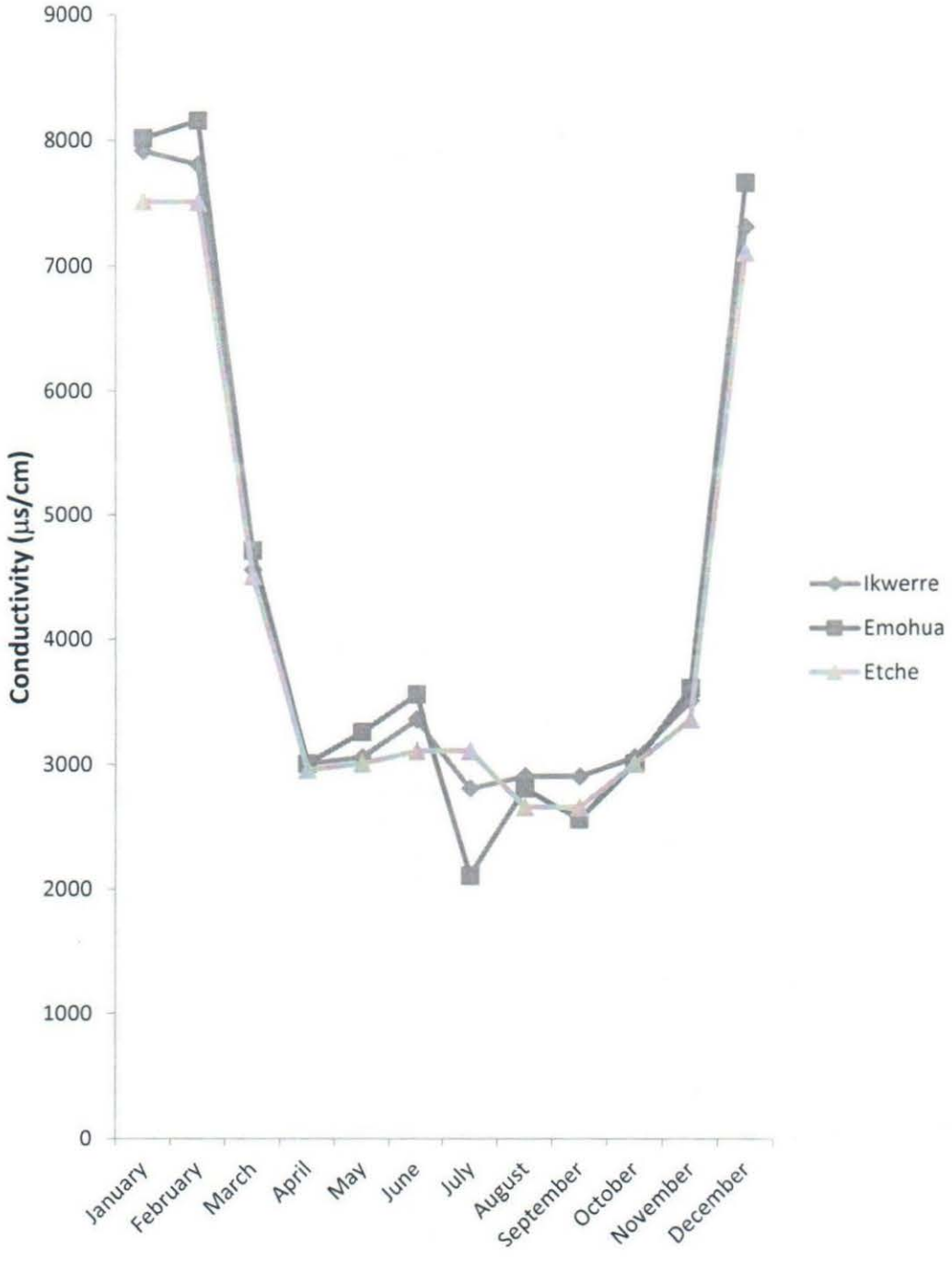


FIG. 65: Mean Conductivity of water from streams in Ikwerre, Emohua, and Etche LGA's of Rivers State.

TABLE 46

ANOVA of Mean Conductivity of stream water samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Ikwerre	12	52185.5	4348.792	4260015
Emohua	12	52442	4370.167	5057307
Etche	12	50485	4207.083	3884409

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*F crit*
Between Groups	188537.2639	2	94268.63	0.021422	3.2849
Within Groups	145219045.8	33	4400577		
Total	**145407583.1**	**35**			

From table 46 above, it can be seen that the calculated F is less than the tabulated F(*F crit*). There is thus no significant difference between the conductivity of water from streams in Ikwerre, Emohua, and Etche LGA's from January to December.

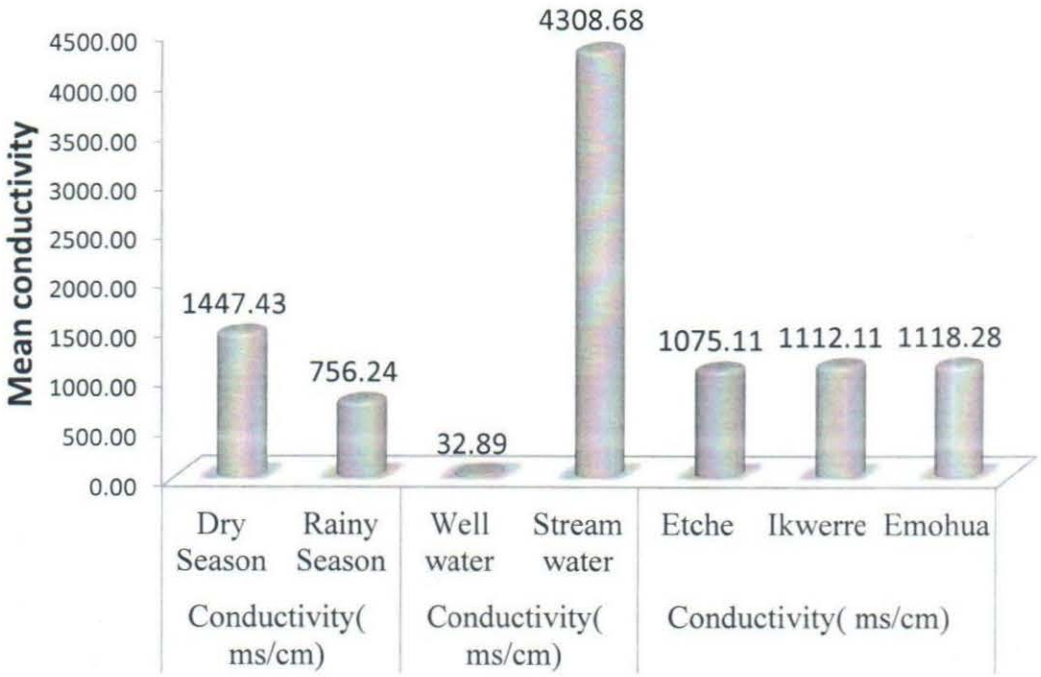


FIG. 66: Comparison of Mean Conductivity(μs/cm) of well and stream water samples.

4.11 Heavy metals concentrations of well and stream water samples from Ikwerre, Emohua and Etche LGA's of Rivers State

4.11.1 Concentration (ppm) of Lead (Pb) in well and stream water samples.

The mean concentrations of lead (Pb) detected in the water samples from Emohua, Etche and Ikwerre LGAs are presented in tables 47, 48 and 49 respectively. From table 47 in Emohua LGA, the lead level ranged from <0.001 to 0.23 pp for the dry season, an d ND-0.02 to ND-0.065 ppm in the wet season.

For Etche LGA (table 48) the lead (pb) concentration was between <0.001 to 0.17pm in the dry season, and ND-0.020 to ND-0.251 ppm. Whereas in Ikwerre LGA (Table 49). The values ranged from ND-0.001 to 0.20 pm for the dry season and ND-0.022 to ND – 0.313ppm during the wet season.

Lead concentration was highest in stream water samples from Emohua LGA (ppm) during the dry season, followed by Ikwerre LGA (0.20ppm) and Etche LGA (0.17 ppm). It was generally not detected ruing the wet season.

4.11.2 Copper (cu) Concentration (ppm) of well and stream water samples.

The concentrations of copper (cu) detected from well and stream water samples from Emohua, Etche and Ikwerre LGA's are shown on tables 50, 51 and 52 respectively.

In Emohua LGA (table 50), copper level was highest in site 6 (0.17 ppm) during the dry season, while the wet season had from <0.001 to 10.003 ppm).
The concentration of copper in Etche LGA (Table 51) ranged between <0.001 to 0.3 ppm in the dry season, and <0.001 to <0.002 for the wet season.

In Ikwerre LGA (table 52),the level of copper was higher in site 6 (0.15ppm) during the wet season, and between <0.001 to <0.002 for the wet season.

TABLE 47

Lead (Pb) concentration (ppm) of water samples from Emohua Local Government Area, Rivers State

Sample Site	Dry season	Wet season
1	<0.001	ND - 0.025
2	<0.001	ND - 0.045
3	<0.001	ND - 0.043
4	<0.001	ND - 0.046
5	<0.001	ND - 0.065
6	ND - 0.002	ND - 0.036
7	0.16	ND - 0.315
8	0.23	ND - 0.260

ND = Not Detected
WHO (2004) 0.01mg/l

TABLE 48
Lead (Pb) concentration (ppm) of water samples from Etche Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	<0.001	ND - 0.020
2	<0.001	ND - 0.035
3	<0.001	ND - 0.035
4	<0.001	ND - 0.040
5	<0.001	ND - 0.054
6	ND - 0.001	ND - 0.030
7	0.12	ND - 0.310
8	0.17	ND - 0.251

ND = Not Detected

WHO (2004) 0.01mg/l

TABLE 49

Lead (Pb) concentration (ppm) of water samples from Ikwerre Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	<0.001	ND - 0.022
2	<0.001	ND - 0.040
3	<0.001	ND - 0.039
4	<0.001	ND - 0.041
5	<0.001	ND - 0.061
6	ND - 0.001	ND - 0.032
7	0.14	ND - 0.313
8	0.20	ND - 0.255

ND = Not Detected
WHO (2004)0.01mg/l

4.11.3 Concentration of Zinc (Zn) from well and stream water samples.

The concentrations of zinc detected from the analysis of water samples from Etche, Emohua and Ikwerre LGA's are shown on tables 52, 53 and 54 respectively. From table 53 in Etche LGA, water samples from site 8 had the highest concentration of 0.23ppm, with the lowest value of 0.001ppm in site 5 during the dry season. The wet season recorded zinc concentrations of <0.001ppm to 0.030ppm. The zinc level from well and stream water samples in Emohua LGA (Table 54), ranged between <0.001ppm to 0.042ppm during the dry season. The highest concentration of 0.16ppm was detected in water samples from site 1. The concentration of zinc detected in Ikwerre LGA (Table 55) shows that sample site 1 had the highest value of 0.14ppm in the dry season 0.005ppm during the wet period.

4.11.4 Concentration of Cadmium (Cd) from well and stream water samples.

The concentrations of Cadmium obtained in water samples from Etche, Ikwerre and Emohua LGA's are presented on tables 55, 56, and 57 respectively. In Etche LGA, sample site 7 and 8 had the highest level (0.02ppm) of cadmium during the dry season. For the season, the cadmium concentration ranged from ND -<0.001 to -<0.016ppm. In Ikwerre LGA, table 57 shows that during the wet season, the concentration was between ND-<0.001 to <0.001ppm. Whereas, in the dry season the level of cadmium rose from <0.001 to 0.03ppm in the dry season with sample site 8 having the highest concentration.

4.11.5 Concentration of Nickle (Ni) from well and stream water samples.

Tables 58, 59 and 60 shows the concentration of Nickle detected from water samples in Etche, Ikwerre and Emohua LGA's respectively. In Etche LGA, table 58 indicates that Nickle concentration was highest in sample site 1 (2.015ppm) and lowest in site 3, 4 and 5 (<0.001ppm) during the dry season. During the wet season, the concentration ranged from <0.001ppm in site 1, 2, 3 and 5 to o.15 in site 8. From Ikwerre LGA, the concentration of Nickle was between <0.001 in sample site 3 and 4, and highest in site 1 and 2 with 2.020 and 2.017ppm respectively. For Emohua LGA, Nickle concentration was between <o.oo1 to 2.023ppm during the dry season, while the concentration dropped from <0.001 to 0.162ppm in the wet season.

4.11.6 Concentration of Mercury (Hg) in well and stream water samples.

The concentration of Mercury obtained from the analysis of well and stream water samples are presented on tables 61, 62 and 63 respectively. In Etche LGA, table 61 indicates that the levels of mercury ranged from -<0.001ppm in site 3 to -<0.15 in site 6 during the dry season. The concentration was higher during the wet <0.15ppm in site 5, while the lowest value of -<0.001ppm was recorded in site 1. For Ikwerre LGA, the concentration ranged from -<0.001ppm in site 2 to 0.001ppm in site 6, 7,and 8 (table 62). Table 63 reveals that the concentration of mercury from Emohua LGA was between 0.001ppm to 0.14ppm during the dry season, whereas the values dropped during the wet season.

TABLE 50

Copper (Cu) concentration (ppm) of water samples from Emohua Local Government Area, Rivers State

Sample Site	Dry Season	Wet Season
1	<0.001	<0.001
2	ND –< 0.001	<0.001
3	<0.001	<0.001
4	<0.001	<0.001
5	<0.001	<0.001
6	0.17	<0.002
7	0.12	<0.003
8	0.13	<0.002

ND = Not Detected

WHO (2004) 2 mg/l

TABLE 51

Copper (Cu) concentration (ppm) of water samples from Etche Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	ND –< 0.001	<0.001
2	<0.001	<0.001
3	<0.001	<0.001
4	<0.001	<0.001
5	<0.001	<0.001
6	0.13	<0.001
7	0.11	<0.001
8	0.12	<0.002

ND = Not Detected

WHO (2004) 2 mg/l

TABLE 52

Copper (Cu) concentration (ppm) of water samples from Ikwerre Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	<0.001	<0.001
2	ND –< 0.001	<0.001
3	<0.001	<0.001
4	<0.001	<0.001
5	<0.001	<0.001
6	0.15	<0.002
7	0.12	<0.002
8	0.12	<0.002

ND = Not Detected

WHO (2004) 2 mg/l

TABLE 53

Zinc (Zn) concentration (ppm) of water samples from Etche Local Government Area, Rivers State

Sample Site	Dry Season	Wet Season
1	0.012	0.005
2	0.003	ND –< 0.014
3	ND –< 0.002	0.001
4	ND –< 0.005	<0.041
5	<0.001	<0.010
6	0.11	<0.001
7	0.021	0.02
8	0.23	0.030

WHO (2004) 3 mg/l

ND: Not Detected

TABLE 54

Zinc (Zn) concentration (ppm) of water samples from Emohua Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	0.16	0.007
2	0.005	ND –< 0.017
3	ND –< 0.002	<0.001
4	ND –< 0.009	<0.042
5	<0.001	<0.013
6	0.12	<0.001
7	0.025	0.003
8	0.026	0.035

WHO (2004) 3 mg/l

ND: Not Detected

TABLE 55

Zinc (Zn) concentration (ppm) of water samples from Ikwerre Local Government Area, Rivers State

Sample Site	Dry Season	Wet Season
1	0.14	0.005
2	0.004	ND –< 0.015
3	ND –< 0.002	<0.001
4	ND –< 0.007	<0.040
5	<0.001	<0.013
6	0.12	<0.001
7	0.023	0.002
8	0.025	0.033

WHO (2004) 3 mg/l
ND: Not Detected

TABLE 56

Cadmium (Cd) concentration (ppm) of water samples from Etche Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	ND –< 0.001	< 0.001
2	ND –< 0.001	–< 0.001
3	ND –< 0.001	ND –< 0.001
4	< 0.001	ND –< 0.001
5	< 0.001	ND –< 0.001
6	< 0.001	ND –< 0.001
7	0.02	ND –< 0.020
8	0.02	ND –< 0.016

WHO (2004) 3 mg/l

ND = Not Detected

TABLE 57

Cadmium (Cd) concentration (ppm) of water samples from Ikwerre Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	< 0.001	< 0.001
2	< 0.001	ND –< 0.001
3	< 0.001	ND –< 0.001
4	ND –< 0.001	< 0.001
5	ND –< 0.001	ND –< 0.001
6	ND –< 0.001	ND –< 0.001
7	0.02	ND –0.021
8	0.03	ND – 0.018

WHO (2004) 3 mg/l

ND = Not Detected

TABLE 58

Nickel (Ni) concentration (ppm) of water samples from Etche Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	2.015	0.004
2	2.011	< 0.001-0.018
3	< 0.001-0.009	< 0.001-0.017
4	< 0.001-0.003	< 0.002
5	< 0.001-0.004	< 0.001-0.019
6	0.012	0.120
7	0.140	0.0130
8	0.147	0.157

WHO (2004) 3 mg/l

ND = Not Detected

TABLE 59

Nickel (Ni) concentration (ppm) of water samples from Ikwerre Local Government Area, Rivers State

Sample Site	Dry Season	Wet Season
1	2.020	0.005
2	2.017	< 0.001
3	< 0.001	< 0.001
4	< 0.001	< 0.002
5	< 0.001	< 0.001
6	0.014	0.122
7	0.148	0.0133
8	0.150	0.161

WHO (2004) 0.02 mg/l

ND = Not Detected

TABLE 60

Nickel (Ni) concentration (ppm) of water samples from Emohua Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	2.023	0.006
2	2.019	< 0.001
3	< 0.001	< 0.001
4	< 0.001	< 0.002
5	< 0.001	< 0.001
6	0.016	0.125
7	0.150	0.0136
8	0.153	0.162

WHO (2004) 0.02 mg/l

ND = Not Detected

TABLE 61

Mercury (Hg) concentration (ppm) of water samples from Etche Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	-<0.14	-<.001
2	-<0.14	-< 0.14
3	-<0.001	< 0.01
4	-<0.14	< 0.01
5	-<0.14	< 0.15
6	-<0.15	0.01
7	-<0.14	0.01
8	0.001	0.01

WHO (2004) 0.02 mg/l

ND = Not Detected

TABLE 62

Mercury (Hg) concentration (ppm) of water samples from Ikwerre Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	-<0.15	-<.0.01
2	<0.001	-< 0.01
3	-<0.15	< 0.01
4	-<0.14	< 0.04
5	-<0.14	< 0.15
6	0.001	<0.01
7	0.001	<0.01
8	0.001	-<0.01

WHO (2004) 0.02 mg/l

ND = Not Detected

TABLE 63

Mercury (Hg) concentration (ppm) of water samples from Emohua Local Government Area, Rivers State.

Sample Site	Dry Season	Wet Season
1	-<0.14	-<.0.01
2	<0.001	< 0.01
3	-<0.14	< 0.01
4	<0.001	-< 0.01
5	-<0.15	-< 0.14
6	-<0.14	-<0.14
7	<0.001	<0.01
8	<0.001	-<0.01

WHO (2004) 0.02 mg/l

ND = Not Detected

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMEDNATIONS

5.1 Discussion

This research work studied the sources of water available to some rural communities in three Local Government Areas of Ikwerre, Emohua and Etche in Rivers State, Nigeria. The study also analysed the microbiological quality, physico-chemical paramaters and heavy metal contents of the water sources in these communities. The results obtained were compared with both national and international standards. The examination of microbiological quality of drinking water sources is intended to prevent the development of waterborne illnesses or outbreaks among the rural dwellers as a result of consumption of water contaminated with harmful microorganisms (Agwaranze et al., 2017). Water or food items to be consumed or water that is designated for drinking should not harbour pathogenic microorganisms or any bacteria indicative of faecal contamination. WHO (2014) stated that the isolation of indicator bacteria with faecal origin in drinking water samples provides a resounding evidence of poor water quality since it is a very difficult task to examine water for the presence of every potential pathogen. For obvious physiological reasons, the enteric pathogens are not able to multiply in water, but water serves as their veritable medium of transmission to both human beings and animals.

5.1.2 Mean total aerobic heterotrophic bacteria count.

The results of the mean total aerobic heterotrophic bacteria counts of the wells and stream water samples from the three Local Government Areas are shown in figures 4 and 5 respectively. For the well waters, the highest number of bacteria count (1.7×10^4 cfu/ml) was observed in Emohua LGA in the month of July, followed by Ikwerre LGA with bacteria count of (8.60×10^2 cfu/ml) in the month of June and Etche LGA

having bacterial count of (3.57 x 10^2 cfu/ml). Similarly, the mean total aerobic heterotrophic bacteria count for the stream waters also recorded the highest count of (2.35 x 10^4cfu/ml) in Emohua LGA, followed by Ikwerre LGA (2.02 x 10^3cfu/ml) and Etche LGA (3.85 x 10^2cfu/ml).The Analysis of Variance of the stream water samples in table 2 reveals that there was a significant difference in all the water samples analysed, the stream water sources produced more aerobic heterotrophic bacteria count than the well water sources.

In a study of well water samples from different locations in Nsukka, Southeast Nigeria, Anyanwu and Okoli (2012) reported mean total heterotropic bacteria count of 1.84 x 10^4cfu/ml. While Olatunji *et al.* (2011), in their assessment of the water quality of Asa river obtained mean total heterotrophic bacteria count of 1.09 x 10^4cfu/ml, Agwaranze et al., (2017) reported total viable bacteria count of 0.86 x 10^4cfu/mlin the bacteriological examination of well water sources in Wukari, Taraba State, Nigeria. Although, the heterotrophic bacterial count observed in the well waters examined were high, the values were all lower than 6.3 x 10^8cfu/ml obtained by Shittu*et al.*, (2008) in their study of the Rivers and well waters in Kuta Town, Ogun State, Nigeria.

Comparing the bacterial count for seasonal variation, figures 4 and 5 shows that the mean total heterotrophic bacteria count of well and stream water samples from the dry season was lower than that of the wet season. In all the wells in the three LGA's, the total heterotrophic bacteria count was higher during the wet season (May– October) than the dry season (November – April). Onuigbo et al., (2017) also recorded highest total bacterial counts during the winter season as compared with other seasons. While Olatunde and Ayandele (2018) also reported increase in bacterial population during the rainy season than in the dry season. The stream water

samples had more total heterotrophic bacterial load than the well samples in both the wet and dry seasons. The minimum microbial count observed in winter might be due to the cold climate condition, which is not supportive for bacterial and fungal duplication in a greater extent (Venkateesharaju *et al.*, 2010). The increased level of bacterial count observed during the wet period may be due to the action of rainfalls, which through run-off wash more microbes and nutrients from the nearby soil into the water bodies. Leaves from trees and decaying organic matter from soil surfaces are equally washed into the wells. This addition makes more substrates available to the heterotrophic organisms thereby enhancing rapid bacterial growth and multiplication. Some of the wells had no concrete casting or permanent metal cover, and so were left open both during day and night. Spilt water arising from domestic activities, dust and all kinds of rubbish can easily find their way unhindered into the open wells. Heterotrophic bacteria includes all bacteria that use organic nutrients for their growth. These group of bacteria are generally present in all types of water, food, vegetation etc, and many of the genera may contain both primary and secondary pathogens (Anyanwu & Okoli, 2012). The United States Environmental Protection Agency (USEPA, 2003) had set a limit of 500 colony forming units per milliliter for heterotrophic bacteria count under the Safe Drinking Water Act. Unfortunately, the well and stream water samples were observed to produce counts that are in excess of this standard and so unsafe for drinking purposes.

5.1.3 Mean total aerobic heterotrophic fungi count.

The results from figures 6 and 7 shows that the mean total heterotrophic fungi count of well and stream water samples occurred more in EmohuaLGA with a count of 1.85 x 10^4cfu/ml, Ikwerre LGA had fungal count of 3.48 x 10^3cfu/ml, while the lowest mean total count was recorded in Etche LGA (2.67 x 10^2cfu/ml). The result of

Analysis of Variance from tables 3 and 4 shows that there difference in the mean total heterotrophic fungal count of the well and stream water samples from the three LGA. The total fungal count from the stream water samples was in the range of 3.00 x 10^2cfu/ml for Etche LGA, 4.20 x 10^3cfu/ml for Ikwerre LGA and 2.55 x 10^4cfu/ml in Emohua LGA. However, the total fungal count from the three LGA's produced the highest growth numbers in the well and stream waters from Emohua LGAs. The fungal counts obtained were more during the wet season than in the dry season. The well water samples had more fungal counts than the well water during the two seasons. Yahya *et al.* (2013) reported total fungal counts of 21 x 10^3cfu/100ml during the winter and 13 x 10^5cfu/100ml during the spring in the assessment of water of Duhok. In a separate study of the occurrence fungal species in a water distribution system Recife, Helena et al., (2016) observed fungal counts of 5 to 207cfu/100ml and a mean number of 53cfu/100ml of water sample.

Fungi are ubiquitous, heterotrophic organisms present in oceans, fresh water and drinking water. Presence of opportunistic and pathogenic fungi in drinking water can pose a health risk to consumers due to daily contact with water, via several exposure points, such as drinking and showering (Monika *et al.,* 2017). Though the presence of fungi in water distribution system and the associated health risks are well documented in the scientific literature, inclusion of fungi in the drinking water regulations is scarce. Most national and international guideline documents (including the World Health Organization) list fungi among the "nuisance organisms" causing odour problems, and do not deem dedicated monitoring necessary (WHO, 2011). The U.S. EPA considered the inclusion of Microsporidia in drinking water regulations earlier, but it was withdrawn from the list of "Contaminant Candidate List" in a later phase. The European Union drinking water directive does not address fungi explicitly either. However, the

directive states that wholesome drinking water should be "free from any micro-organisms and parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health" (USEPA, 2016). This definition implies that the presence of pathogenic or allergenic fungi in the drinking water is not acceptable either. Filamentous fungi in drinking water sources can cause blockage of water pipes, organoleptic biodeterioration act as pathogens and allergens or cause mycotoxin contamination (Helena *et al.*, 2016).

The sources, colonization and growth of fungi in well and stream water bodies depend on several factors, such as location of primary water source, sun irradiation, temperature, ion composition and pH, presence of organic material, dissolved oxygen concentration, water treatment, use of materials for water distribution systems and consequently the possibility of biofilm formation (Novak et al., 2015). The concentration of organic matter in water depends on the location and the surface area of water bodies. Small surface water bodies or water with low flow receive the most of organic matter due to the plant vegetation, and larger water bodies and streams on high altitude are mainly supplied with organic matter due to the algal primary producers. Surface water with slow flow close to the stream mouth are rich on nitrate, nitrite, phosphate and other products of organic material degradation, such as plant debris, lignin, hemicelluloses and cellulose. Besides these, also human habitation may contribute to the water pollution with organic substances via fertilizers or industrial and household waste. Consequently, surface water contains high biomass and rich diversity of plant degrading filamentous fungi (Tsui *et al.*, 2016).

5.1.4 Mean total coliform bacterial count

The total coliform bacteria test is a primary indicator of potability and suitability for consumption of drinking water. It measures the concentration of total coliform bacteria associated with the possible presence of disease causing organisms. Coliform bacteria are not generally disease causing organisms, but are only mildly infectious. If large numbers of coliforms are found in water, there is a high probability that other pathogenic bacteria or organisms may be present. Microbiologically, the examination of water for the presence of coliform bacteria serves as an indication of the contamination of such water body by materials from living organisms, especially animals and human beings. Due to the public health hazards posed by some species of the coliform group, the World Health Organization (WHO, 20011) gave a guideline coliform of zero per 100ml (0/100ml) of any water to be used for drinking purposes. This suggests that for any water that is intended for drinking by human beings no coliform bacteria should be detected during normal examination of the water samples. Results from the total coliform bacterial count of the wells and stream water sources in this study revealed the presence of coliform bacteria in many of the wells and streams across the three LGA's. The results from figures 8 and 9 shows that the total coliform count of well and stream water samples was highest in Ikwerre LGA, followed by Emohua and Etche LGA's respectively. However, the ANOVA result from table 5a showed that there was no statistically significant difference in the total coliform count of the samples based on the three LGA's ($F2, 285=2.51$, $p>.05$). The ANOVA result from table 5b shows that there is significance difference in the total coliform count between the well and stream water sources ($F1,286=8.296$, $p<.05$). This indicates that the total coliform count was higher in the stream water than in the well water. From figures 8 and 9, the total coliform count of well and stream water samples from dry

season was lower than that of the rainy season. And the ANOVA result on table 5c shows that there is statistically significant difference in the total coliform count of the water samples based on the two seasons ($F1, 286=40.230$, $p<.05$). This reveals that for those wells and streams in the three LGA's where there was coliform contamination, the counts were relatively high especially during the wet season than in the dry season. The total coliform bacteria counts in these wells and streams generally exceeded the WHO standard for drinking water.

The result of this study is in line with the findings of Yahya *et al.* (2013) who reported that the contamination of water sources by coliform can be high during raining season than the dry season. This is evident when the water sources are not shielded from surface run-off during the wet season. Moreso, the grazing of domestic animals which are seen freely roaming about in the various communities of the three LGA could have also added to the pollution of the water sources. Coliform bacterial contamination of the hand-dug wells from the three LGAs reveals pollution of the ground water in these communities. Pollution of the ground water could have arisen from the combination such factors as waste dumps, use of pit latrines and open defecation as was practiced in all the rural communities sampled.

As pointed out by Adekunle *et al.* (2007), high coliform counts seems to be a regular feature of ground water sources in most rural communities in Nigeria. Nevertheless, WHO (2007) stated that the presence of coliform bacteria in water samples may not be definitive of contamination of pathogenic microbes. Griffith *et al.*, (2003) alluded to this position when they noted that coliform bacteria occur widely in nature from diverse sources and so does not necessarily reveal faecal pollution. However, it can be said that the high coliform bacteria count is a sign of the prevailing poor sanitary conditions in the affected communities. This is true as the perennial lack

of potable water, unhygienic practices and poor sanitary environments continues to bedevil the yearning for good health and social development of the rural populace. *E. coli* and *Aerobacter aerogenes* are the two most significant coliform bacteria group. While *E. coli* is known as a faecal contaminant, *A. aerogenes* is a non faecal contaminant (Dubey and Maheshwari, 2013). This is why the detection of *E. coli* during water analysis is very essential as its indicative of the presence of pathogenic microorganisms, such as the *Salmonella* and *Vibrio* species.

5.1.5 Mean Total *E. coli* count

The results from this study shows substantial presence of *E. coli* in majority of the wells and streams analysed in the three LGA's. The prevalence of *E. coli* detected was slightly more in the water samples from Ikwerre LGA, followed by Emohua and Etche LGA's respectively as shown in figures 11 and 12. The ANOVA result from table 6a shows that there was no statistically significant difference in the mean *Escherichia coli* count of the well and stream water samples collected from communities in the three LGA's ($F_{2, 285}=.815$, $p>.05$). On the other hand, ANOVA result from table 6b shows that there was a significance difference in the total *Escherichia coli* count of the water samples based on source of water ($F_{1,286}=4.062$, $p<.05$). This indicates that the total *Escherichia coli* count observed was significantly higher in the stream water than in the well water sources. The use of pit latrines and the practice of open defecation may have been responsible for the introduction of the organism in the open wells and streams. Comparing the *E. coli* count for seasonal occurrence, the ANOVA result from table 6c shows that there was a statistically significant difference in the mean *Escherichia coli* count of well and stream water sources based on the seasons ($F_{1, 286}=.815$, $p<.05$). *E. coli* also exhibited seasonal variation in its occurrence, as it was detected more in the wet season than in the dry

season. The number of *E. coli* detected equally exceeded the World Health organization and the United States Environmental Protection Agency (USEPA, 2003) recommendation for drinking and recreational water.

Emanuel *et al.* (2015) also reported the isolation of high counts of *E.coli* in the microbiological assessment of wells from Samaru, Zaria, Kaduna State, Nigeria. Jesse et al., (2017) found high numbers of *E .coli* and Coliform bacteria in a study of private and small public well waters from Alberta, Canada. Similarly, Niba and Chrysanthus (2013) in a study of the bacteriological quality of well water sources in Bambui Student Residential Area revealed that most of the wells were grossly contaminated with bacteria pathogens such as *Klebsiella* species (95%) and *Escherichia coli* (52%). *Escherichia coli* is a faecal coliform commonly found in the intestines of animals and humans, that are associated with human or animal wastes. The presence of *E. coli* in water is a strong indication of recent sewage or animal waste contamination and suggests that other disease-causing bacteria, viruses, protozoa may likely be present (WHO, 2014). *Escherichia coli* strains 0157:H7 and *E. coli* 0111 cause bloody diarrhoea indistinguishable from hemorrhagic colitis. Between 2% and 7% of cases can develop the potentially fatal hemolytic uremic syndrome, which is characterized by acute renal failure and hemolyticanemia. Children under 5 years of age are at most risk of developing hemolytic uremic syndrome.

It is desirable for water used for drinking purposes not to contain any organism of faecal origin (WHO, 2014). The presence of *E. coli* in the well sample renders the water unsuitable for human consumption without disinfection, according to the WHO guidelines for drinking water quality.

5.1.6 Mean total *Salmonella* sp count.

The results from figures 14 and 15 shows that the mean total *Salmonella* sp count of the well and stream water samples from communities occurred more in Ikwerre LGA, followed by and that of Emohua and Etche LGA's. The ANOVA result from table 7a indicates that there was no statistically significant difference between the mean total *Salmonella* sp count of the well and stream water samples from the three LGA's analysed ($F2, 285=1.016$, $p>.05$). In all, the number of *Salmonella* sp detected was higher than the zero per 100ml (0/100ml) limit set by WHO and the Environmental Protection Agency. Comparison between the two water types in figure 16 indicates that the total *Salmonella* count was higher in the stream water than in the well water. Accordingly, the ANOVA result from table 7b shows that there was significance difference in the total *Salmonella* sp count based on the type of water ($F1,286=7.368$, $p<.05$). The ANOVA result in figure 7c also shows that there was statistically significant difference in the mean total Salmonella count of well and stream water based on season ($F1, 286=16.308$, $p<.05$). *Salmonella* species were detected more during the wet season than in the dry season in all the communities from the three LGA's. *Salmonella* species, especially *S. typhi* is of significant public health importance, been connected with the development of gastrointestinal infection such as typhoid fever in human beings. In the same vein, Azuonwu et al., (2017) reported mean total *Salmonella* count of 4.52×10^4cfu/100ml in the evaluation of bacteriological quality of surface, well, borehole and river water in Khana Local Government Area of Rivers State, Nigeria.

Onuorah *et al.*, (2016) in a study of the bacteriological quality assessment of hand-dug shallow water wells in Awka metropolis, Anambra State, Nigeria noted that *Salmonella typhi*, *Proteus vulgaris* and *Pseudomonas aeruginosa* were detected in 40.00%,

46.67% and 53.33% of the water samples respectively. Romulus et al., (2012) also isolated *Salmonella, Escherichia coli, Vibrio, Enterobacter, Klebsiella* and *Pseudomonas from* the shallow wells in Kitui Town, Kenya. Crump *et al.,* (2004) reports that the World Health Organization estimated an annual typhoid fever infection rate of 21.6 million people with 600,000 death rate per year due to *Salmonella typhi* and Africa and Asia both share the higher percentage of the death burden. According to Wegener *et al.,* (2003) water or foodborne diseases caused by *Salmonella* species cost Denmark between $10.4 - $25.5 million in 2001 and in the United states of America, the pathogen accounted for about 16,000 hospitalizations and over 500 deaths annually which cost $2.3 million. The economic effects of *Salmonella* sp infection to many countries is also very huge. In 2010 alone, more than 550 million eggs including tomatoes, raw tuna, pickles and olives eggs were recalled from supplies due to possible *Salmonella* species contamination, leading to one of the largest recalls in recent time (Linscott, 2011).

5.1.7 Mean total *Vibrio* sp count

From the result on figure 17 and 18, the mean total *Vibrio* count of well and stream water samples was slightly higher from samples in Etche LGA, followed by Ikwerre and Emohua LGA's. However, the result from figure 19 shows that the mean total Vibrio count of well and stream water samples from the rainy season was much more than in the dry season. *Vibrio cholerae* is a waterborne pathogen and the outbreak of the organism is likely to spread faster during the rainy season, so that might be a reason for the high *Vibrio cholera* count observed in this study. Tista et al., (2007) observed the occurrence of *Vibrio cholerae* in the range of 0.84% amongst other organisms during a study of the microbiological analysis of drinking water of kathmandu valley. Uzoigwe and Agwa (2012) reported the highest percentage

frequency of occurrence of *Salmonella* sp (14.29%) and *Vibrio* sp (9.52%) in the analysis of microbiological quality of water collected from boreholes sited near refuse dumpsites in Port Harcourt, Nigeria. Okunye and Odeleye (2015) isolated and identified *Vibrio* sp in their bacteriological investigation of well water samples from selected market locations in Ibadan, Nigeria. Md.Khalid et al., (2017) also reported that the highest concentration of *Vibrio cholera* counted in Dhaleshwari river water sample was 9.66×10^4cfu/ml during the month of June while minimum concentration was found to be 4.2×10^4cfu/ml in the month of April. Compared to *E. coli* and *Salmonella sp count*, the prevalence of *Vibrio* species was relatively lower as the organism was not detected in a good number of well water samples in all the three LGA studied. Although, the *Vibrio* species showed lower counts, their detection at all from the water sources is of significant risk for public health, especially as the World Health Organization (2010) estimated that out of 3-5 million cases of cholera that occur annually, all over the world, between 100,000 to 170, 000 persons infected die of the disease.

5.1.8 Biochemical and molecular identification

The result of the biochemical characterisation of the bacterial isolates is shown on table 8. The result of the biochemical test indicated the presence of *E. coli* species, *Klebsielle* sp, *Enterobacter aerogenes*, *Staphylococcus aureus*, *Pseudomonas aeroginosa*, *Salmonella* sp, *Vibrio* sp, *Shigella* sp, and *Bacillus* sp. Romulus et al., (2012) also isolated *Salmonella, Escherichia coli, Vibrio, Enterobacter, Klebsiella* and *Pseudomonas from* the shallow wells in Kitui Town, Kenya. Okunye and Odeleye (2015) isolated and identified *Vibrio* sp in their bacteriological investigation of well water samples from selected market locations in Ibadan, Nigeria.

5.1.9 Molecular identification of isolates

The result of the agarose gel electrophoresis of the bacterial isolates is presented on plate 13 and the phylogenetic tree showing the evolutionary distance between the organisms is shown on figure 20. The obtained 16s rRNA sequence from the isolate produced an exact match during the megablast search for highly similar sequences from the NCBI non-redundant nucleotide (nr/nt) database. The 16S rRNA of the isolate B8 showed a percentage similarity to other species at 99%. The evolutionary distances computed using the Jukes-Cantor method were in agreement with the phylogenetic placement of the 16S rRNA of the isolate within the *Salmonella sp* revealed a closely relatedness to *Salmonella bongori* strain KC153129.116(MG663494) than other *Salmonella* sp and bacterial sp respectively. The other organisms identified are; *Vibrio* sp strain 201707CJKOP-Y162(MG593726), *Bacillus sbtilis* clone N55(JQ622582), *Chryseobacterium* sp strain CB2915-325-DE_0621(MH512534), *Enterobacter* sp strain AB55(MF407145), *Klebsiella pneumonia* strain M792-16(MH680830), *Shigella sonnei* strain AR_0030(CP032523), *Escherichia coli* strain WECHEC025943(CP027205), according to the phylogenetic tree on figure 20.

5.1.10 Reports of waterborne diseases from Ikwerre, Emohua and Etche LGA's

The proportion of cases of waterborne diseases obtained from the hospital records of some communities in Ikwerre, Emohua and Etche LGA's are presented in figures 21, 22and 23, while the comparison of percentage occurrence of the diseases in shown on table 9 respectively. The study revealed that mild/acute diarrhoea due to *E.coli* had the highest proportion of 178.51 and percentage 49.6% occurrence in Emohua LGA. According to Ifeoma et al., (2018) during the assessment of the incidence of diarrhoea in children under 5 years at the Institute of Child Health, Banzazzau, Zari, the hospital records showed a preponderance of male children over

females that presented with diarrhoea (55.4%) and that children within the age of 12-23 months had the most diarrhoeal cases (36.8%). This was followed by enteric fever or gasteroenteritis due to *Salmonella* sp covering a proportion of 80.33 representing 26.7% in Etche LGA. Udujih *et al.* (2017) in their studies on *Salmonella* infection among undergraduate students of Imo State University, Owerri, Nigeria reported that *Salmonella* infection had a proportion of 36.89%. Abioye et al., (2017) in a study of the prevalence of *Salmonella typhi* infection in Karu Local Government Area of Nasarawa State, Nigeria, noted that out of the 252 samples screened, 158 were found to be positive for *S. typhi* with a prevalence of 62.70%. In developing countries, the most common cause of gastroenteritis which affects humanity is due to lack of safe and clean drinking water sources. The cases of Cholera disease reported in the three LGA's had low prevalence percentages for Ikwerre, Emohua and Etche LGA's respectively. Elsewhere in Nigeria, NCDC (2017), revealed that a total of 5,138 cases and 136 deaths from Cholera disease have been reported from different LGA's in seven states of Nigeria including; Borno, Kebbi, Zamfara, Kano, Lagos, Oyo and Kwara States with confirmed outbreak. Poor sanitary conditions observed in the affected communities of these LGA's is one of the predisposing factors for the cholera outbreak. And, an important risk factor is unarguably the lack of access to clean drinking water and poor hygiene conditions.

Amoebiasis is basically an acute disease acquired by: (i) ingestion of cysts present in contaminated food, water, orplants, (ii) through person to person contact, (iii) exposure in endemic areas, and (iv) swimming in contaminated water, Ben and Sabbahi (2017). Nyenke *et al.* (2017) in a study of the prevalence of intestinal Amoebiasis in infant and Junior School Children in Degema General Hospital and Environs, Rivers State found out that the prevalence rates of intestinal amoebiasis among these patients

were 11%. The World Health Organization reported that *Entamoeba histolytica* affects approximately 500 million people worldwide, resulting in symptomatic diseases in 50 million and mortality in 100,000 persons (Lozano et al., 2012). Approximately 4 to 10% of the carriers of this amoeba infection develop clinical symptoms within a year and amoebic dysentery is considered as the third leading cause of death from parasitic disease worldwide after Malaria and Schistosomiasis (Ghasemi et al., 2015). Improved community based sanitation, personal hygiene and deliberate government policy for sustainable rural potable water supply will reduce or prevent faecal contamination of food and water sources.

5.1.11 Antibiogram profile of *E.coli*, *Salmonella* sp and *Vibrio* sp.

In addition to the infections caused by these organisms, another major problem associated with these pathogens is the development of drug resistance. Saif *et al.*, (2014) stated that antibiotic resistant bacteria can infect human via contaminated food and drinking water, or directly from the environment. According to Samantha and Janeas (2016), these superbugs result in infections that are only responsive to treatment with a few if any currently available antimicrobial agent. What is worrisome, is that these resistant organisms cause waterborne infections that leads to high rate of morbidity and mortality among residents of affected communities. There is therefore, a huge healthcare cost usually expended on waterborne diseases caused by resistance pathogens.

The responses of *E. coli, Vibrio sp* and *Salmonella sp* to the antibiotic sensitivity test is shown in their antibiograms. For *E. coli* isolates, the antibiogram profile on table 11 shows that there was strong resistance to Augumentin and Amoxicillin antibiotics, and a high sensitivity to Nitrofurantoin, Oflaxicin, Nalixidic acid and moderate sensitivity to Gentamicin and Tetracycline. Adekunle et al., (2011)

during a study on the antibiotics sensitivity patterns of Escherichia coli and Aerobacteraerogenes isolated from well water in Ile–Ife, Nigeria reported that *E. coli* was sensitive to cotrimoxazole, streptomycin, tetracycline, colistin, gentamicine andnalidixic acid but resistant to nitrofurantoin, ampicillin, cephalocidine, sulphafurazole, carbenicillin and sulfamethazole. The antibiotics susceptibility pattern of *Escherichia coli* isolated from well water in Afikpo, South Eastern Nigeria showed that all the *E. coli* isolates were 100% resistant to gentamicin and amoxicillin, Stanley (2015). Similarly, Gideon *et al.* (2017) in the analysis of antibiotic susceptibility profile of bacteria isolated from drinking water sources in Amai Kingdom, Delta State, Nigeria showed that *E. col I* and other Gram negative bacterial strains displayed significant sensitivity to Ciprofloxacin, Ofloxacin and Gentamicin, and resistant to, Ampicillin, Tetracycline and Norfloxacin.

The antibiogram of the *Salmonella* isolates revealed high sensitivity to Nitrofurantoin, Nalixidic acid and Oflaxicin antibiotics. Amoxicillin, Augumentin, Cotrimoxazole and Tetracycline were not effective against the bacterium as shown in table 12. But Tolessa *et al.* (2016) stated that all *Salmonella* species isolated from Lake Hasswa water recorded highest resistance for amoxicillin but no resistance pattern was observed against norfloxacillin and kanamycin. The *Salmonella* isolates exhibited the highest rate of resistance against Ampicilin-10 µg (72.9%) and the least against Gentamicin-10 µg (1.4%). All the *Salmonella* isolates were sensitive to Chloramphenicol-30, Ciprofloxacine-5 µg and Imipenem-10 µg and hence the most sensitive Nchawa and Bassey (2015). In addition to Amoxicillin and Augumentin, the antibiotic profile of *Vibrio sp* showed strong resistance to Tetracycline and Cotrimoxazole antibiotics. The *Vibrio sp* exhibited sensitivity to Nalixidic acid, Nitrofurantoin and Oflaxicin antibiotics as seen on table 13. Chigozie

and Samuel (2015) reported that *V. parahaemolyticus*_MP-2_AY911391 = TBSHy isolate was strongly susceptible to the antibiotics, Tetracycline, Ciprofloxacin, Gentamicin and Ceftazidime and resistant to Ampicillin Amoxillin. Ampicillin resistance in the isolates suggests low efficiency of ampicillin in management of *V. parahaemolyticus* infection. Poor sanitation and overcrowding are important factors that promote the persistence of *Vibrio cholerae* in the environment, an etiological agent of cholera. Also, *V. cholera* is known to express two major virulence factors, namely the cholera toxin (CT), which is borne on filamentous cholera-causing toxin phage (CTX phage); and a colonization factor named toxin co-regulated pilus (TCP), which is one of the crucial intestinal establishment factors and the host receptor for the cholera toxin. The cholera toxin causes prolific squelchy diarrhoea, and the two subsets of the isolates are acquired by lateral gene transfer (LGT) (Huq *et al.*, 2006).

The treatment of the cholera disease condition is centered on the physiological ideology of replacing water and electrolytes and maintaining the intravascular volume. The main goal is to replenish potassium and bicarbonate, which were discharged along with choleric stool. For severely ill patients, the Centre for Disease and Control (CDC) recommends the use of antibiotics along with fluid replacement. The application of this physiological principle is primarily made available to patients who are sternly dehydrated and who continue to discharge large volumes of stool throughout the rehydration treatment. The use of antibiotic treatment is also recommended for all patients who are hospitalized. Antimicrobial agents are useful in aiding the rehydration treatment of cholera, because their use reduces the duration of diarrhoea (which in turn reduces the spread of the disease), and treats acute illnesses (by reducing the volume of diarrhoea). CDC recommends that the class of antibiotics used for treating any infection

should be based on indigenous antibiotic susceptibility patterns (Charles & Anthony, 2017).

Potentially, pathogenic bacteria are continuously entering into water bodies and the organisms, may contain mobile genetic elements like plasmids interns and transposon. Those transposable genetic elements are able to move horizontally to other non-pathogenic bacteria, which become pathogenic, or virulent due to acquired resistance to multiple antibiotics (Chen *et al.*, 2015). Results of bacterial antibiotic sensitivity tests assist medical practitioners in the prescription of the most effective drug for the treatment of a specific water or food borne disease.

The implication of *E.coli, Salmonella* sp and *Vibrio* sp in the causation of gastroententritis which produces diarrhoea results in high morbidity and mortality among children have been documented by Nyenje and Ndip (2013). The disease symptom, diarrhoea, is normally accompanied with the loss of fluids and electrolytes, hypokalaemia and acidiosis (Tilkian *et al.*, 1979). According to Finkelstein *et al.*, (1973), the bacterial pathogens colonise the epithelial surfaces of the hosts small intestines where they produce heat-labile, LT – protein, enterotoxin which induces production of cyclic AMP (cAMP) that causes net secretion of fluid into the intestinal lumen. The mechanism of diarrhoeal symptomology can be used to study the pathogenesis of *E. coli*, *Vibrio* sp and *Salmonella* sp in an intact live animal. Koupal and Diebel (1975) and Takeda *et al.*, (1978) have all demonstrated net fluid secretion in response to oral or intra-intestinal inoculation with viable bacteria or its enterotoxin in rats, infant rabbit or suckling mice and hemsters. So, the actual potential of the E. coli, *Vibrio* sp and *Salmonella* species isolated from the different water sources in the three local government areas studied to cause waterborne disease was tested by oral injection of the pathogens into selected group of live rats.

5.1.12 Enterotoxicity test in rats

From results of the enterotoxicity test obtained in this study, tables 14, 15 and 16 shows that only *E. coli* isolate (EC 07) in Emohua, *Salmonella* isolate (SP 05) and from Ikwerre Local Government Area and *Vibrio* isolates (Vp 07) from Etche Local Government Areas respectively were able to induce net fluid accumulation (i.e toxicity). ETEC causes diarrhoea in animals and humans by first colonizing the small intestine and then producing toxins responsible for fluid secretion and accumulation in the intestines (Turner et al., 2006b). Adherence by the pathogen to the walls of the small intestine is mediated by colonization factors. These can exist as filamentous surface appendages called fimbriae on which adhesins, which are specific proteins involved in binding to eukaryotic cells, are found. Colonization of the intestinal mucosa allows for the localized delivery of enterotoxins. The *E. coli* enterotoxins are classified based on their thermal stability.They are divided into heat-labile (LT-I and LT-II) and heatstable (STa, STb and EAST1) toxins (Daniel, 2008). Adeleye et al., (2010) reported that different strains of *Vibrio* sp such as *V. parahaemolyticus*, *V. cholerae*, two strains of *V. mimicus*, one strain each of *V. alginolyticus* and *V. harveyi* caused erosion of the epithelial linings of the intestines of experimental mice. Thus, indicating that the species can cause infections in humans by invasion of the epithelial linings of the intestine. In a related study of the enterotoxigenicity profile of *Escherichia coli*, *Vibrio* and *Salmonella* species isolated from well and river water sources in Oproama Town usingfluid accumulation (FA) ratio, Asiton et al., (2012) also found that Salmonella species from the river caused moderate toxicity.

The evidence of induction of fluid accumulation (i.e diarrhoea) or toxicity by the *E. coli*, *Salmonella* sp and *Vibrio* sp is a confirmation of the relationship between the development of waterborne diseases and the use of water from well and stream

sources from the affected communities in the three Local Government Areas. It is also a further proof of the poor water quality and the health risks that face residents of these communities.. However, regular investigations are still necessary to further assess the overall safety of these water sources due to the potential risk of the occurrence of waterborne diseases.

5.1.12 Physico-chemical analysis

Another critical factor that impacts on the potability water and its sources is the prevailing physicochemical contamination of the water body. Determination of the presence and concentration levels of the different physicochemical parameters gives additional assurance of the quality of drinking water source.

i. Temperature ranges of the water sources

The temperature of any given water body could affect the rate of proliferation of the indigenous microorganisms. The temperatures observed in the well and stream water sources from the three LGA's in this study are in the ranges of 24^{oC} to 28^{oC} and all fell within the acceptable standard limit of 28 to 30°C as shown in Figures 24 and 25 (WHO, 2011). However, the mean temperature ranges of the stream water was significantly higher than that of the well water sample. Comparatively, the mean temperature ranges of the well and stream water during the dry season was significantly higher than that of the rainy season (figure 26). From the ANOVA, tables 17 and 18 indicates that there was significant difference between the temperature ranges of the well water samples (F= 7.6606, and F crit = 3.2849). Igwemmar et al., (2013) found similar temperatures during the assessment of the physical and chemical parameters of some selected borehole water in Gwagwalada, Abuja. Olatunde and Ayandele (2018) observed similar results in the microbiological and physico-chemical analyses of hand

dug well-water near pit latrine in a rural area of Western Nigeria. Bello et el., (2018) in a bacteriological and physicochemical analyses of borehole and well water sources in Ijebu-Ode found that both borehole and well waters analysed maintained normal temperature ranges of 22 - 28°c and 21 to 27° c respectively. Microorganisms have preference for different temperature ranges and tolerance for their growth and survival in any particular environment. In any water body, temperature ranges play a vital role for the interactions of the organisms. The organisms could survive within the temperatures especially as aquatic organisms are noted to tolerate minor changes in temperature (Alabster & Lloyds, 1980).

ii. pH ranges of the well and stream water sources

The pH values for the well and stream waters ranged between 5.97 for Etche LGA, 6.09 for Ikwerre LGA and 6.79 for Emohua LGA respectively (figures 27 and 28). From the results, the mean pH showed acidic values of 5.97 for the well waters, while the stream samples were more alkaline 7.24. Though, the well water were acidic, the pH fell within the recommended value of (6.5-8.8) for drinking water (WHO, 2011). The mean pH of well and stream water samples in dry season, was found to be 6.62±5.18 whereas that of rainy season was 5.95±0.81 (Figure 29). The ANOVA result on table 19 shows there was no significant difference between the pH values of the well water samples. In a study on the seasonal patterns and behaviour of water quality parameters of Achenkovil River, Divya and Sharon (2016) showed a maximum range of acidic pH of 5.83 and 5.92 during monsoon season and post-monsoon season. Rutuja et al., (2018) also reported similar values from the physicochemical and bacteriological analysis of water quality in drought prone areas of Pune and Satara districts. The (APHA, 2002) observed that the presence of certain acidic oxides like No_2, So_2, etc could lower the pH value of a given water source. The acidic water pH

ranges could also be due to the predominance of organic matter in the underlying soils within the communities which constantly finds its way into the water bodies.

iii. Total hardness of well and stream water sources.

Water hardness is primarily the amount of calcium and magnesium, and to a lesser extent, iron in the water. Hard water is mainly an aesthetic concern because of the unpleasant taste that a high concentration of calcium and other ions give to water. It also reduces the ability of soap to produce a lather, and causes scale formation in pipes and on plumbing fixtures. In some agricultural areas where lime and fertilizers are applied to the land, excessive hardness may indicate the presence of other chemicals such as nitrate.

The mean values recorded for total hardness of water in all the well and stream water samples analysed are presented in figures 30 and 31.The mean total hardness (mg/l) of well and stream water samples from Etche LGA was found to be 11.01 ±7.92 mg/l, whereas that of Ikwerre LGA was 10.98±7.98mg/l and Emohua LGA was 128.21±1141.94 mg/l. The mean total hardness was slightly higher in the well water than in the stream water. The well and stream waters also showed seasonal variation, with the dry season maintaining higher values (91.79±932.21mg/l) than the wet season (8.33±2.46mg/l) as presented in figure 32. The ANOVA results on tables 21 and 22 revealed that there was no significant difference in the values for total hardness of water for the well and stream water samples respectively. All the well samples had values below the WHO, (2004) recommended maximum limit of 400 mg/l.

In a study on the quality of some water sources in Ogun state, Nigeria, Adelekan (2011) reported values of total hardness within the range of 6 and 246mg/l. Sanjoy and Rakesh (2013) in a comparative study found that total water hardness values for surface water are within the permissible limit, while in the groundwater most of the

study sites crossed the WHO maximum permissible limit. Olatunji et al., (2015) observed in an assessment of ground water quality of Illorin Meteropolis that total hardness, calcium and nitrate concentrations occurred in quantities higher than WHO's recommended limits at some sampling locations in the study area. Gupta *et al.*, (2009) noted that certain polyvalent metallic ions, such as magnesium, calcium, barium, manganese, zinc and iron are the major sources of total hardness in water. Adelekan (2010) equally asserted that higher concentrations of total hardness in fresh water are as a result of dissolution of polyvalent metallic ions from sedimentary rocks, seepage and soil surface run-off.

iv. Dissolved Oxygen (DO) concentration of well and stream water sources.

Dissolved oxygen is a most important aquatic parameter, whose existence is essential to aquatic fauna. It plays an important role in life process of animals. The mean dissolved oxygen ranges of the well and stream water samples from the three LGA's are shown in figures 33,34, and 35. The DO values for the well and stream samples increased during the dry season than the wet season for all the communities. During the dry season, the atmospheric temperature increases, leading to a decrease in the solubility of oxygen, while in the wet season, the temperature decreases, resulting in lower oxygen solubility in water. Also, during the dry season, when the temperature of the water is increased, microorganisms decomposing organic matter become more metabolically active and use more oxygen, resulting in lower DO levels. The ANOVA result on tables 23 and 24 indicates that there was significant difference between the DO values of the well and stream water samples. However, all the DO values recorded were within 7.5mg/l range stipulated by WHO (2003). Dhanaji et al., (2016) in a study on Physico-Chemical analysis of drinking water samples of different places in Kadegaon Tahsil found DO values from 1.9 to 5.2 mg/L for well water and 3.0 to 5.2

mg/L for the bore well water. According to Envuladu et al., (2017) very low DO may result in anaerobic conditions that cause bad odours The result obtained in this study shows DO levels that are normal and acceptable for drinking water purposes.

v. Nitrate concentration of well and stream water sources.

The result from figures 36, 37, and 38 shows that the mean nitrate concentration (mg/l) of well and stream water samples was higher in Emohua LGA (0.52±0.54 mg/l) than in Ikwerre LGA (0.51±0.54 mg/l) and Etche LGA 0.50±0.55mg/l). The nitrate concentration was significantly higher in the well water than in the stream water samples figure 39. The ANOVA result incates there was no significant difference between the mean values of the well and stream water samples (tables 25 and 26).The nitrate concentrations are all below the WHO (20011) limit of 50 mg/l for water meant for domestic consumption. Adejuuson and Mbuk (2011) in a similar work reported the determination of nitrate concentration of 23.5 to 50.6mg/l during the analysis of shallow well water samples from Ikorodu Town, Lagos, Nigeria. Olatunji *et al.* (2015) reported that nitrate (NO_2) occurred in concentrations (56.0mg/l) higher than the WHO's recommended limits in some ground water locations around Illorin metropolis, noting that this could have arisen from the influence of the geology of the study area. The USPA (2004) states that water containing higher nitrate concentration could lead to shortness of breath, diuresis, haemorrhaging of the spleen. Prwlson *et al.* (2008) traced the development of blue baby syndrome also known as methaemoglobinaemia in infants to the use of water containing high concentrations of nitrate. Benson *et al.* (2006) stated that ammonium (NH_4) ion and Nitrate (NO_3) obtained from some agricultural activities such as the application of fertilizers contributes close to 50% nitrate pollution of water sources. Rain water leaches out

these nitrates and carries it into nearby streams, whereas other nitrates infiltrates into the ground, eventually contaminating the ground water.

vii. Biological Oxygen Demand (BOD_5) of the Water Sources.

The measurement of 5 - Day Biological Oxygen Demand (BOD_5) of the water samples is shown in figures 39, 40 and 41 for the wells and streams from the three study LGA's. The observed values for BOD_5 showed seasonal variation, with the wet season having higher values than the dry season (figure 38). Though, the wet season had higher BOD_5 measurements, the values were not above the acceptable limits of 30 mg/l recommended by WHO (2004). The ANOVA results on tables 27 and 28 indicates that there was no significant difference between the BOD_5 of the well and stream water samples. The result obtained from the BOD_5 test revealed the measure of the amount of oxygen consumed by microorganisms in breaking down the organic matter content of the water body. Jihyun *et al.* (2013) reported high turbidity and BOD in their work, while Olatunde and Ayandele (2018) also reported that water BOD often increases during periods of heavy rain and high river flows - as organic matter are washed in from surrounding lands and drainage channels. High heterotrophic activity resulting from the huge abundance of organic materials around the study areas that are been washed into the open wells and streams during the wet season may be responsible for the recorded high BOD_5.

viii. Salinity of well and stream water sources

Salinity is a measure of salt concentration of a given water body and the World Health Organization (WHO, 2004a) recommends that the salinity of drinking water should not be above 250 mg/l. From figure 42, the salinity of all the well water samples ranged from 14-37 mg/ml , whereas the salinity of the stream water samples

(figure 43) was between 12-36 mg/ml for three LGA's respectively. A comparison of the mean salinity (figure 44) shows that Emohua LGA had the highest value, followed by Ikwerre and Etche LGA's. The results shown on figure 44 also indicates that the salinity was slightly higher in the well water than in the stream water sources. The measured values for the well samples in the Local Government Areas are within the WHO acceptable limits.). The values were lower during the wet season for the well water samples, and this may be attributable to dilution of the water body caused by regular rainfall. For the stream water, the increased intensity of sunlight during the dry season leads to evaporation causing the water to be more saline. From tables 29 and 30, the ANOVA results shows that there was no significant difference in the salinity of the water. During the sampling of water from a creek in Buguma city, Rivers State. Akinrotim *et al.*, (2011) reported salinity values between 16.18 to 21. 11 during the dry season. Ajibare (2014) also reported salinity values of 16.35 - 16.65 ‰ from some water sources in Ilaji, Ondo State, Nigeria and this agrees favourably with the report of Ezekiel et al., (2011). Salinity which is regarded as the total concentration of electrically charged ions in the water. These ions are the four major cations including; calcium, magnesium, potassium and sodium, and the four common anions such as carbonates (CO_3), sulphates (SO_4), chlorides (Cl) and bicarbonates (HCO). Other components of salinity are charged nitrogenous compounds mainly nitrates (NO_3), ammonium ions (NH_4) and phosphates (PO_4). In general, the salinity of river and well waters depends on the drainage of the area, the nature of its rock, precipitation, anthropogenic activity in the area and its proximity to marine water (Ajibare, 2014).

ix. Chloride concentration of well and stream water sources.

The results of the mean chloride content of well and stream water samples from the three LGA's are shown on figures 45 and 46. Comparison of the mean chloride

content (figure 47) for the three LGA's indicates Etche had 8.68±7.03 mg/l, 9.29±7.68 mg/l for Ikwerre LGA, and 9.94±7.69 mg/l for Emohua LGA. The chloride content was significantly higher in the well water than in the stream water. With respect to seasons, the values for chloride concentration determined in this study revealed that chloride levels were higher during the dry season than in the wet season in three LGA's. According to the ANOVA results on tables 31 and 32, the chloride content did not vary significantly between the well and stream water samples. During the dry season, water level decreases due to the effect of high heat, leading to increase in concentration of chloride. The values fell within the maximum permissible limit of 250mg/l stipulated by the WHO (2004).

x. Iron concentration of well and stream water sources.

Iron is one of the most abundant metals in the earth crust and is essential for plants and human beings. But excess iron in drinking water produces an ink taste and a muddy odour. The result shows the mean iron concentration of well and stream water samples are presented on figures 48, 49 and 50. A comparison of the iron content from the areas shows that Etche LGA had 0.32±0.40mg/l, while Ikwerre LGA was 0.34±0.44mg/l and Emohua LGA was 0.34±0.43 mg/l. Based on water source, the mean iron concentration was higher in the well water than in the stream water source. According to the seasons, the values were higher during the dry season, and above the 0.2mg/l of iron recommended by the WHO (2004a) for drinking water. According to Sanjoy and Rakesh (2013), the concentration of iron level for surface water in their study was also within the maximum permissible limit. However, in the ground water the concentration of iron in many of the samples were above the highest desirable limit of 0.1 mg/l but still within the safe limit for drinking water standard. The high concentration of iron in some of the drinking water sources from these study

communities is very significant and calls for urgent attention. In water, iron occurs mainly in ferrous or ferric state. Iron in surface water generally present is ferric state. It is an essential and non-conservative trace element found in significant concentration in drinking water because of its abundance in the earth's crust. Usually, iron occurring in ground water is in the form of ferric hydroxide, in concentration less than 500 µg/L, Oyeku and Eludoyin (2010). The shortage of iron causes disease called anemia and prolonged consumption of drinking water with high concentration of iron may lead to liver disease known as haermosiderosis, Emhemmed et al., (2014). The presence of higher concentration of iron in water sources may be responsible for the experience of bitter taste, staining of laundry materials and abdominal pain.

xi. Total dissolved solids.

The result of the Total Dissolved Solids TDS (mg/l) is presented in figures 53 and 54. The level of TDS (mg/l) was highest in Emohua LGA followed by Ikwerre and Etche LGA's respectively for both the well and stream water samples, although the stream water sources had greater values than the well sources. The total dissolved solids from the stream water samples were significantly higher than that of the well waters. Sanjoy and Rakesh (2013) observed that total dissolved solids (TDS) values in all the surface water studied in different seasons were within the desirable limit, but that in the ground water, the recorded values fluctuated from 668 to 1545 mg/l and are much higher than the standard drinking water values prescribed by WHO (2011). They also noted that elevated TDS in ground water may be due to ground water pollution when waste waters from both residential and commercial areas are discharged into pits, ponds enabling the waste to migrate down to the water table.

xii. Turbidity

Turbidity results from the presence of particulate matters such as clay, silt, finely divided organic matter etc. in any water source. These colloidal materials provide adsorption sites for chemicals that may be harmful to health or cause undesirable tastes or odours Bello et al., (2013). The mean turbidity of the well water samples from the three LGA's ranged 10-52 NTU while that of the stream water samples was between 12-19 NTU as shown in figures 55, 56 and 57. From table 33 and 34, the analysis of variance of both the well and the stream water samples indicates there was no significant difference in the mean conductivity based on the LGA's, although the difference was significant when comparing the seasons. Majority of the water samples had conductivity values above the recommended level of 5.0 NTU. This finding is line with the observation of Envuladu et al., (2017) who noted that all the wells in his study had turbidity greater than the acceptable value of not more 5.0 NTU. With 18 (45%) of the wells having values of 10-19 NTU, 19 (47.5%) wells having values as high as 20-29 NTU, whereas 1(2.5%) well had a value of 30-39 NTU and 2(5%) wells with values of 40-49 NTU.

xiii. Calcium

The principal elements that promote hardness of water are calcium magnesium, alongside their chlorides, sulphates and carbonates. The results from figures 58, 59 and 60 shows that the mean calcium concentration of well water samples was 3.77±2.04mg/l, while the mean calcium concentration of stream water was 36.35±44.70 mg/l. The result indicates that the calcium concentration was significantly higher in the stream water than in the well water. In terms of seasons, the mean calcium concentration of well and stream water samples from dry season was 15.35±34.13mg/l whereas that of rainy season was 8.48±14.50mg/l. This shows that there was significant

difference in the mean calcium concentration of the samples based on season. Comparing the calcium concentration in surface and ground water, the calcium content of ground water is slightly greater than that of surface water. Fortunately, calcium has no adverse physiological manifestation on human health; in fact persons consuming water containing calcium are likely to have less chances of heart trouble or cardiac disorder, than a person drinking water without calcium content Sanjoy and Rakesh (2013). Though calcium toxicity is rare, as the body requires about 0.7-2.0g of calcium intake per day, excessive consumption can cause the development of kidney stones.

xiv. Magnessium

The result from figures 61, 62 shows the mean magnesium concentration (mg/l) of magnesium from well and stream water samples. A comparison of the results as shown in figure 63 reveals that the magnesium levels from Etche LGA was 3709.09±10700.83 mg/l, whereas that of Ikwerre LGA was 4275.13±11737.64 mg/l and Emohua LGA was 3724.51±11362.08 mg/l. There was no significant mean difference in the magnesium concentration of the samples based on LGA's ($F2, 285=.079$, $p>.05$). However, the ANOVA result shows that there is significance difference in the magnesium concentration based on source of water ($F1, 286=162.944$, $p<.05$). This indicates that the magnesium concentration was significantly higher in the stream water than in the well water. From figure 63, the mean magnesium concentration of well and stream water samples from the dry season was found to be 3351.18±9224.30 mg/l, whereas that of the rainy reason was 4454.63±12953.81mg/l. The result of ANOVA shows that there was no significant mean difference in the magnesium concentration of the samples based on season ($F1, 286=.693$, $p>.05$). The high level of magnesium may be due to the high heat intensity of the sunshine

during the dry season, causing a decrease in water volume and an increase in the concentration of the elements. In the analysis of shallow well water samples from Ikorodu Town, Lagos, Adejuwon and Mbuk (2011) reported values of 40-92 mg/l for calcium and 4-12.5 mg/l for magnesium. These values, as well as the ones measured in this study are all below the WHO(2004a) recommendation of 75-200 mg/l for calcium and 30-150 mg/l for magnesium.

xv. Conductivity

The results obtained for conductivity are shown on figures 64, 65 and 66. The conductivity was higher in the stream than the well water sources and higher than the recommended limits. In a similar analysis, the results of the analysis conducted by Singh *et al.* (2010) showed that the conductivity values obtained in the water samples ranged from 206 to 767 µS/cm in rainy season, while the highest value was observed in site K3 (659 µS/cm) and the least was found to be 70 µS/cm in K9 during the dry season. Electrical conductivity is a measure of waters ability to conduct an electric current, and it is related to the amount of dissolved minerals in the water, but it does not give an indication of the element present. Higher value of conductivity is a good indicator of the presence of contaminants such as sodium, potassium, chloride or sulphate (Orebiyi *et al.*, 2010). The results obtained corresponds to that of and Jayalakshmi *et al.* (2011) who reported different ranges of electrical conductivity as a good and rapid method to measure the total dissolved ions which is directly related to the total solids in the water sample.

5.1.13 Heavy metals concentrations in well and stream water sources.

The heavy metals are common air pollutants, being emitted mainly as a result of various industrial activities. Although the atmospheric levels are low,

they contribute to the deposition and build-up in soils. Heavy metals are persistent in the environment and are subject to bioaccumulation in food-chains, Emhemmed *et al.,* (2014). Heavy metals can be detected in small quantities in some water bodies. The sources of heavy metals contamination of open well and stream waters may be through natural processes and anthropogenic activities.

i. Lead (Pb)

Lead is the most significant of all the heavy metals because it is toxic, very common and harmful even in small amounts. The concentrations of lead detected in the water samples from the three LGA's are shown on tables 47, 48 and 49. Apart from water samples from site 7 and 8 which had higher values, all the other water samples showed lower lead levels that fell within the WHO (2007) recommended limits of 0.0l ppm for drinking water. Emhemmed *et al.* (2014) also observed similar levels of lead concentration during the analysis of heavy metals in underground water wells in the Gharian district. The high lead concentration occurred during the dry season. Lead contamination is one of the most important heavy metal toxicant in water, so monitoring the level of lead in water sources is very necessary because of the negative effect on human health. Though, Klassen (2001) stated that lead poisoning is rare, but continued exposure of the body to low levels causes interference of the red blood cell chemistry, delays in physical and mental development of infants and young children. Lewis and Cohen (2004) reported that the ability of lead ion to undergo metathesis reactions with zinc iron and calcium ion metalloproteins leading to the loss of metabolic function remains the source of the harmful effect of lead exposure.

ii. Copper (Cu)

Copper is widely distributed and is an essential metal required by all living organisms in some of enzyme systems, but at higher concentration it acts as pollutant. The results obtained for the analysis of copper (cu) in all the water samples from the three LGA's are presented on tables 50, 51 and 52. In both the wet and dry season, copper was detected in very small quantities below the 2mg/l standard limit of the WHO (2004a). The result thus suggest that the water sources in the communities are free of copper poisoning. Sanjoy and Rakesh (2013) also reported in their work that concentrations of copper in most of the samples of surface water were not detected. Even though detected at some samples; they were very low concentrations well below the permissible limit for drinking water guidelines prescribed by WHO The low level of copper concentration indicates that there was no significant source of copper pollution in all the study sites.

iii. Zinc (Zn)

Another important trace metal is zinc (Zn), as studies by Florianncyk and Trojanowski (2009) reveals that excess intake of zinc ions can lead to death of neuron. And the toxicity due to high concentrations of zinc can cause vomiting and diarrhoea as well as impart unpleasant taste to drinking water sources. Fortunately, the concentration of zinc detected in this study for all the water samples in both the wet and dry seasons are far below the 3mg/l recommended by WHO (2007), (53, 54, and 55). Zinc does not accumulate in the body with continued exposure, but modulated by the body systems homeostasis mechanism. Zinc is an essential element for plant and human beings found in water and soil as an organic complexes and inorganic salts. It enters the water supply and water bodies from industrial wastes, deterioration of galvanized iron and dezincification of brass etc. Zinc

sulphates containing fertilizers are also responsible for higher values of Zn in water (Wu *et al.*, 2008).

iv. Cadmium (Cd)

Analysis for Cadmium in all the water samples showed that the heavy metal occurred in very insignificant quantities in a few of the samples, while in the majority it was not detected at all (tables 56, 57, and 58). In water samples where it was recorded, the concentration was equally below the WHO (2004a) recommendation of 0.004mg/l of Cadmium in drinking water sources. However, slightly higher values was detected for the stream water samples, which makes it a potential health risk for the residents of those communities. The concentration levels of Cd in both surface and ground water in maximum number of study sites were greater than the permissible limit of 0.01 mg l as set by both WHO. Therefore, considering the level of Cadmium concentrations detected, it may be concluded that the water in this area are not suitable for drinking purposes because of its high toxicity which is responsible for adverse renal arterial changes in kidneys in man, Sanjoy and Rakesh (2013). Ingestion of Cadmium by human beings through continued exposure puts the kidney the target organ at danger, as the WHO (2014) had estimated the biological life of cadmium to be between 20-30 years in the kidney. Kakei*et al.*, (2009) revealed that chronic Cadmium exposure in human beings can lead to defective formation of crystals especially as electron microscopy showed the presence of crystals that are perforated suggesting that the normal process of crystal nucleation could have been disrupted by ingestion of high concentrations of Cadmium.

v. Nickel (Ni)

The concentration of Nickel detected in the water samples are presented on tables 58, 59 and 60 for Ikwerre, Emohua, and Etche LGA's respectively. The Nickel

level was high in wells number 1 and 2 and in all the stream water samples especially during the dry seasons. However, except for those instances where a slightly high values for Nickel was detected in the dry season, results of all the other water samples showed values below the WHO (2004a) and NIS (2007) 0.0 2mg/l limit. The Nickel (Ni) concentrations for the stream samples were above the recommended permissible limits indicating a possible health risk. The associated health consequence of consumption of water bearing high levels of Nickel is the development of cancerous cells (NIS, 2007). This result agrees with the findings of Emhemmed et al., (2014), who reported that the concentration of Ni in some of the water samples analysed in their work were relatively high (largest value, 0.045 mg/L) when compared to the International standard values of 0.02 mg/L.

v. Mercury (Hg)

Many of the well and stream water samples had mercury levels above the WHO recommended value of 0.02mg/l as shown on tables 61, 62, 63. The high values were recorded more during the dry season than the raining season. Sanjoy and Rakesh (2013) also reported high values for Hg and Cd contents in a few studied sites of surface andground water which showed very wide variations and crossed the WHO maximum permissible limit of 0.02mg/l. In a study of heavy metals concentrations in ground water from Northern Nigeria, Shabanda and Shabada (2016) observed high levels of mercury in the water samples. Similarly, Ratuja et al., (2018) noted high levels of mercury in their analysis of the physicochemical parameters of surface and ground waters. Elemental (metallic) mercury and its compounds are toxic and exposure to excessive levels can permanently damage or fatally injure the brain and kidneys. Elemental mercury can also be absorbed through the skin and cause allergic

reactions. Ingestion of inorganic mercury compounds can cause severe renal and gastrointestinal toxicity (Emhemmed *et al.*, 2014).

5.2 Summary

i. The contamination of water resources used for household chores and drinking purposes with harmful microorganism, metal ions or heavy metals account for a major health problem, especially among the low income group and the rural dwellers.

ii. Microbiological analysis of the well and stream water sources for the various communities in the three local government areas investigated showed a slightly high values for bacteria and fungi count.

iii. Total heterotrophic bacteria occurred more in Emohua LGA with count of 1.7 $x10^4$cfu/ml than in Ikwerre and Etche LGA's. Analysis of Variance reveals that there was significant difference between the mean total heterotrophic bacterial counts of the well water sources from the three LGA's.

iv. The biochemical characterization and molecular identification of the isolates revealed the presence of potential waterborne pathogens, such as *E. coli, Salmonella* sp, *Vibrio sp* and others such as *Staphylococcus* sp, *Bacillus* sp,*Klebsiella* sp that are hazardous to human health when consumed or ingested.

v. The *E.coli, Salmonella* sp and *Vibrio* sp isolated from the water samples proved to be the major pathogens of public health risk, since their enterotoxin showed high toxigenicity values in experimental rats. These pathogens may be responsible for the reported cases of waterborne illnesses witnessed by members of the communities in the affected Local Government Areas.

vi. In general, seasonal changes showed significantly higher bacteriological count in the wet season than in the dry season. This result indicates a higher risk of waterborne diseases in the wet season and this is consistent with similar studies carried out on hand dug wells.

vii. The antibiotics of choice for the treatment of these observed waterborne diseases include; Oflaxicin, Nitrofurantoin and Nalixidic acid because of the high sensitivity of these drugs. The pathogens were resistant to Amoxicillin, Augumentin and Cotrimazole antibiotics.

viii. In contrast to the well water samples, the stream water recorded values above the WHO recommended concentrations for Copper, Zinc, Magnessium, Conductivity, Chloride, Cadmium, Nitrates, Nickel, Lead, Mercury, Total Dissolved Solids etc..

ix. Based on the WHO standards, the well and stream water samples that were obtained from all the communities in the three LGA's are not acceptable for human consumption because of their high bacterial loads both during the wet and dry seasons .

5.3 Conclusion

The majority of wells and streams in the three Local Government Areas studied contained total coliform and *E.coli* counts in numbers high above the WHO recommended value of (0/100ml) for drinking water sample. The wells and streams used by the residents of the communities cannot therefore be considered as good sources of water for human consumption.

The high levels recorded for some of the physico-chemical parameters may have further exacerbated the poor quality of the well and stream water sources. This is an indication of pollution hazards and weak drinking water treatment practices

in these areas which, in turn, have implications on the health of the people. The quality of well and stream water sources from all the study communities became poorer during the wet season due to the influence of seasonal variation.

Access to good quality or potable drinking water and efficient sanitary practices are fundamental to human health and economic development. The occurrence of pathogenic bacteria in natural water sources requires routine evaluation in order to forestall the outbreak of waterborne disease epidemics. Although, some progress have been made by both the local, state and federal authorities towards the provision of potable water to prevent the occurrence of waterborne disease, a lot still remains to be done to totally eradicate this deadly menance.

5.4 Recommendations

i. The incidences of waterborne diseases from different water sources, underscores the need to explore their prevalence rates, antibiograms and enterotoxigenicity for proper planning, effective control and prevention strategies for managing the hazards that may compromise the safety of drinking water.

ii. Government should provide safe, affordable and potable water to avoid the occurrence and spread of waterborne diseases among the citizens, especially among the rural communities and the poor urban residents.

iii. In the absence of potable water supplies, well water sources should be carefully constructed with concrete lining and suitable metal cover.

iv. Poor hygiene practices such as open defecation, dumping of refuse close to the stream and well water sources should be discouraged by individual households.

v. The residents should be exposed to regular enlightenment campaigns on the health risk of poor hygiene and poor sanitary practices. Health officials or Sanitary Marshalls can be engaged by the government to monitor the activities of residents in the communities towards a clean environment.

vi. Members of the rural communities be should advised on the need to use simple treatment and purification techniques for drinking water meant for their household.

vii. Routine evaluation of the water quality is required by health officials and other allied professionals to ensure timely intervention where necessary.

5.5 Contributions to Knowledge

i. Carry out this work research and documentation of the actual prevailing living conditions of these seemingly unheard rural communities in the respective LGA's of Rivers State is major contribution.

ii. The study has shown to the general public that the sources of water available to residents of the three LGA's are hand-dug wells and shallow streams, causing unexpected waterborne diseases outbreaks.

iii. The study will help to attract and direct the attention of policy makers to provide basic social amenities to the areas.

iv. The established antibiogram profiles of *Escherichia coli*, *Salmonella* sp and *Vibrio* sp will be of immense guide to medical practitioners in the treatment of waterborne illnesses caused by these pathogens.

v. This attempt at molecular identification of the organisms in the various water sources from the Local Government Areas will provide a baseline information for further research.

REFERENCES

Abioye, J. O. K; Salome, B. and Adogo, L. Y. (2017). Prevalence of *Salmonella typhi* Infection in Karu Local Government Area of Nasarawa State, Nigeria. *Journal of Advances in Microbiology* 6(2); 1-8, 2456-7116.

Abui, M.Y., Garba, D.P., Rikichi, B. and Stephen, S. (2016). The Challenges of Rural water supply in Nigeria. *Dynamic Journal of Environmental Science and Technology*, 1(4): 24-30.

Adekunle, I.M., Adetunji, M.T., Gbadebo, A.M. and Banjoko, O.B. (2007). Assessment of ground water quality in a typical rural settlement in southwest Nigeria. *International Journal of Environmental Research Public Health,* 4(4); 307-18.

Adekunle, O. A; Mary, A. B; Oyinade, A. A; Bridget, O. F. and Adebanke, O. A.(2011). Antibiotics sensitivity patterns of Escherichia coli and Aerobacteraerogenes isolated from well water in Ile–Ife, Nigeria, *International Journal of Medicine and Medical Sciences* 3(5);155-160.

Adelekan, B. A. (2010). Water Quality of domestic wells in typical African Communities: A case studies from Nigeria. *International Journal of Water Resources and Environmental Engineering,* 2(6); 137-147.

Adeleye, I. A; Daniels, F. V. and V.AEnyinnia, V. A. (2010). . Characterization And Pathogenicity Of *Vibrio Spp*. Contaminating Seafoods In Lagos, Nigeria. Internet Journal of Food Safety, 12, 1-9.

Adepoju-Bello, A. A., Ojomolade, O. O., Ayoola, G. A. and Coker, H. A. B. (2009). Quantitative analysis of some toxic metals in domestic water obtained from Lagos metropolis. *The Nigeria Journal of Pharmacy*, 42(l); 57-60.

Adeyemi, O., Oloyede, O. B. and Oladiji, A. T. (2007). Physiochemical and microbial characteristics of Leachate contaminated ground water. *Asian Journal Biochemistry*, 2(5); 343-348.

Adeyinka, S. Y., Wasiu, J. and Akintayo, C. O. (2014). Review on prevalence of waterborne disease in Nigeria. *Journal of Advancement in Medical and Life Sciences,* 1(2);1-3.

Agwaranze, D.I., Ogodo, A. c., Nwaneri, C. B. and Agyo, B. (2017).Bavteriological examination of well water in Wukari, Nigeria. *International Journal of Scientific Research in Environmental Sciences,* 5(2)., 0042-0046.

Ajibare, A. O. (2014). Assessment of Physico-Chemical Parameters of Waters in Ilaje Local Government Area of Ondo State, Nigeria. *International Journal of Fisheries and Aquatic Studies*, 1(5)., 84-92.

Akoto, O. and Adiyah, J. (2007). Chemical Analysis of drinking water from some communities in the Brong Ahafo Region. *International Journal of Environmental Sciences and Technology,* 4(2);211-214.

Alabaster, J.S. and Llyod, R. (1980). Water quality for fresh fish. 1st Edition. Butterworth, London, p. 283.

Alayande, M. O., Edungbola, L. D., Fabiyi, J. P., Faleke, O. O., Babatunde S. K., Akanbi A. A., and Nyamngee, A. (2012). *Toxoplasma gondii* and intestinal helminth infections among owned and strayed cats in Sokoto, Nigeria. *Research Journal Verterinary Science,* 5:69-74.

Al-Ghamdi,A.Y., Mohamed El-Shahate, I. S, Al-Ghamdi, A. O. and S.A. Zabin, S. A. (2014).Study Of Physico-Chemical Properties of the Surface And Ground Water . *American Journal of Environmental Sciences,* 10 (3); 219-235

Allerberger, F. and Wagner, M. (2010). Listeriosis: A resurgent foodborne infection. *Clinical Microbiology Infection,* 16:16-23.

Altekruse, S. F., Stern, N. J., Fields, P. I., and Swerdlow, D. L. (1999). *Campybbacter jejuni* — an emerging foodborne pathogen. *Emerging Infectious Disease,* 5; 28- 35.

Aminata, K., Linda, P., Nathan, A., Kelli, W., Kurt, P. and Dale, Y. (2018). Evaluation of Well Designs to Improve Access to Safe and Clean Water in Rural Tanzania. *International Journal of Environmental Research and Public Health*, 13 (6) ., 1-11.

Anju, G., Pratap, C. R., Vysakhi, M. V. and Anu, A. S. (2012). Physical and bacteriological quality of well water samples from kanakkary panchayath, kottayam district, kerala state, india. International Journal of Plant, *Animal and Environmental Sciences*, 2 (3)., 133-138.

Anyanwu, C.U. and Okoli, E. N. (2012). Evaluation of the bacteriological and Physico-chemical quality of water supplies in Nsukka, Southeast, Nigeria. *African Journal of Biotechnology*, 11(48)., 10868-10873.

Aranda, K. R. S; Fabbricotti, S. H; Fagundes-Neto, U. and Scaletsky, C. A. (2007). Single multiplex assay to identify simultaneously enteropathogenic, enteroaggregative, enterotoxigenic, enteroinvasive and Shiga toxin-producing Escherichia coli strains in Brazilian children. *Federated European Microbiology Society Letters*, 267; 145-150.

Argudin, M. A., Mendoza, M. C, and Rodicio, M.R. (2010). Food poisoning and *Staphylococcus aureus* enterotoxins". *Toxins,* 2(7); 175-73.

Asiton, A. D; Gideon, O. A; Stella, N. I.(2012). Enterotoxicigenicity profile of Escherichia coli, Vibrio, and Salmonella species isolated from well and river water sources in Oproama town in the Niger Delta, Nigeria. *Biokemistri*, 24(2); 64-66.

Asthana, D. K, and Meera, A. (2013). Environment, Problems and Solution. S. Chand and Company, New Delhi, Indian. Pp. 167-172

Azuonwu, O; Azuonwu, T, C.and Nwizug, W. L. (2017). Evaluation of Bacteriological Quality of Surface, Well, Borehole and River Water in Khana Local Government Area of Rivers State, Niger Delta. *Annual Clinical Laboratory Research,* 5(3);183-189.

Babiker, M.A., Ali, M.S., and Ahmed, E.S. (2009). Frequency of intestinal parasites among food-handlers in Khartoum, Sudan. *East Mediterrian Health Journal,* 15(5);1098-1104.

Balaban N., and Rasooly, A. (2000). Staphylococcal enterotoxins. *International Journal Food Microbiology,* 61:1-10.

Balasubramanian, A. and Nagaraju, D. (2015).*The Hydrologic Cycle*. Available from: https://www.researchgate.net/publication/315125743_The_Hydrologic_Cycl E [accessed Oct 17 2018]. *American Journal of Environmental Sciences,* 10 (3); 219-235.

Balselki, V., Briggs, R., and Parker, C. (1977). Intestinal Fluid Accumulation induced by oral challenge with *Vibrio cholerae* or Cholera toxin in Infant Mice. *Infection and Immunity,* 15(3); 704-712.

Bansal, R. C., and Goyal, M. (2010). Activated carbon adsorption. Critical Review of Microbiology press. Pp154-160.

Barakat, M. A. (2011). New trends in removing heavy metals from industrial wastewater. *Arabian Journal of Chemistry*, 4(4); 361-377.

Barrabeig, I., Rovira, A, Buesa, J., Bartolome, R., Pinto, R., Prellezo, H., and Dominguez, A. (2010). Foodborne norovirus outbreak: the role of an asymptomatic food handler. *BMC Infectious Disease*, 10:269-276.

Becker, K, Keller, B., von Eiff, C., Bruck, M., Lubritz, G., Etienne J, and Peters, G. (2001). Enterotoxigenic potential of *Staphylococcus intermedius". Applied Environmental Microbiology* 67:5551-5557.

Bello, O. O., Osho, A., Bankole, S. A. and Bello, T. K. (2013). Bacteriological and physicochemical analyses of borehole and well water sources in Ijebu-Ode, Southwestern Nigeria. *Journal of Pharmacy and Biological Sciences,* 8 (2); 18-25.

Ben Ayed, L., and Sabbahi, S. (2017). Entamoebahistolytica. In: J.B. Rose and B. Jiménez-Cisneros, (eds) Global Water Pathogens Project. http://www.waterpathogens.org (R. Fayer and W. Jakubowski, (eds) Part 3 Protists) www.waterpathogens.org/book/entamoeba-histolytica Michigan State University, E. Lansing, MI, UNESCO.

Benson, V. S., VanLeeuwen, J. A. , Sanchez, J. , Dohoo, I. R. and Somers, G. H. (2006). Spatial Analysis of Land Use Impact on Ground water Nitrate Concentrations. *Journal of Environmental Quality,* 35:421-432.

Binnie, C., Kimber, M., Smethurst, G. (2002). Basic water treatment. Royal Society of Chemistry, London, Pp. 105-115.

Blessy, B. M. and Krishnamurthy, N. B. (2014). Water: Its Constituents & Treatment Methods. Open Journal of Renewable and Sustainable Energy, 1(2)., 21-28.

Boyd, E.F., Cohen, A.L., Naughton L.M., Ussery D.W., Binnewies T.T., Stine, O.C., and Parent, M.A. (2008). Molecular analysis of the emergence of pandemic *Vibrio parahaemolyticus. BMC Microbiology*, 8:110-124.

Bryden, W.L. (2012). Mycotoxin contamination of the feed supply chains Implications for animal productivity and feed security. *Animal Feed Science Technology* ,173:134-158.

Brzuszkiewicz, E., Thijrrner, A., Schuldes, J., Leirnbach, A., Liesegang, H., and Meyer, F.D. et al. (2011). Genome sequence analyses of two isolates from the recent *Escherichia coli* outbreak in Germany reveal the emergence of a new pathotype: Entero-Aggregative-Haemorrhagic *Escherichia coli* (EAHEC). *Archives Microbiology*, 93(12) ; 883-891.

Carmo, L.S., Dias, R.S., Linardi, V.R., de Seria, M.J., and dos Santos, D.A. (2003). An Outbreak of Staphylococcal food poisoning in the municipality of Passes, Mg, Brazil. Braz. *Archives Biology Technology*, 46:581-586.

Carson, P., & Mumford, C. J. (2002). Hazardous chemicals handbook. Butterworth-Heinemann. Pp.121-130.

Center for Disease Control and Prevention (2011). *Escherichia coli* O157:H7 and other Shiga toxin-producing *Escherichia coli* (STEC). Available from: http://www.cdc.gov/nczved/divisions/ dfbmd/diseases/ecoli_o157h7/ (accessed 01.10.18).

Charles, A. O. and Anthony, I. O.(2017). Vibrio Pathogens: A Public Health Concern in Rural Water Resources in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health,* 14, 1188-1215.

Cheesbrough, M. (2006). District laboratory practice in tropical countries part 2. Cambridge University Press, New York; . ISBN-13 978-0-511-34842-6.

Chen,S. Li X. , Sun, O., Zhang, Y. Su J. et al., (2015). Heavy metal induced antibiotic resistance in bacterium LS/C7. *International Journal Molecular Science*, 16(10);23390-23404.

Cheremisinoff, N. P. (2001). Handbook of water and wastewater treatment technologies. Butterworth-Heinemann. Pp. 112-130.

Chessebrough, M. (1984). *Medical Laboratory Manual for Tropical Countries.* 2nd Edition. Butterworths-Heinemann Limited, London. P.111-116.

Chigor,V.N., Umoh, V.J. and Smith, S.I.(2010) Occurrence of *Escherichia coli* O157 in a river used for fresh produce irrigation in Nigeria. *African Journal of Biotechnology,* 9:178-82.

Chigor,V.N., Umoh, V.J. and Smith, S.I.(2010). Occurrence of *Escherichia coli* O157 in a river used for fresh produce irrigation in Nigeria. *African Journal of Biotechnology,* 9:178-82.

Chigozie, O. and Samuel, T. O. (2015). Prevalence and antimicrobial susceptibility of *Vibrio parahaemolyticus* isolated from seafoods in Lagos. Lagoon, Nigeria. *Cogent Food & Agriculture*, 1, 1041349-1041350.

Chitambar, S., Gopalkrishna, V., Chhabra, P., Patil, P., Verma, H., Lahon, A., Arora, R., Tarte, V., Ranshing, S., Dhale, G., Kolhapure, R., Tikute, S., Kulkarni, J., Bhardwaj, R., Akarte, S., and Pawar, S. (2012). Diversity in the enteric viruses detected in outbreaks of gastroenteritis from Mumbai, Western India. *International Journal Environment Research Public Health*, 9:895-915.

Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J., and Tchobanoglous, G. (2012). MWH's Water Treatment: Principles and Design. John Wiley Sons Inc., pp. 118-213.

Cruickshank, R., Duguid, J. R., Maimion, B. P., and Swain, R. H. A. (1980). Medical Microbiology. 12th Edition, Vol. II: *The Practice of Medical Microbiology.* Churchill Livingstone, Edinburgh. P.96-108.

Crump, J. A., Luby, S. P. and Mintz, E. D. (2004). The Global Burden of typhoid fever? *Bulletin of World Health Organisation,* 82: 346-353.

Dale, J.W. and Park, S.(2004). Molecular genetics of bacteria. Ontario, Canada: John .Wiley & Sons. 294-295. ISBN 0 470 85085 X

Daniel, D. J. (2008). Escherichia coliSTb toxin and colibacillosis: knowing is half the battle *Federation of European Microbiology Society Microbiology Letters.* 278; 137-145.

Dean, A. G., Ching, Y. C, Wmiams, R. Q. and Harden, L. B. (1972). Test for Escherichia coli enterotoxin using infant mice: application in a study of diarrhoea in children in Honolulu. *Journal Infectious Diseases,* 135:407-411.

Dhanaji K.G, Shagufta S. A, and Pramod J. N. (2016). Physico-Chemical Analysis of Drinking Water Samples of Different Places in KadegaonTahsil, Maharashtra (India). *Advances in Applied Science Research*, 7(6):41- 44.

Divya, S. R. and Sharon, M. S. (2016). Seasonal pattern s and behaviour of water quality parameters of Achenkovil River. *International Journal of Fisheries and Aquatic Studies*, 4(6); 489-494.

Dorny, P., Praet, N., Deckers, N., Gabriel, S. (2009). Emerging foodborne parasites. *Veterinary Parasitology,* 163:196-206.

Doudrick, K., Monzón, O., Mangonon, A., Hristovski, K., and Westerhoff, P. (2011). Nitrate Reduction in Water Using Commercial Titanium Dioxide Photocatalysts (P25, P90, and Hombikat UV100). *Journal of Environmental Engineering*, 138(8); 852-861.

Dubey, R. C. and Maheshwari, D. K. (2013). A textbook of Microbiology, S. Chand and company Ltd. Ram Nagar, New Delhi. Pp. 901-918.

Dworkin, M. S., D. P. Goldman, T. G. Wells, J. M. Kobayashi and B. L. Herwaldt (1996). Cryptosporidiosis in Washington State: An Outbreak associated with well water. *Journal of Infectious Disease,* 174:1372- 1376.

Eja, M.E., Abriba, C., Etok, C.A., Ikpeme, E.M., Arikpo, G.E., Enyi-Idoh K.H., and Ofor, U.A. (2008). Seasonal occurrence of *Vibrios* in water and shellfish obtained from the great Kwa River Estuary, Calabar, Nigeria. *Bulletin Environmental Toxicology,* 81:245-248.

Elberling, B. (2002). Grundvandskemi (Groundwater chemistry). In: Vandforsyning (Water supply), Karlby H. and Sorensen I., 2nd edition, Ingeniorenboger, Copenhagen, Denmark, pp. 83-102.

Emhemmed, A., Khadija, A., and Abulnabi, B. (2014). Concentration of Heavy Metals in underground water wells in Gharian district, Libya. *International Conference on Agricultural, Ecological and Medical Sciences* (AFEMS) , Feb. 6-7. P, 35-39.

Emmanuel, A. A., Fatima, J. G. and Giwa, A. (2015). Microbiological assessment of well waters in Samaru, Zaria, Kaduna, State, Nigeria. *Annuals of African Medicine*, 14 (1); 32-38.

Envuladu, E. A., Chingle, M. P., Banwat, M. E., Lar, L. A., Yusuff, O. E., Audu., S., Dakhin, A. and Zoakah, A. I. (2017). The quality of drinking well waters in Jos metropolis, North Central Nigeria. Jos Journal of Medicine, 6 (1); 17-21.

Esteban, J.I., Oporto, B., Aduriz, G., Juste, R.A., and Hurtado, A. (2008). A survey of food-borne pathogens in free-range poultry farms. *International Journal Food Microbiology,* 123 (1-2):177-182.

Even, S., Leroy, S., and Charlier, C. (2010). Low occurrence of safety hazards in coagulase negative Staphylococci isolated from fermented foodstuffs. *International Journal Food Microbiology*, 139:87–95.

Ezekiel, E.N., Hart, A.I. and Abowei, J. F.N. (2011). The Physical and Chemical Condition of

Fayer, R. (2004). *Cryptosporidium*: A waterborne zoonotic parasite. *Veterinary Parasitology,* 126:37-56.

Felsenstein J. (1985). Confidence limits on phylogenies: An approach using the bootstrap. *Evolution,* 39:783-791.

Finkelstein, R. A. (1973). Cholera. Critical Review of Microbiology, 2: 553-623.

Fiore, A. E. (2004). Hepatitis A transmitted by food. *Clinical Infectious Disease*, 38: 705-715.

Frank, C., Faber, M.S., Askar, M., Bernard, H., Fruth, A., Gilsdorf, A., Höhle, M., Karch, H., Krause, G., Prager, R., Spode, A., Stark, K., and Werber, D. (2011). Large and ongoing outbreak of haemolytic uraemic syndrome, Germany, Euro Surveillance, 16(21);pii=19878. Available online: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=19878. Accessed 10/10/2018.

Genigeorgis, C.A. (1998). Present state of knowledge on staphylococcal intoxication. *International Journal Food Microbiology,* 9: 327-360.

Ge, S. and Gorelick, S.M.(2015). Hydrology, floods and droughts of groundwater and surface water. In Encyclopedia of Atmospheric Sciences (Second Edition). Elsevier. Pp.201-216.

Ghasemi, E; Rahdar, M. and Rostami, M. (2015). Prevalence of Entamoebahistolytica/dispar in drinking water in the city of Cush, Khuzestan Province in 2011. *International Journal of Current Microbiology and Applied Sciences*. 4, 581–588.

Gideon, I. O; Inamul, H. M; Alexander, A. O. and Iftikhar, A. T. (2017). Antibiotic Susceptibility Profile of Bacteria Isolated from Drinking, Water Sources in Amai Kingdom, Delta State, Nigeria. *Annual Research & Review in Biology*, 14(1); 1-9.

Griffith, J. F., Weisberg, B. S. and D. C. McGee (2003). Evaluation of microbial source, tracking methods using mixed faecal sources in aqueous test samples. *Journal of Water Health,* 1:141-151.

Guillet, C., Lambert, O.J., Le Monnier, A., Leclercq, A., Mechaï, F., MamzerBruneel, M.F., Bielecka, M.K., Scortti, M., Disson O, Berche P., VazquezBoland, J., Lortholary, O., and Lecuit, M. (2010). Human Listeriosis caused by *Listeria ivanovii*. *Emerging Infection Diseases,* 16:136-138.

Gupta, D. P., Sunita and Saharan, J. P. (2009). Physiochemical Analysis of Ground Water of selected Area of Kaithal City (Haryana) India. *Researcher*, 1(2): 1-5.

Harrigan, W. F. and McCance, M. E. (1976). Laboratory Methods in Food and Microbiology. Academic Press Inc. Ltd., London. P.199-231.

Harris, D. C. (2007). Quantitative Chemical Analysis, 7th edition, W. H. Freeman and Company, New York

Helmes, M., Vastrup, P., Gerner-Smidt, P. and Molbak, K. (2003). Short and long term mortality associated with foodborne bacterial gastrointestinal infections: Registry-based study. BMC (Clinical Research Ed.), 326(7385), 357.

Hennekinne, J.A., Brun, V., De Buyser, M.L., Dupuis, A., Ostyn, A., and Dragacci, S. (2010). Innovative contribution of mass spectrometry to characterize staphylococcal enterotoxins involved in food outbreaks. *Applied Environmental Microbiology*, 75:882-884.

Hiyoshi, H., Kodama, T., Iida, T. and Honda, T. (2010). Contribution of *Vibrio parahaemolyticus* virulence factors to cytotoxicity, enterotoxicity, and lethality in mice. *Infection and Immunity*, 78:1772-1780.

Holt, J. G; Krieg, N. R; Sneath, P. H. A; Staley, J. T. and Williams, S. T. (1994). Bergey's manuel of determinative bacteriology, 9th Edition, Wolters Kluwer Company, New York. Pp. 87-112.

Hughes, K.A. and Thompson, A. (2004). Distribution of 58. sewage pollution around a maritime Antarctic research station indicated by faecal coliforms, *Clostridium perfringens* and faecal sterol markers. *Environmental Pollution*, 127(3);315-21.

Huq, A.; Grim, C. and Taylor, R. (2006). Detection, Isolation, and Identification of Vibrio cholerae from the Environment. *In Current Protocols in Microbiology*; John Wiley & Sons: New York, NY, USA, p. 136.

Ifeoma, B. U; Achadu, A. E; Kpurkpur, T .and Drenkat, M. N. (2018). Assessment of the incidence of diarrhea in children under 5 years at the Institute of Child Health, Banzazzau, Zaria. *Animaljournal.com*, 16, 1-5. Accessed October, 2018.

Ignatius, R., Gahutu, J.B., Klotz, C., Steininger, C. and Shyirambere, C. (2012). High Prevalence of Giardia duodenalis Assemblage B Infection and Association with Underweight in Rwandan Children. *PLoS Negl. Tropical Diseases*, 6:112-118.

Igwemmar, N. C., Kolawole, S. A. and Okunoye, L. K. (2013). Physical And Chemical Assessment Of Some Selected Borehole Water In Gwagwalada, Abuja. *International Journal of Scientific & Technology Research*, 2(11); 324-328.

Imani, F.A.A., Iman, I.D., Hosseini, D.R., Karami, A. and Marashi, S.M. (2013).Design of a multiplex PCR method for detection of toxigenic-pathogenic in *Vibrio cholerae. Asian Pacific Journal of Tropical Medicine,* 6(2); 11 5-8.

Internet Journal of Food Safety, Vol.12, 2010, p. 1-9 Food Safety Information Publishing

Jacobson, L. (2008). Listeriosis. *Pediatrics Review*, 29; 410-411.

Jaishankar, M., Mathew, B. B., Shah, M. S. (2014). Biosorption of Few Heavy Metal Ions Using Agricultural Wastes. *Journal of Environment Pollution and Human Health*, 2(1); 1-6.

Jayalakshmi, V., Lakshmi, N. and Singaracharya, M. A (2011). Assessment of physico-chemical parameters of water and wastewater in and around Vijayawada. International Journal Red Pharmarcy and Biomedical Sciences, 2;1040-104.

Jesse, I., Alessandro, M., Herman,W. B. and Sylvia, L.C.(2017). Total coliform and *Escherichia coli* contamination in rural well water: Analysis for passive surveillance. *Journal of Water and Health.* 15(5); 1 – 11.

Jidauna, G. G., Dabi, D. D., Saidu, J. B., Bitrus Abaje, B. and Ndabula, C. (2013). Assessment of Well Water Quality in Selected Location in Jos, Plateau State, Nigeria. *International Journal of Marine, Atmospheric & Earth Sciences,* 1(1); 38-46.

Jihyun, K. B; Eunhee , K. and Hyunook, K. (2013). Estimation of Biochemical Oxygen Demand Based on Dissolved Organic Carbon, UV Absorption, and Fluorescence Measurements. *Journal of Chemistry*, 13:1-9.

Jiménez-Coello, M., Acosta-Viana, K.Y., Guzmán-Marín, E., Puerto-Solís, M. and Ortega-Pacheco, A. (2012). Toxoplasmosis: A relevant zoonotic food borne disease in tropical conditions. *African Journal Microbiology Research,* 6:2956- 2964.

Júlio, C., Vilares, A., Oleastro, M., Ferreira, I., Gomes, S., Monteiro, L., Nunes, B., Tenreiro, R. and Ângelo, H. (2012). Prevalence and risk factors for Giardia duodenalis infection among children: A case study in Portugal. *Parasitology Vectors,* 5:22-25.

Kakei, M., Sakae, T. and Yoshikawa, M. (2009) Mechanism of cadmium induced crystal defects in developing rat tooth enamel. *Proceedings of JPN Academy,* Series B 85:500-507.

Klaassen, C. D. (2001). Heavy Metals and heavy-metal antagonists. In: Hardman, J. D., L Limbird and A. G. Gilman (eds). *The Pharmacological Basis of Therapeutics,* 12th Ed. McGraw Hill, New York. ppl851-1875.

Koopmans, M. and Duizer, E. (2004). Foodborne viruses: An Emerging Problem. *International Journal of Food Microbiology,* 90:23-41.

Koupal, L. R. and Diebel, R. H. (1975). Assay characterization and localization of an enterotoxin produced by *Salmonella. Infection and Immunity,* 11:14-18.

Krumperman, P. H. (1985). Multiple antibiotic indexing of *Escherichia coli* to identify high-risk sources of feacal contamination of foods. *Applied Environmental Microbiology*, 46: 165-170.

Kumar, A. & Awasthi, A. (2009). Bioseparation Engineering. IK International Pvt Ltd, India. Pp. 186-200.

Kumar, V., Das, S. & Jameel, S. (2010). The biology and pathogenesis of hepatitis viruses. *Current Science,* 98:312-325

Lewis, J. A. & S. M. Cohen (2004). Addressing lead toxicity, complexation of lead II with thopyrone and hydroxypridine-O, S-mixed chelators. *Inorganic Chemistry*, 43:6534-6546.

Linscott AJ (2011). Foodborne illnesses. *Clinical Microbiology Newsletter,* 33(6);41-46.

Liu, F., Kariyawasam, S., Jayarao, B.M., Barrangou, R., Gerner-Smidt, P., Ribot, E.M., Stephen, J., Knabel, S.J. and Dudley, E.G. (2011). Subtyping *Salmonella enterica* Serovar Enteritidis isolates from different sources by using sequence typing based on virulence genes and clustered regularly interspaced short palindromic repeats (CRISPRs). *Applied Environmental Microbiology,* 77:4520-4526.

Logsdonl, G. S., Freeman, S. D., Hulsey, R. A., and Veerapaneni, S. (2004). Cryptosporidium and GilI, dltl Contamination and Removal. *Advances in Water and Wastewater Treatment*, 487.

Loir, Y., Baron, F. and Gautier, M. (2003). *Staphylococcus aureus* and food poisoning. *Genetics Molocular Research,* 2:63-76.

Longhi, C., Conte, M.P., Penta, M., Cossu, A., Antonini, G., Superti. F. and Seganti, L. (2004). Lactoferricin influences early events *of L. monocytogenes* infection in THP-1 human macrophages. *Journal Medical Microbiology,* 53:87-91.

Lu X., Gao Y., Luo J., Van, S.H., and Rengel, Z., et al. (2014) Interaction of veterinary antibiotic tetracyclines and copper on their fates in water and water hyacinth *(Efcnhornia crassipes). Hazard Material,* 280: 389-398.

Majuru, B. Michael-Mokoena, M. Jagals, P. and Hunter, P.R. (2011). Health Impact of small-community water supply reliability. *International Journal of Hygiene Environment and Health,* 214(2); 162-166.

Manahan, S. E. (2004). Environmental Chemistry. CRC Press. Pp 202-213.

Manja, K.S., Maurya, M.S. and Rao, K.M. (1982). A simple field test for the detection of faecal pollution in drinking water. *Bulletin of the World Health Organization,* 60: 797-801.

Manji, P. L. Antai, S.P. and Jacob, L.O. (2012). Prevalence of Staphylococcus aureus and multiple antibiotic-resistant strains of Coliforms in Rural water supplies in Odukpani LGA. *Journal of Pure and Applied Microbiology,* 6(4); 1637 - 1644.

Marcovecchio, J.E., Boile, S.E. and Freije, R.H., (2007). Heavy Metals, Major Metals, Trace Elements. In: Handbook of Water Analysis. L.M. Nollet, (Ed.). 2nd Edn. London: CRC Press, pp: 275-311.

Marthin , J. A., Stephen, C. E. and Donald, J. R. (2004). Heterotrophic plate count bacteria- What is their significance in drinking water. *International Journal of Food Microbiology*. 92, 265-274.

Md. Khalid, H. R; Natasha, K; Md. Younus, M. and Marufa, N.(2017). Assessment of Water Quality and Microbial Load of Dhaleshwari River Tangail, Bangladesh. *Advances in Microbiology;* 7, 52 -55.

Mercier, A., Devillard, S., Ngoubangoye, B., Bonnabau, H., Bañuls, A.L., Durand, P., Salle, B., Ajzenberg, D. and Dardé, M.L. (2010). Additional haplogroups of *Toxoplasma gondii* out of Africa: population structure and mouse-virulence of strains from Gabon. PLoS Negl. *Tropical Disease,* 4:871-876.

Miller, W.A., Gardner, I.A., Atwill, E.R., Leutenegger, C.M, Miller, M.A., Hedrick, R.P., Melli, A.C., Barnes, N.M. and Conrad, P.A. (2006). Evaluation of methodsv or improved detection of *Cryptosporidium* spp. in mussels (*Mytilus californianus*). *Journal Microbiology Methods*, 65:367-379.

Mohammed, O. & Fohad, M. H. (2016). Antibiotics and Heavy Metal Resistance Emergence in water borne Bacteria. *Journal of Investigative Genomics,* 3(2);12440-12445.

Momodu, M.A. & Anyakora, C.A. (2010). Heavy Metal Contamination of Ground Water: The Surulere Case Study. *Research Journal of Environmental and Earth Sciences,* 2(1);39-43.

Monika, N. B; Nina, G; Marta, V; Zsofia, T., Donat, M; Cristina, V; Raquel, S; Carla, V. W. M., and Joao, B. (2017). Fungal Contaminants in Drinking Water Regulation? A Tale of Ecology, Exposure, Purification and Clinical Relevance. *International Journal of Environmental Research in Public Health*, 14(6), 63619.

Nachamkin, I. (2003). *Campylobacter* and *Arcobacter*. In: Manual of Clinical Microbiology, 8th ed. ASM Press, Washington, DC. pp. 902- 914.

Nainan, O., Xia, G., Vaughan, G. and Margolis, H.S. (2006). Diagnosis of hepatitis A virus infection: A Molecular Approach. *Clinical Microbiology Review*, 19:63-79.

Nair, G.B., Ramamurthy, T., Bhattacharya, S.K., Dutta, B., Takeda, Y. and Sack, D.A. (2007). Global dissemination of *Vibrio parahaemolyticus* serotype O3 :K6 and its sero-variants. *Clinical Microbiology Review,* 20:39-48.

National Committee for Clinical Laboratory Standards (NCCLS) (2005). *Performance Standards for antimicrobial Susceptibility testing: Fifteenth Informational Supplement.* CLSI document M100-S11. Pennsylvania, USA.

National Committee for Clinical Laboratory Standards (NCCLS) (2006). *Performance Standards for antimicrobial Susceptibility testing: Sixteenth Informational Supplement.* CLSI document M100-S11. Pennsylvania, USA.

NCDC (2017). National Cholera Situation Report; Week 36.

Nchawa, Y. Y. and Bassey, E. B. (2015). Antimicrobial Susceptibility Patterns of Salmonella Species from Sources in Poultry Production Settings in Calabar, Cross River State, Nigeria. *American Journal of Health Research*, 3(2); 76-81.

Ndip, R.N; Akoachere, J. F.T.K; Mokosso, D. K; Ndip, L. M; Anyangwe, I. A N . (2002). Carriage of Vibrio species by shrimps harvested from the coastal waters of South West Cameroun. East African Medical Journal, 79: 146-149.

Niba, R. N. and Chrysanthus, N. (2013).Bacteriological Analysis of Well Water Sources in the Bambui Student Residential Area. *Journal of Water Resource and Protection*, 5; 1013-1017.

Nigeria Industrial Standard (2007). Nigerian Standard for Drinking Water Quality. NIS 554.

NMWSOCM, (2013). New Mexico Water Systems Operator Certification Study Manual, Version IV.1, New Mexico Environment Department Utility Operator Certification Program, NMED Surface Water Quality Bureau, Santa Fe, NM 87502.

Novak Babič M., Zalar P., Ženko B., Džeroski S., Gunde-63. Tsui C.K.M., Baschien C., Goh T.-K. Biology and ecology of freshwater fungi. In: Li D.-W., editor. Biology of Microfungi. 1st ed. *Springer International Publishing*; Cham, Switzerland: 2016. pp. 285–313.

Nwabor, F.O., Nnamonu, E. I. and Martins, P.E. (2016). Water and Waterborne Diseases: A Review. *International Journal of Tropical Disease and Health,* 12(4);1-14.

Nyamngee, A., Kolawole, O.M., Durowade, K.A. and Kolawole, C.F. (2009). Prevalence of giardiasis among children in Guma refugee camp in Guma, Benue state, Nigeria. *Savannah Medical Journal*, 6:32-39.

Nyenje, M.E. and Ndip, R. N. (2013). The challenges of foodborn pathogens and antimicrobial chemotherapy: A Global Perspective. *African Journal of Microbiology Research*, 7(14);1158-1172.

Nyenje, M.E., Odjadjare, C.O., Tanih, N.F., Green, E. and Ndip, R.N. (2012b). Foodborne pathogens recovered from ready-to-eat foods from roadside cafeterias and retail outlets in Alice, Eastern Cape Province, South Africa: Public health implications. *International Journal Environmental Research Public Health,* 9:2608-2619.

Nyenke, C; Chukwujekwu, D. C; Stanley, H. O; Awoibi, N. K. (2017). Prevalence of Intestinal Amoebiasis in Infant and Junior School Children in Degema General Hospital and Environ. *Journal of Applied Science and Environmental Management*, 12(3); 83 – 87.

Odjadjare, E.E.O., Obi, L.C. and Okoh, A.I. (2010).Municipal wastewater effluents as a source of listerial pathogens in the aquatic milieu of the Eastern Cape Province of South Africa: A concern of public health importance. *International Journal of Environmental Research and Public Health,* 7:2376-94.

Olatunde, S. K. and Ayandele, A. A. (2018). Microbiological and physico-chemical analyses of hand dug well-water near pit latrine in a rural Area of Western Nigeria. *African Journal of Environmental Science and Technology,* 12(4); 132-140.

Olatunji, J. A., Odediran, O. A., Obaro, R. I., Olasehinde, P. I. (2015). Assessment of Groundwater Quality of Ilorin Metropolis using Water Quality Index Approach. *Nigerian Journal of Technological Development*.12(1); 18-21.

Olatunji, M. K.., Kolawole, T. A., Albert, B. O. and Anthony, I. O. (2011).Assessment of water quality in Asa River and its indigenous Clariasgariepinus fish. *International Journal of Environmental Research and Public Health*, 8, 4332-4352.

Omoruyi, B., Matongo, F., Nkwetshana, N.T., Green, E., Clark, A.M. and Ndip, R.N. (2011). Environmental and demographic risk factors associated with the prevalence of *Cryptosporidium* infection in the Alice rural settlements of the Eastern Cape Province of South Africa: a pilot study. *Review Environmental Health,* 26(2);127-133.

Onuigbo, A.C., Onyia, C., Nwosu, I. G. and Oyeagu, U. (2017). Impacts of bacterial pollution on hand- dug well water quality in Enugu, Enugu State, Nigeria. *African Journal Environmental Science Technology,* 11(6); 331-338.

Onuorah, S; Elesia, R.andOdibo, F.(2016). Bacteriological Quality Assessment of Hand-dug Shallow Water Wells in Awka Metropolis, Anambra State, Nigeria. *Universal Journal of Applied Science* 4(2); 17-24.

Oporto, B., Esteban, J.I., Aduriz, G., Juste, R.A., and Hurtado, A. (2007). Prevalence and strain diversity of thermophilic campylobacters in cattle, sheep and swine farms. *Journal Applied Microbiology*, 103(4);977-984.

Orebiyi, E. O., Awomeso, J. A., Idowu, O. A., Martins, O. O. and Taiwo, A. M. (2010). Assessment of pollution hazards of shallow well water in Abeokuta and environs, southwest, Nigeria. *American Journal of Environmental* Science, 6(1);50-56.

Ostyn, A., De Buyser, M.L., Guillier, F., Groult, J., Fe´lix, B., Salah, S., Delmas, G. and Hennekinne, J.A. (2010). First evidence of a food-poisoning due to Staphylococcal enterotoxin type E in France. *Eurosurveillance*, 15:19528.

Ottaviani, D., Leoni, F., Rocchegiani, E., Canonico, C., Potenziani, S., Santarelli, S., Masini, L., Scuota, S. and Carraturo, A. (2010). *Vibrio parahaemolyticus*-associated gastroenteritis in Italy: persistent occurrence of O3:K6 pandemic clone and emergence of O1:KUT serotype. *Diagnostic Microbiology Infectious Diseases*, 66:452-455.

Oyeku, O.T. and Eludoyin, A.O. (2010). Heavy metal contamination of ground water resources in a Nigerian urban settlement. *African Journal of Environmental Science and Technology*, 4(4); 201-214.

Panin, G. N. (2013). Types and Properties of Water. EOLSS. London. Pp, 201- 241.

Pepper, I.L. and Gerba, C.P. (2004). Environmental & microbiological laboratory manual. 2nd ed. 54 Burlington MA 01803, USA: Elsevier Academic Press. 157-162.

Pooja, N. (2017). *Physical, Chemical and Biological Characteristics of Water (e Content Module)*. Available from: https://www.researchgate.net/publication/322419790_Physical_Chemical_and_Biological_Characteristics_of_Water_Content_Module [accessed Oct 17, 2018].

Powlson, D. S., Addiscott, T. M., Benjamin, N. , Cassman, K. G. , De Kok, T. M., Grinsven, H.V., L'hirondel, J. L. , Avery, A. A. and Kessel, C. V. (2008). When Does Nitrate Become a Risk for Humans. America Society of Agronomy, Soil Science Society of America, Crop Science Society of America. *Journal of Environmental Quality*, 37: 291-295.

Rajappa, B., Manjappa, S. and Puttaiah, E. T. (2010). Monitoring of heavy metal concentration in ground water of Hakinaka Taluk, India. *Contemporary Engineering Sciences*, 3(4); 183-190.

Raji, M.I.O. Ibrahim, Y.K.E. and Ehinmidu, J.O. (2010). Bacteriological quality of public water sources in Shuni, Tambuwal and Sokoto towns in north-western Nigeria. *Journal Pharmacy Bioresource*, 7(2);55-64.

Ralph, M. and Ji-Dong, G.U. (2010). Environmental Microbiology, 2nd Edition, New Jersey, U.S.A. John Wiley and Sons Inc. pp. 126-150.

Romulus, A, M. Mutemi, M. E, M; Kennedy, M. and Cecilia, M. M. (2012). Physicochemical and bacteriological quality assessment of shallow wells in Kitui town Kenya. *Journal of Environmental Science and Water Resource,* 1(2);27-33.

Rossiter, H.M.A., Owusu, P.A., Awuah, E., MacDonald, A.M. and Schafer, A.L. (2010). Chemical Drinking Water Quality in Ghana: water costs and scope for advanced treatment. *Journal of Science and Total Environment,* 408(11); 2378-2386.

Rutuja, D., Nuzhat, Aina, C. W., Isabel, S., Appasaheb, G. and Tannaz, B. (2018). Physicochemical and Bacteriological Analysis of Water Quality in Drought Prone Areas of Pune and Satara Districts of Maharashtra, India. *Environments*, 5(61); 1-20.

Saghaian, S.H., Maynard, L.J. and Reed, M.R. (2006). Contributed paper presented at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18.

Saif, N.A., Mohammed, I.Y., Paulser, J.R., and Musharafi, S.K. (2014). Survival and Growth of Antibiotic Resistant Bacteria in treated wasterwater and water distribution system and their implication in Human Health: A Review. *The International Arabic Journal of Antimicrobial Agents,* 4(4);31-10.

Saitou N. and Nei, M. (1987). The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Molecular Biology and Evolution* 4:406-425.

Samantha, L.L. and James M.H.(2016). Antimicrobial Reistance, Food Safety, and one's Health: The need for convergence. *Annual Review of Food Science and Technology*, 7: 287-312.

Samson, R. A., Hoekstra, E. S. and Oorschot, Van (1981). *Introduction to Food-borne Fungi.* 3rd Edition. Centralbulreau Voor Schimelcultures, Baarn. P. 246.

Sánchez-Hervás, M., Gil, J.V., Bisbal, F., Ramón, D. and Martínez-Culebras, P.V. (2008). Mycobiota and mycotoxin producing fungi from cocoa beans. *International Journal of Food Microbiology,* 125:336-340.

Sanjoy, M. L. and Rakesh, K. H. (2013). A comparative study of the ground and surface water quality with reference to heavy metal concentrations in the Imphal valley Manipur, India. *International Journal of Environmental Sciences* 3(6); 1857-1867.

Saulat, J. (2014). Epidemiology of Foodborne Illnesses. Research and Information Unit, Ministry of Health, kingdom of Saudi Arabia. 321-342.

Scallan, E., Hoekstra, R.M., Angulo, F.J. V., Tauxe, R.V., Widdowson, M.A., Roy, S.L., Jones, J.L., Patricia, M. and Griffin, P.M. (2011). Foodborne illness acquired in the United States-Major pathogens. *Emerging Infectious Diseases*,17:7-15.

Schelin, J., Wallin-Carlquist, N., Cohn, M.T., Lindqvist, R., Barker, G.C. and Rådström, P. (2011). The formation of *Staphylococcus aureus* enterotoxin in food environments and advances in risk assessment.*Virulence,* 2:580-592.

Scott, W. G., Scott, H. M., Lake, R. J., and Baker, M. G. (2000). Economic cost to New Zealand of foodborne infectious disease. *The New Zealand Medical Journal,* 113(1113), 281-284.

Shabanda, I. S. & Shabanda, I. J. (2016).Heavy Metals Concentrations in Ground Water from Northern Nigeria. *Advances in Environmental and Geological Science and Engineering*, 7(5); 428-433.

Sharma, V.K. and Dean-Nystrorn, E.A. (2006). Detection of enterohemorrhagic *Escherichia coli* O157:H7 by using a multiplex real-time PCR assay for genes encoding intimin and Shiga toxins.*Veterinary Microbiology*, 93: 247-60.

Shuler, M. L., Kargi, F. (2002). Bioprocess engineering New York: Prentice Hall. pp. 249-254.

Singh, D. V; Isac, S. R. and Colwell, R. R. (2002). Development of a hexaplex PCR assay for rapid detection of virulence and regulatory genes in *Vibrio cholera* and *Vibrio mimicus*. *Journal of Clinical Microbiology*, 40(11); 4321-4324.

Sombreiro River, Niger Delta, Nigeria. *Research Journal of Environmental and Earth Sciences.* 3(4);327-340.

Stanley, C. O. (2015). The antibiotics susceptibility pattern of *Escherichia coli* isolated from well water in Afikpo, South Eastern Nigeria. *American Association Science and* Technology *Journal of Biology,* 1(3); 38-42.

Su, Y.C. and Liu, C. (2007).*Vibrio parahaemolyticus*: A concern of seafood safety. *Food Microbiology,* 24:549-558.

Takeda, T., Takeda, Y., Miwatani, T. and Ohtomo, N. (1978). Detection of Cholera Enterotoxin Activity in Suckling Hamsters. *Infection and Immunity,* 19(2); 752-754.

Tarr, P.I., Gordon, C.A. and Chandler, W.L. (2005). Shiga-toxin-producing *Escherichia coli* and haemolytic uraemic syndrome. *Lancet,* 365:1073-1086.

Teunis, P.F.M., Moe, C.L., Liu, P., Miller, S.E., Lindesmith, L., Baric, R.S., Le Pendu, J. and Calderon, R.L. (2008). Norwalk virus: How infectious it is. *Journal Medical Virology,* 80:1468-1476.

Thomas, D., Chou, S., Dauwalder, O. and Lina, G. (2007). Diversity in *Staphylococcus aureus* enterotoxins. *Chemistry Immunology Allergy, 93*:24-41.

Tigini, V., Prigione, V., Giansanti, P., Mangiavillano, A., Pannocchia, A., & Varese, G. C. (2010).Fungal biosorption, an innovative treatment for the decolourisation and detoxification of textile effluents. *Water*, 2(3); 550-565.

Tilkian, S. M; Conover, M. C. and Tilkian, A. G. (1979). Blood chemistry and electrolytes. In: Clinical implication of laboratory tests. 2nd Ed. The C. V. Mosby Company. Missouri. Pp 3-26.

Tista, P; Binod, L; Dev, R. J. and Madhav, P. B. (2007). Microbiological analysis of drinking water of Kathmandu valley. *Scientific World*, 5(5); 112-114

Tolessa, M; Etana, D. and Ofgea, K. C. (2016). Antibiotic sensitivity pattern of pathogenic bacterial isolates of public health concern from Lake Hawassa water, Ethiopia. *International Journal of Water Resources and Environmental Engineering,* 8(4); 52-58.

Tsui C.K.M., Baschien C., Goh T.-K. Biology and ecology of freshwater fungi. In: Li D.-W., editor. Biology of Microfungi. 1st ed. *Springer International Publishing*; Cham, Switzerland: 2016. pp. 285–313.

Turner, S. M; Scott-Tucker, A; Cooper, L. M. and Henderson , I. R. (2006b). Weapons of mass destruction: virulence factors of the global killer enterotoxigenic Escherichia coli. FEMS Microbiology Letters, 263; 10–20.

Udujih, H. I; Ibe, S.N.O; Udujih, O.G; Iwuala, C.C; Edward, U.C. and Kenechukwudozie, Q.O.(2017). Salmonella Infection Among Undergraduate Students of Imo State University Owerri, Nigeria. *International Journal of Health, Safety and Environments*, 3(6); 128-133.

United Nations Children's Fund (UNICEF), (2010). Progress on Sanitation and Drinking Water. New York: UNICEF.

United Nations Children's Fund. (2008). Handbook on Water Quality. United Nations Plaza. New York, NY 10017, USA.

United States Environmental Protection Agency (USEPA) (2003). Drinking Water: National Primary Drinking Water Regulations.

USDIBR (2010). Water Treatment Primer for Communities in Need, Desalination Series Report No. 68, U.S. Department of the Interior Bureau of Reclamation.

Uzoigwe, C. I. & O. K. Agwa, O.K. (2012). Microbiological quality of water collected from boreholes sited near refuse dumpsites in Port Harcourt, Nigeria. *African Journal of Biotechnology*, 11(13); 3135-3139.

Van Looveren, M., Daube, G., De Zutter, L., Dumont, J.M., Lammens, C., Wijdooghe, M., Vandamme, P., Jouret, M., Cornelis, M. & Goosens, H. (2001). Antimicrobial susceptibilities of *Campylobacter* strains isolated from food animals in Belgium. *Journal Antimicrobial Chemotherapy, 48*: 235-240.

Venkatesharaju K, Ravikumar P, Somashekar, R. K. and Prakash, K. L. (2010). Physico- chemical and bacteriological investigation on the river Cauvery of Kollegal stretch in Karnataka. Kathmandu University. *Journal of Science Engineering Technology*, 6 (1); 50- 59.

Vugai, D.J., Samuel, M., Farley, M.M., Marcus, R., Shiferaw, B. & Shallow, S. (2004). Invasive *Samonella* infections in the United States, Foodnet, 1996-1999: incidence, serotype distribution, and outcome. *Clinical Infectious Diseases,* 38:S149-156.

Wagacha, J.M. & Muthomi, J.W.(2008). Mycotoxin problem in Africa: current status, implications to food safety and health and possible management strategies. *International Journal Food Microbiology,* 10(124);1-12.

Weese, J.S., Reid-Smith, R., Rousseau, J. & Avery, B. (2010). Methicillinresistant *Staphylococcus aureus* contamination of retail pork. *Canadian Veterinary Journal*, 51:749-752.

Wegener, H. C; Hald, T; LoFo Wong, D. M; Madsen, M; Korgaad, H. and Bager, F. (2003). *Salmonella* control programmes in Denmark. *Emerging Infectious Diseases*, 9, 774-780.

WHO (2007). Food safety and foodborne illnesses Fact sheet no. 237. http://www.who.int/mediacentre/factsheets/fs237/en/ Accessed on 9/10/2012.

WHO (2011). Enterohaemorrhagic *Escherichia coli* (EHEC). Fact sheet no.125 http://www.who.int/mediacentre/factsheets/fs125/en/. Accessed on 9/10/2012.

WHO (2014).World Health Organization.Guidelines for Drinking-Water Quality.Microbial Fact Sheet. p. 229-31. Available from: http://www.who.int/water/gdwq3rev/en. 23g dwq3_11.pdf G .[Last accessed on 2014 Apr].

WHO/UNICEF. (2005). World Malaria Report. Roll Back Malaria partnership, WHO/UNICEF. Available: http://rbm.who.int/wm r2005/ 45.

Wild, C.P. & Gong, Y.Y. (2010). Mycotoxins and human disease: a largely ignored global health issue. *Carcinogenesis* 31:71-82.

Williams, A.P., Quilliam, R.S., Thorn, C.E., Cooper, D., Reynolds, B. & Jones, D.L. (2012). Influence of land use and nutrient flux on metabolic activity of *E. coll* O157 in river water. *Water Air Soil Pollution,* 223: 3077-83.

World Health Organisation and United Nations Children's Emergency Fund (2010). Progress on Sanitation and Drinking Water; update. Joint Monitoring Programme for Water Supply and Sanitation.

World Health Organization (WHO), (2001). Wate quality: Guidelines, standards and health. Edited by Lorna Fewtrell and Jamie Bartram. Published by IWA Publishing, London, UK. ISBN: 1 900222 28 0

World Health Organization (WHO), (2003). Heterotrophic Plate Counts and Drinking-water safety. Edited by J. Bartram. P. 201-205.

World Health Organization (WHO), (2004a). Guidelines for drinking water quality. Vol. 1,Recommendations. 3rd Ed. WHO Geneva.

World Health Organization (WHO). (2011a). Food Safety. Retrieved June 26, 2011, from http:// www. who .int/foodsafety/foodborne_disease/fergl/ en/ index.html

World Health Organization (WHO). (2011a). Food Safety. Retrieved June 26, 2011, from http:// www. who .int/foodsafety/foodborne_disease/fergl/ en/ index.html

World Health Organization (WHO). (2011c). Initiative to estimate the Global Burden of Foodborne Diseases: Information and Publications. Retrieved June 26, 2011, from http:// www. who.int/foodsafety/foodborne_disease/ferg/ en/ index7.html

Wu, C.J., Hsueh, P.R. and Ko, W.C. (2011). A new health threat in Europe: Shiga toxinproducing Escherichia coli O104:H4 infections. *Journal Microbiology, Immunology Infections,* 44:390-393.

Wu, C.J., Hsueh, P.R. and Ko, W.C. (2011). A new health threat in Europe: Shiga toxinproducing Escherichia coli O104:H4 infections. *Journal Microbiology, Immunology Infections,* 44:390-393.

Yah, C. S ., Chineye, H. U. & N. G. Eghafona (2007). Multi-antibiotics-resistance plasmid profile of enteric pathogens in paediatnc patients from Nigeria. *Biokemistri*, 19(1); 35-42.

Yahaya, A. S., Hero, M. I. & Akhter, A. A. (2013). Bacteriological and mycological assessment for water quality of Duhok reservoir. Jordan Journal of Biological Sciences, 6 (4)., 308-315.

Zell, C., Resch, M., Rosenstein, R., Albrecht, T., Hertel, C. and Gotz, F. (2008). Characterization of toxin production of coagulase negative Staphylococci isolated from food and starter cultures. *International Journal of Food Microbiology,* 49:1577-1593.

Zhou, H. (2013). Tertiary Nitrification Using Membrane Aerated Biofilm Reactors: Process Optimization, Characterization and Model Development (Doctoral dissertation).

Zoe, J. (2015). What are the biological properties of water?www.quora.com. Accessed 18.10.1

APPENDIX I

Microbiological data obtained from the three LGAs

Table AI.1a: Total heterotrophic bacterial population of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	TOTAL HETEROTROPHIC BACTERIAL POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	3.1×10^2	3.5×10^2	4.1×10^3	3.3×10^2	4.0×10^2	2.4×10^2	3.0×10^2	3.6×10^2
February	2.6×10^3	3.1×10^2	4.0×10^2	2.0×10^2	4.2×10^2	2.1×10^2	2.8×10^3	3.0×10^3
March	2.2×10^2	3.0×10^2	3.7×10^2	2.5×10^2	2.5×10^2	2.2×10^2	2.0×10^3	2.6×10^2
April	4.6×10^2	3.3×10^2	3.8×10^2	3.0×10^3	3.0×10^2	2.4×10^2	2.7×10^3	3.1×10^2
May	4.0×10^2	2.1×10^2	1.6×10^3	3.0×10^2	3.1×10^2	5.0×10^2	3.0×10^3	3.5×10^2
June	4.7×10^2	3.4×10^2	5.0×10^2	3.0×10^3	3.3×10^2	5.2×10^2	2.4×10^3	4.3×10^2
July	8.0×10^2	4.1×10^2	3.0×10^3	2.7×10^3	7.2×10^2	4.0×10^2	3.2×10^3	4.5×10^2
August	6.5×10^2	5.5×10^2	6.2×10^2	3.0×10^3	3.3×10^2	5.1×10^2	3.5×10^3	5.3×10^2
September	4.1×10^2	7.4×10^2	6.1×10^2	2.8×10^3	4.0×10^2	4.3×10^2	3.3×10^3	5.1×10^2
October	5.4×10^2	4.7×10^2	7.4×10^2	1.8×10^3	6.9×10^2	3.4×10^2	2.6×10^3	5.6×10^2
November	5.0×10^2	4.1×10^2	5.3×10^2	4.6×10^2	5.2×10^2	3.0×10^2	3.2×10^2	4.7×10^2
December	4.2×10^2	3.6×10^2	4.8×10^2	4.0×10^2	4.7×10^2	2.6×10^2	3.8×10^2	3.7×10^2

Table AI.1b: Total heterotrophic bacterial population of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	TOTAL HETEROTROPHIC BACTERIAL POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	5.2×10^3	1.3×10^4	1.4×10^4	5.4×10^3	5.3×10^3	4.2×10^3	6.2×10^3	5.8×10^3
February	1.1×10^4	3.4×10^3	4.1×10^3	1.2×10^4	2.1×10^3	2.6×10^3	2.4×10^4	1.7×10^4
March	1.6×10^3	1.5×10^3	3.1×10^3	2.4×10^3	1.3×10^4	1.9×10^3	1.4×10^4	1.1×10^3
April	3.5×10^3	2.3×10^3	4.1×10^3	2.5×10^4	4.2×10^3	1.6×10^3	1.3×10^4	2.2×10^3
May	3.2×10^3	1.7×10^3	2.4×10^4	1.7×10^3	2.4×10^3	4.3×10^3	2.5×10^4	2.6×10^3
June	3.6×10^3	2.5×10^3	4.3×10^3	2.3×10^4	2.3×10^3	4.4×10^3	1.1×10^4	5.2×10^3
July	2.3×10^4	3.3×10^3	2.3×10^4	2.4×10^4	2.6×10^4	3.5×10^3	2.0×10^4	3.6×10^3
August	4.1×10^3	3.5×10^3	4.0×10^3	2.2×10^4	2.4×10^4	2.2×10^3	1.6×10^4	1.2×10^3
September	2.2×10^3	4.3×10^3	4.4×10^3	2.3×10^4	1.3×10^3	1.4×10^3	3.3×10^3	2.2×10^4
October	3.2×10^3	2.4×10^3	5.2×10^3	3.4×10^3	2.1×10^3	2.3×10^3	2.3×10^4	2.4×10^4
November	5.1×10^3	2.2×10^4	2.1×10^4	2.1×10^3	1.1×10^3	1.2×10^3	1.3×10^3	4.2×10^3
December	2.4×10^3	4.1×10^3	2.0×10^4	2.4×10^3	2.3×10^3	2.1×10^3	4.3×10^3	4.4×10^3

TABLE AI.1c: Total heterotrophic bacterial population of well and stream water samples from communities in Etche Local Government Area, Rivers State

	TOTAL HETEROTROPHIC BACTERIAL POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	3.3×10^2	2.7×10^2	2.5×10^2	3.4×10^2	3.2×10^2	2.8×10^2	4.3×10^2	3.0×10^2
February	3.0×10^2	3.1×10^2	2.6×10^2	2.8×10^2	3.0×10^2	2.9×10^2	3.3×10^2	2.2×10^2
March	1.7×10^2	1.8×10^2	2.0×10^2	2.0×10^2	2.1×10^2	2.0×10^2	2.5×10^2	3.3×10^2
April	2.6×10^2	2.1×10^2	2.3×10^2	2.1×10^2	3.2×10^2	1.4×10^2	2.4×10^2	3.6×10^2
May	2.8×10^2	1.6×10^2	7.0×10^2	2.6×10^2	2.2×10^2	3.1×10^2	3.0×10^2	3.9×10^2
June	3.1×10^2	2.4×10^2	3.8×10^2	3.6×10^2	2.7×10^2	3.5×10^2	3.7×10^2	4.0×10^2
July	4.0×10^2	3.0×10^2	4.3×10^2	2.0×10^2	3.5×10^2	3.6×10^2	2.1×10^2	4.0×10^2
August	4.2×10^2	4.3×10^2	4.5×10^2	2.2×10^2	2.0×10^2	4.2×10^2	2.3×10^2	4.0×10^2
September	4.3×10^2	4.6×10^2	3.2×10^2	2.4×10^2	1.6×10^2	3.1×10^2	2.5×10^2	4.3×10^2
October	3.4×10^2	3.6×10^2	3.0×10^2	2.0×10^2	3.3×10^2	2.7×10^2	2.0×10^2	2.5×10^2
November	4.1×10^2	3.9×10^2	2.8×10^2	3.2×10^2	2.4×10^2	2.2×10^2	2.7×10^2	2.8×10^2
December	3.0×10^2	2.1×10^2	2.2×10^2	2.1×10^2	2.2×10^2	1.9×10^2	2.2×10^2	3.0×10^2

Table AI.1d: Mean heterotrophic bacterial population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean THB population, cfu/ml)		
January	9.55×10^{2}	7.85×10^{3}	2.98×10^{2}
February	6.90×10^{2}	5.87×10^{3}	2.90×10^{2}
March	2.68×10^{2}	3.92×10^{3}	1.93×10^{2}
April	7.85×10^{2}	6.78×10^{3}	2.28×10^{2}
May	5.53×10^{2}	6.22×10^{3}	3.22×10^{2}
June	8.60×10^{2}	6.68×10^{3}	3.18×10^{2}
July	1.34×10^{3}	1.71×10^{4}	3.40×10^{2}
August	9.43×10^{2}	9.97×10^{3}	3.57×10^{2}
September	8.98×10^{2}	6.10×10^{3}	3.20×10^{2}
October	7.63×10^{2}	3.10×10^{3}	3.00×10^{2}
November	4.53×10^{2}	8.75×10^{3}	3.10×10^{2}
December	3.98×10^{2}	5.55×10^{3}	2.25×10^{2}

Table AI.1e: Mean heterotrophic bacterial population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean THB population, cfu/ml)		
January	3.30×10^{2}	6.00×10^{3}	3.65×10^{2}
February	2.90×10^{3}	2.05×10^{4}	2.75×10^{2}
March	1.13×10^{3}	7.55×10^{3}	2.90×10^{2}
April	1.51×10^{3}	7.60×10^{3}	3.00×10^{2}
May	1.68×10^{3}	1.38×10^{4}	3.45×10^{2}
June	1.42×10^{3}	8.10×10^{3}	3.85×10^{2}
July	1.83×10^{3}	1.18×10^{4}	3.05×10^{2}
August	2.02×10^{3}	8.60×10^{3}	3.15×10^{2}
September	1.91×10^{3}	1.27×10^{4}	3.40×10^{2}
October	1.58×10^{3}	2.35×10^{4}	2.25×10^{2}
November	3.95×10^{2}	2.75×10^{3}	2.75×10^{2}
December	3.75×10^{2}	4.35×10^{3}	2.60×10^{2}

Table AI.2a: Total fungal population of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	TOTAL FUNGAL POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	2.3x 10^3	2.6 x 10^3	2.4 x 10^3	2.1 x 10^3	2.7 x 10^3	1.2 x 10^3	2.5 x 10^3	2.9 x 10^3
February	2.1 x 10^3	2.4 x 10^3	2.1 x 10^3	2.2 x 10^3	3.1 x 10^3	1.1 x 10^3	2.3 x 10^3	2.6 x 10^3
March	3.4 x 10^3	3.0 x 10^3	2.0 x 10^3	2.5 x 10^3	3.2 x 10^3	2.4 x 10^3	3.0 x 10^3	3.1 x 10^3
April	2.7 x 10^3	3.0 x 10^3	2.8 x 10^3	2.6 x 10^3	2.1 x 10^3	2.4 x 10^3	1.7 x 10^3	1.5 x 10^3
May	3.6x 10^3	3.3 x 10^3	2.5 x 10^3	4.0 x 10^3	2.5 x 10^3	2.9 x 10^3	2.1 x 10^3	2.4 x 10^3
June	2.4 x 10^3	2.7 x 10^3	2.8 x 10^3	3.4 x 10^3	3.1 x 10^3	3.2 x 10^3	3.5 x 10^3	3.6 x 10^3
July	3.5 x 10^3	3.3 x 10^3	3.0 x 10^3	3.9 x 10^3	2.7 x 10^3	2.9 x 10^3	3.1 x 10^3	3.7 x 10^3
August	3.1 x 10^3	2.6 x 10^3	2.9 x 10^3	3.2 x 10^3	3.0 x 10^3	3.0 x 10^3	3.2 x 10^3	3.0 x 10^3
September	4.0 x 10^3	3.8 x 10^3	3.2 x 10^3	3.4 x 10^3	3.4 x 10^3	3.1 x 10^3	4.1 x 10^3	4.3 x 10^3
October	3.6 x 10^3	3.1 x 10^3	3.0 x 10^3	2.9 x 10^3	2.8 x 10^3	2.6 x 10^3	3.0 x 10^3	3.2 x 10^3
November	3.0 x 10^3	2.7 x 10^3	3.7 x 10^3	3.3 x 10^3	3.0 x 10^3	3.9 x 10^3	3.1 x 10^3	3.0 x 10^3
December	2.5 x 10^3	2.6 x 10^3	2.8 x 10^3	2.5 x 10^3	2.7 x 10^3	2.9 x 10^3	3.0 x 10^3	3.2 x 10^3

Table AI.2b: Total fungal population of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	TOTAL FUNGAL POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	1.1×10^3	2.2×10^3	1.9×10^3	2.6×10^3	5.1×10^3	1.3×10^3	1.0×10^3	1.1×10^3
February	1.0×10^3	2.1×10^3	1.7×10^3	2.4×10^3	4.9×10^3	1.2×10^3	1.1×10^3	1.2×10^3
March	1.2×10^3	3.1×10^3	1.6×10^3	1.8×10^3	1.5×10^3	1.1×10^3	2.1×10^3	2.2×10^3
April	1.5×10^4	1.8×10^4	1.4×10^4	1.0×10^4	1.5×10^4	2.1×10^4	1.3×10^4	1.0×10^4
May	3.2×10^4	2.2×10^4	1.0×10^4	3.1×10^4	1.2×10^4	2.2×10^4	1.4×10^4	1.2×10^4
June	1.3×10^4	2.1×10^4	2.2×10^4	2.7×10^4	2.4×10^4	2.8×10^4	1.6×10^4	1.3×10^4
July	4.4×10^3	1.0×10^4	1.2×10^4	4.1×10^4	1.0×10^4	1.1×10^4	1.0×10^4	4.1×10^4
August	1.4×10^4	1.1×10^4	1.0×10^4	1.3×10^4	2.3×10^4	1.4×10^4	1.1×10^4	1.0×10^4
September	2.3×10^4	4.1×10^4	1.1×10^4	1.0×10^4	1.4×10^4	1.2×10^4	1.3×10^4	1.1×10^4
October	1.3×10^4	1.1×10^4	1.4×10^4	1.2×10^4	1.3×10^4	1.0×10^4	1.2×10^4	1.0×10^4
November	1.6×10^3	1.3×10^3	4.1×10^3	1.1×10^3	1.5×10^3	3.1×10^3	1.0×10^3	1.1×10^3
December	1.4×10^3	1.4×10^3	1.0×10^3	1.2×10^3	1.1×10^3	1.4×10^3	1.3×10^3	1.6×10^3

Table AI.2c: Total fungal population of well and stream water samples from communities in Etche Local Government Area, Rivers State

	TOTAL FUNGAL POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	1.3 x 10^2	1.4 x 10^2	1.2 x 10^2	1.7 x 10^2	2.0 x 10^2	1.5 x 10^2	1.6 x 10^2	2.0 x 10^2
February	1.4 x 10^2	1.5 x 10^2	1.5 x 10^2	1.7 x 10^2	2.2 x 10^2	1.2 x 10^2	2.1 x 10^2	2.0 x 10^2
March	1.4 x 10^2	2.1 x 10^2	1.5 x 10^2	1.4 x 10^2	2.2 x 10^2	1.0 x 10^2	2.1 x 10^2	2.2 x 10^2
April	1.6 x 10^2	2.2 x 10^2	1.6 x 10^2	1.8 x 10^2	2.4 x 10^2	1.8 x 10^2	2.3 x 10^2	2.4 x 10^2
May	1.8 x 10^2	2.2 x 10^2	1.6 x 10^2	2.1 x 10^2	2.0 x 10^2	2.0 x 10^2	2.5 x 10^2	2.5 x 10^2
June	2.1 x 10^2	2.3 x 10^2	1.8 x 10^2	2.3 x 10^2	2.3 x 10^2	2.1 x 10^2	2.7 x 10^2	2.6 x 10^2
July	2.3 x 10^2	2.5 x 10^2	2.0 x 10^2	2.6 x 10^2	2.5 x 10^2	2.2 x 10^2	2.7 x 10^2	2.7 x 10^2
August	2.6 x 10^2	2.4 x 10^2	2.2 x 10^2	2.9 x 10^2	3.0 x 10^2	2.9 x 10^2	3.0 x 10^2	2.8 x 10^2
September	2.6 x 10^2	2.6 x 10^2	2.4 x 10^2	3.0 x 10^2	2.8 x 10^2	2.6 x 10^2	3.0 x 10^2	3.0 x 10^2
October	2.6 x 10^2	2.5 x 10^2	2.1 x 10^2	2.5 x 10^2	3.0 x 10^2	2.3 x 10^2	2.7 x 10^2	2.5 x 10^2
November	2.2 x 10^2	1.9 x 10^2	2.0 x 10^2	2.1 x 10^2	2.6 x 10^2	1.8 x 10^2	2.2 x 10^2	2.0 x 10^2
December	2.0 x 10^2	1.2 x 10^2	1.4 x 10^2	1.3 x 10^2	2.0 x 10^2	1.6 x 10^2	1.8 x 10^2	2.1 x 10^2

Table AI.2d: Mean fungal population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Fungal population, cfu/ml)		
January	2.22×10^3	2.37×10^3	1.52×10^2
February	2.17×10^3	2.22×10^3	1.58×10^2
March	2.75×10^3	1.72×10^3	1.60×10^2
April	2.60×10^3	1.55×10^4	1.90×10^2
May	3.13×10^3	2.15×10^4	1.95×10^2
June	2.93×10^3	2.25×10^4	2.15×10^2
July	3.22×10^3	1.47×10^4	2.35×10^2
August	2.97×10^3	1.42×10^4	2.67×10^2
September	3.48×10^3	1.85×10^4	2.67×10^2
October	3.00×10^3	1.22×10^4	2.50×10^2
November	3.27×10^3	2.12×10^3	2.10×10^2
December	2.67×10^3	1.25×10^3	1.58×10^2

Table AI.2e: Mean fungal population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Fungal population, cfu/ml)		
January	2.70×10^3	1.05×10^3	1.80×10^2
February	2.45×10^3	1.15×10^3	2.05×10^2
March	3.05×10^3	2.15×10^3	2.15×10^2
April	1.60×10^3	1.15×10^4	2.35×10^2
May	2.25×10^3	1.30×10^4	2.50×10^2
June	3.55×10^3	1.45×10^4	2.65×10^2
July	3.40×10^3	2.55×10^4	2.70×10^2
August	3.10×10^3	1.05×10^4	2.90×10^2
September	4.20×10^3	1.20×10^4	3.00×10^2
October	3.10×10^3	1.10×10^4	2.60×10^2
November	3.05×10^3	1.05×10^3	2.10×10^2
December	3.10×10^3	1.45×10^3	1.95×10^2

Table AI.3a: Total coliform population of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	TOTAL COLIFORM POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	2	0	0	0	2	0	0	2
February	0	0	0	0	0	0	3	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	2	4	0	0
May	0	3	0	0	0	0	7	4
June	6	0	0	0	0	5	0	0
July	0	0	0	0	7	0	0	0
August	0	5	0	0	0	10	0	10
September	12	0	0	0	9	10	7	0
October	5	8	0	0	0	6	8	13
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.3b: Total coliform population of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	TOTAL COLIFORM POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	1
April	0	0	0	0	0	0	0	2
May	0	0	0	0	0	1	0	4
June	2	1	0	0	0	0	0	4
July	0	0	0	0	0	0	6	3
August	3	0	0	0	0	3	6	6
September	4	3	0	0	0	0	7	0
October	6	0	0	0	2	7	8	10
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.3c: Total coliform population of well and stream water samples from communities in Etche Local Government Area, Rivers State

	TOTAL COLIFORM POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	3	0	0	0	0	0	0	2
April	0	0	0	0	0	4	3	0
May	0	0	0	1	0	0	0	0
June	0	0	0	0	0	0	0	0
July	5	0	0	4	0	6	0	3
August	0	0	0	6	0	0	2	0
September	0	0	0	5	0	0	0	4
October	15	0	0	0	0	7	3	4
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.3d: Mean total coliform population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean total coliform population, cfu/ml)		
January	0.7	0.0	0.0
February	0.0	0.0	0.0
March	0.0	0.0	0.5
April	1.0	0.0	0.7
May	0.5	0.2	0.2
June	1.8	0.5	0.0
July	1.2	0.0	2.5
August	2.5	1.0	1.0
September	5.2	1.2	0.8
October	3.2	2.5	3.7
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Table AI.3e: Mean total coliform population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean total coliform population, cfu/ml)		
January	1.0	0.0	0.0
February	1.5	0.0	0.0
March	0.0	0.5	1.0
April	0.0	1.0	1.5
May	5.5	2.0	0.0
June	0.0	2.0	0.0
July	0.0	4.5	1.5
August	5.0	6.0	1.0
September	3.5	3.5	2.0
October	10.5	9.0	3.5
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Table AI.4a: *Salmonella* population of well and stream water samples from communities in Ikwere Local Government Area, Rivers State

	***Salmonella* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	2	0	1
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	1	0
May	0	0	0	0	3	0	0	3
June	0	2	0	0	0	2	0	0
July	0	0	0	0	0	0	0	0
August	2	0	0	0	0	0	0	0
September	0	2	0	0	0	0	0	2
October	0	0	0	0	1	2	1	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.4b: *Salmonella* population of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	***Salmonella* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	1
June	0	0	0	0	0	0	0	5
July	3	0	0	0	0	0	1	0
August	0	0	0	0	0	0	0	2
September	0	0	0	0	0	2	0	0
October	0	0	0	0	0	0	3	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.4c: *Salmonella* population of well and stream water samples from communities in Etche Local Government Area, Rivers State

	***Salmonella* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	3	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	3
September	0	0	0	0	0	2	0	0
October	3	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.4d: Mean *Salmonella* population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean *Salmonella* population, cfu/ml)		
January	0.3	0.0	0.0
February	0.0	0.0	0.0
March	0.0	0.0	0.0
April	0.0	0.0	0.0
May	0.5	0.0	0.0
June	0.7	0.0	0.0
July	0.0	0.5	0.0
August	0.3	0.0	0.0
September	0.3	0.3	0.3
October	0.5	0.0	0.5
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Table AI.4e: Mean *Salmonella* population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean *Salmonella* population, cfu/ml)		
January	0.5	0.0	0.0
February	0.0	0.0	0.0
March	0.0	0.0	0.0
April	0.5	0.0	0.0
May	1.5	0.5	0.0
June	0.0	2.5	1.5
July	0.0	0.5	0.0
August	0.0	1.0	1.5
September	1.0	0.0	0.0
October	0.5	1.5	0.0
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Table AI.5a: *Escherichia coli* population of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	***Escherichia coli* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	1	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	1	3	0
April	0	2	0	0	0	0	0	3
May	0	0	0	0	2	0	0	0
June	0	0	0	0	0	0	0	0
July	2	0	0	0	0	0	0	1
August	0	2	0	0	0	4	0	0
September	0	1	0	0	0	0	4	2
October	2	0	0	0	3	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.5b: *Escherichia coli* population of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	***Escherichia coli* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	1
April	0	0	0	0	0	0	2	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	3	0	0	0	0	0	3	2
August	0	0	0	0	0	2	1	0
September	2	1	0	0	0	0	0	2
October	4	0	0	0	0	3	2	4
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.5c: *Escherichia coli* population of well and stream water samples from communities in Etche Local Government Area, Rivers State

	***Escherichia coli* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	1
August	0	0	0	0	0	0	0	0
September	6	0	0	3	0	0	0	0
October	2	0	0	0	0	4	0	3
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.5d: Mean *Escherichia coli* population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean *E. coli* population, cfu/ml)		
January	0.2	0.0	0.0
February	0.0	0.0	0.0
March	0.2	0.0	0.0
April	0.3	0.0	0.0
May	0.3	0.0	0.0
June	0.0	0.0	0.0
July	0.3	0.5	0.0
August	1.0	0.3	0.0
September	0.2	0.5	1.5
October	0.8	1.2	1.0
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Table AI.5e: Mean *Escherichia coli* population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean *E. coli* population, cfu/ml)		
January	0.0	0.0	0.0
February	0.0	0.0	0.0
March	1.5	0.5	0.0
April	1.5	1.0	0.0
May	0.0	0.0	0.0
June	0.0	0.0	0.0
July	0.5	2.5	0.5
August	0.0	0.5	0.0
September	3.0	1.0	0.0
October	0.0	3.0	1.5
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Table AI.6a: *Vibrio* population of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	Vibrio POPULATION (cfu/ml)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	1	0	0	2	0	0	0
July	0	0	0	0	0	0	1	0
August	2	0	0	0	0	3	0	0
September	0	0	0	0	0	0	1	0
October	0	1	0	0	2	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.6b: *Vibrio* population of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	***Vibrio* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	1	0	1
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	1	0
August	0	0	0	0	0	2	0	0
September	1	0	0	0	0	0	0	4
October	0	0	0	0	0	0	2	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0

Table AI.6c: *Vibrio* population of well and stream water samples from communities in Etche Local Government Area, Rivers State

	***Vibrio* POPULATION (cfu/ml)**							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	2	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	2	0	0
September	0	0	0	0	0	0	0	3
October	6	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	6	0	0	0	0	0	0	0

Table AI.6d: Mean *Vibrio* population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean *Vibrio* population, cfu/ml)		
January	0.0	0.0	0.0
February	0.0	0.0	0.0
March	0.0	0.0	0.0
April	0.0	0.2	0.0
May	0.0	0.0	0.0
June	0.5	0.0	0.3
July	0.0	0.0	0.0
August	0.8	0.3	0.3
September	0.0	0.2	0.0
October	0.5	0.0	1.0
November	0.0	0.0	0.0
December	0.0	0.0	1.0

Table AI.6e: Mean *Vibrio* population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean *Vibrio* population, cfu/ml)		
January	0.0	0.0	0.0
February	0.0	0.0	0.0
March	0.0	0.0	0.0
April	0.0	0.5	0.0
May	0.0	0.0	0.0
June	0.0	0.0	0.0
July	0.5	0.5	0.0
August	0.0	0.0	0.0
September	0.5	2.0	1.5
October	0.0	1.0	0.0
November	0.0	0.0	0.0
December	0.0	0.0	0.0

APPENDIX II

Physicochemical data obtained from the three LGAs

Table AII.1a: Temperature of well and stream water samples from some communities in Ikwerre Local Government Area, Rivers State

	TEMPERATURE (°C)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	26	26.5	25	26	25.5	26.5	26	25.5
February	26	25.5	25	25.5	25	25.5	25.5	26
March	25.5	25	25	25	24.5	24.5	27	25.5
April	25.5	25	25	25	25.5	24	26.5	26
May	24.5	25	24.5	24.5	25	24	26	25.5
June	24.5	24.5	24.5	24.5	24.5	24.5	26	26
July	25	25.5	24	24	24.5	24.5	25.5	26
August	24.5	25	24	24.5	24	24.5	25.5	26
September	25	25	24.5	24.5	24	25	26	26.5
October	25	25	25.5	25	25.5	26	25.5	26.5
November	26	26	25.5	25.5	25.5	25.5	26	26.5
December	25.6	26	25.5	26	26	26	27	26.5

Table AII.1b: Temperature of well and stream water samples from some communities in Emohua Local Government Area, Rivers State

	TEMPERATURE (°C)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	26	25	25	25.5	24	25	25	25.5
February	26	24.5	25	25.5	25	25	25	26
March	25.5	24.5	25	25	24.5	26	25.5	25.5
April	26	25	25.5	24.5	24.5	25	25.5	26
May	25.5	24.5	24.5	24.5	24.5	24.5	25	25
June	26.5	24.5	24.5	24.5	25	24.5	25.5	26
July	25	24.5	24.5	24.5	24.5	24.5	25.5	26
August	24.5	26	24.5	24.5	24.5	24.5	25	25.5

September	25	25.5	25.5	25	25	25	26	25
October	26.5	25.5	26	26	25.5	24.5	25.5	25
November	26.5	24.5	26	25.5	25.5	26	26	26.5
December	26.5	26	26	25.5	26	26	27	26.5

Table AII.1c: Temperature of well and stream water samples from some communities in Etche Local Government Area, Rivers State

	TEMPERATURE (°C)							
	WELL						STREAM	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	24	25	25	24	24.5	25	25	25.5
February	24.5	24	25	24.5	24	24.5	25	25
March	24.5	24.5	24.5	24	24.5	24	24.5	25.5
April	24.5	24	25	24	25	24	24.5	25
May	24	26	24	25	24.5	24.5	25	25
June	24.5	24	24.6	24.5	24.5	24	25	25
July	25	24.5	24	24	24	23	24.5	25.5
August	24.5	25	24.5	24.5	24.5	24	25	25
September	25	26	25	24.5	24	25	24	25.5
October	25	25	25	24	24	24	24.5	25.5
November	24.5	26	25	24.5	24.5	24.5	25	25
December	24	26	24	24	24.5	26	25	26

Table AII.1d: Mean temperature of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean temperature, °C)		
January	25.9	25.1	24.6
February	25.4	25.2	24.4
March	24.9	25.1	24.3
April	25.0	25.1	24.4
May	24.6	24.7	24.7
June	24.5	24.9	24.4
July	24.6	24.6	24.1
August	24.4	24.8	24.5
September	24.7	25.2	24.9
October	25.3	25.7	24.5
November	25.7	25.7	24.8
December	25.9	26.0	24.8

Table AII.1e: Mean temperature of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean temperature, °C)		
January	25.8	25.3	25.3
February	25.8	25.5	25.0
March	26.3	25.5	25.0
April	26.3	25.8	24.8
May	25.8	25.0	25.0
June	26.0	25.8	25.0
July	25.8	25.8	25.0
August	25.8	25.3	25.0
September	26.3	25.5	24.8
October	26.0	25.3	25.0
November	26.3	26.3	25.0
December	26.8	26.8	25.5

Table AII.2a: pH of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	pH							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	5.65	6.70	5.75	5.70	6.10	6.10	7.30	7.48
February	5.50	6.55	5.80	5.72	6.15	6.05	7.25	7.43
March	5.58	6.60	5.50	5.75	6.03	6.15	6.50	6.61
April	5.60	6.60	5.43	5.55	5.74	6.00	7.00	7.15
May	5.52	5.71	5.40	5.50	5.36	6.10	7.15	7.30
June	5.41	5.64	5.35	5.15	5.30	6.20	7.50	7.20
July	5.50	5.50	5.40	5.20	5.32	6.16	6.70	7.63
August	5.40	5.40	5.30	5.25	5.30	6.07	6.51	6.51
September	5.46	5.46	5.32	5.30	5.36	6.18	7.30	7.41
October	5.41	5.75	5.38	5.35	5.50	6.20	7.25	7.50
November	5.70	6.11	5.45	5.50	5.75	6.22	6.30	7.55
December	5.76	6.60	5.52	5.77	6.90	6.25	7.45	7.60

Table AII.2b: pH of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	pH							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	5.71	6.77	5.80	5.66	6.00	6.20	7.40	7.53
February	5.68	6.78	5.85	5.89	6.10	6.15	7.45	7.50
March	5.67	6.03	5.58	5.80	6.05	6.20	7.80	7.70
April	5.66	5.80	5.50	5.64	5.53	6.00	7.19	7.20
May	5.60	5.85	5.31	5.60	5.4	6.4	7.30	7.40
June	5.52	5.76	5.34	5.20	5.36	6.26	7.25	7.30
July	5.46	5.57	5.43	5.26	5.30	6.20	7.82	7.75
August	5.38	5.45	5.34	5.30	5.35	6.14	7.76	7.40

September	5.50	5.50	5.37	5.36	5.40	6.20	7.42	7.45
October	5.45	5.82	5.41	5.38	5.52	6.27	7.34	7.60
November	5.80	5.21	5.56	5.60	5.80	6.28	7.25	7.68
December	5.81	5.75	5.57	5.62	5.09	6.30	7.54	7.70

Table AII.2c: pH of well and stream water samples from communities in Etche Local Government Area, Rivers State

	pH							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	5.60	6.65	5.60	5.60	6.10	6.00	7.20	7.26
February	5.45	6.60	5.60	5.63	6.10	6.07	7.26	7.20
March	5.40	5.70	5.44	5.67	5.8	6.10	6.50	6.43
April	5.50	5.50	5.40	5.45	5.30	6.01	7.9	6.60
May	5.43	5.62	5.30	5.40	5.20	6.00	7.05	6.71
June	5.36	5.54	5.23	5.30	5.26	6.12	7.00	7.00
July	5.42	5.43	5.30	5.20	5.30	6.10	6.60	7.51
August	5.33	5.30	5.20	5.25	5.28	6.00	6.45	7.22
September	5.40	5.40	5.25	5.30	5.30	6.10	7.00	7.40
October	5.42	5.60	5.35	5.35	5.40	6.15	7.10	7.34
November	5.60	5.65	5.40	5.45	5.60	6.11	7.00	7.40
December	5.66	5.50	5.46	5.60	5.81	6.20	7.30	7.46

Table AII.2d: Mean pH of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua (Mean pH)	Etche
January	6.00	6.02	5.93
February	5.96	6.08	5.91
March	5.94	5.89	5.69
April	5.82	5.69	5.53
May	5.60	5.69	5.49
June	5.51	5.57	5.47
July	5.51	5.54	5.46
August	5.45	5.49	5.39
September	5.51	5.56	5.46
October	5.60	5.64	5.55
November	5.79	5.71	5.64
December	6.13	5.69	5.71

Table AII.1e: Mean pH of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua (Mean pH)	Etche
January	7.39	7.47	7.23
February	7.34	7.48	7.23
March	6.56	7.75	6.47
April	7.08	7.20	7.25
May	7.23	7.35	6.88
June	7.35	7.28	7.00
July	7.17	7.79	7.06
August	6.51	7.58	6.84
September	7.36	7.44	7.20
October	7.38	7.47	7.22
November	6.93	7.47	7.20
December	7.53	7.62	7.38

Table AII.3a: Total hardness of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	TOTAL HARDNESS (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	31.000	40.201	11.300	9.100	10.401	8.000	10.310	10.000
February	29.500	36.002	10.201	10.301	10.602	7.100	9.200	10.000
March	29.100	34.200	9.402	9.503	8.100	8.100	8.000	9.600
April	5.004	6.000	9.300	5.000	7.000	9.200	9.220	7.400
May	7.100	11.001	13.100	7.001	10.401	11.300	11.100	8.500
June	5.200	11.502	12.201	7.102	9.200	10.201	7.000	8.500
July	5.100	11.201	9.100	6.000	8.210	9.312	7.200	8.602
August	5.100	9.701	7.100	4.210	8.100	9.604	6.000	9.303
September	5.210	11.200	6.000	5.000	9.404	9.000	6.2000	7.300
October	5.102	11.100	6.201	5.101	7.600	6.100	6.000	9.200
November	29.101	28.300	11.404	6.506	9.200	7.204	7.000	9.200
December	33.000	41.104	12.201	7.200	10.100	7.450	7.200	10.400

Table AII.3b: Total hardness of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	TOTAL HARDNESS (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	32.200	42.302	12.100	9.501	10.700	8.202	11.200	11.100
February	30.000	38.03	11.101	11.000	11.100	7.002	10.300	11.100
March	29.301	36.400	9.600	10.301	8.401	6.400	9.220	10.200
April	5.000	6.104	9.600	5.202	7.420	10.003	10.100	8.200
May	7.100	12.001	15.000	7.201	11.100	13.100	12.200	9.400
June	5.200	13.101	13.400	7.230	10.300	11.400	7.100	9.402
July	5.100	11.000	10.000	5.004	9.303	10.301	8.200	9.404

August	5.100	10.202	7.500	4.630	9.204	9.702	6.310	10.201
September	5.210	12.300	6.100	5.200	10.220	10.100	5.410	8.000
October	5.102	12.001	6.601	5.320	8.501	7.210	6.100	10.300
November	29.101	30.100	12.000	7.300	10.340	8.520	7.210	10.400
December	33.000	44.501	14.402	7.420	10.341	8.530	7.100	11.300

Table AII.3c: Total hardness of well and stream water samples from communities in Etche Local Government Area, Rivers State

	TOTAL HARDNESS (mg/l)							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	31.000	40.100	11.500	9.100	10.000	8.000	10.510	10.340
February	30.100	36.000	10.000	10.600	10.200	6.600	10.200	10.300
March	29.000	34.200	9.200	10.000	8.000	6.500	9.000	9.600
April	5.001	6.000	9.400	5.100	6.100	9.100	9.100	8.100
May	7.000	10.200	13.100	6.300	10.300	11.200	11.200	9.000
June	5.000	11.300	12.200	6.420	10.700	10.100	7.000	8.570
July	5.000	10.560	9.401	6.100	9.000	9.400	7.750	8.600
August	5.100	10.000	7.200	4.401	8.640	8.501	6.100	9.403
September	5.200	11.100	5.750	5.000	9.200	9.200	5.000	7.502
October	4.750	11.200	6.100	5.100	8.001	8.000	5.610	9.401
November	28.202	28.000	11.300	7.002	9.501	8.300	6.560	10.100
December	31.400	41.100	12.400	7.201	10.200	8.450	7.000	11.000

Table AII.3d: Mean hardness of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean hardness, mg/l)	
January	18.33	19.17	18.28
February	17.28	18.04	17.25
March	16.40	16.73	16.15
April	6.92	7.22	6.78
May	9.98	10.92	9.68
June	9.23	10.11	9.29
July	8.15	8.45	8.24
August	7.30	7.72	7.31
September	7.64	8.19	7.58
October	6.87	7.46	7.19
November	15.29	16.23	15.38
December	18.51	19.70	18.46

Table AII.3e: Mean hardness of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean hardness, mg/l)	
January	10.16	11.15	10.43
February	9.60	10.70	10.25
March	8.80	9.71	9.30
April	8.31	9.15	8.60
May	9.80	10.80	10.10
June	7.75	8.25	7.79
July	7.90	8.80	8.18
August	7.65	8.26	7.75
September	6.75	6.71	6.25
October	7.60	8.20	7.51
November	8.10	8.81	8.33
December	8.80	9.20	9.00

Table AII.4a: Dissolved oxygen of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	DISSOLVED OXYGEN (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.8	7.70	6.80	7.2	7.4	5.5	6.0	6.5
February	7.5	7.72	6.90	7.0	7.2	5.6	6.0	6.7
March	7.2	8.10	5.80	6.5	6.3	5.8	6.3	6.3
April	7.40	6.20	6.00	6.6	6.3	5.7	6.2	6.3
May	8.10	7.60	6.80	6.7	6.7	5.3	6.5	5.8
June	8.30	7.70	6.90	6.9	7.2	6.20	6.20	7.0
July	8.50	7.70	7.10	6.9	7.2	6.20	7.0	6.0
August	8.60	7.80	7.20	7.1	7.5	6.30	7.1	6.2
September	8.80	7.9	7.30	7.5	7.8	6.40	7.2	6.7
October	8.80	8.0	7.32	7.6	8.0	6.10	7.4	7.0
November	8.90	7.90	7.30	7.4	7.7	6.0	6.3	7.1
December	8.00	7.10	6.90	7.0	7.2	5.6	6.0	6.2

Table AII.4b: Dissolved oxygen of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	DISSOLVED OXYGEN (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	8.00	7.82	7.00	7.8	7.9	5.7	6.4	7.0
February	7.80	7.81	7.00	7.3	7.7	5.8	6.2	7.2
March	7.70	6.00	6.00	6.5	6.3	5.9	6.8	6.7
April	7.50	6.30	6.20	6.8	6.5	4.5	6.9	6.7
May	8.40	7.90	7.00	6.9	7.10	6.10	7.10	6.00
June	8.70	7.86	7.10	7.00	7.3	6.30	7.2	6.20
July	8.80	7.80	7.40	7.1	7.6	6.5	7.5	6.5
August	8.91	7.91	7.62	7.4	7.8	6.6	8.0	7.0
September	8.90	8.02	7.60	8.4	8.0	6.4	8.0	7.2
October	8.90	8.06	7.60	8.2	8.2	6.2	7.8	7.6
November	8.92	8.10	7.60	7.7	8.1	6.2	6.8	7.4
December	8.20	7.70	7.10	7.5	7.8	5.7	6.6	7.0

Table AII.4c: Dissolved oxygen of well and stream water samples from communities in Etche Local Government Area, Rivers State

	DISSOLVED OXYGEN (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.2	7.00	6.20	6.7	7.00	5.00	5.3	6.0
February	7.1	7.20	6.20	6.9	6.80	5.00	5.3	6.1
March	7.0	7.20	6.00	5.7	5.10	5.30	5.4	6.0
April	7.10	6.00	5.70	5.8	5.20	5.31	5.7	5.3
May	7.30	6.30	6.10	6.00	5.8	5.60	6.0	5.5
June	7.40	6.70	6.40	6.20	6.1	5.90	6.6	5.7
July	7.60	6.90	6.80	6.30	6.1	6.00	6.8	5.9
August	7.80	7.10	6.90	6.60	6.3	6.10	7.0	5.8
September	8.00	7.30	7.10	7.20	7.5	6.10	7.0	6.1
October	8.20	7.60	7.20	7.40	7.8	5.9	7.2	6.8
November	8.10	7.00	7.00	7.20	6.9	5.7	6.1	6.7
December	7.80	6.4	6.60	6.80	7.0	5.20	5.5	5.8

Table AII.4d: Mean dissolved oxygen of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean dissolved oxygen, mg/l)		
January	7.07	7.37	6.52
February	6.99	7.24	6.53
March	6.62	6.40	6.05
April	6.37	6.30	5.85
May	6.87	7.23	6.18
June	7.20	7.38	6.45
July	7.27	7.53	6.62
August	7.42	7.71	6.80
September	7.62	7.89	7.20
October	7.64	7.86	7.35
November	7.53	7.77	6.98
December	6.97	7.33	6.63

Table AII.4e: Mean dissolved oxygen of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean dissolved oxygen, mg/l)		
January	6.25	6.70	5.65
February	6.35	6.70	5.70
March	6.30	6.75	5.70
April	6.25	6.80	5.50
May	6.15	6.55	5.75
June	6.60	6.70	6.15
July	6.50	7.00	6.35
August	6.65	7.50	6.40
September	6.95	7.60	6.55
October	7.20	7.70	7.00
November	6.70	7.10	6.40
December	6.10	6.80	5.65

Table AII.5a: Nitrate concentration of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	NITRATE CONCENTRATION (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	2.183	0.610	0.166	0.160	0.141	0.226	0.231	0.232
February	2.321	0.431	1.160	0.157	0.156	0.467	0.242	0.241
March	2.300	0.470	0.257	0.194	0.189	0.501	0.219	0.252
April	2.232	0.471	0.321	0.205	0.218	0.193	0.230	0.216
May	1.731	0.452	0.410	0.311	0.328	0.140	0.231	0.200
June	1.740	0.440	0.433	0.320	0.345	0.127	0.242	0.247
July	1.752	0.420	0.480	0.333	0.368	0.136	0.289	0.240
August	1.800	0.430	0.514	0.342	0.400	0.140	0.300	0.231
September	1.808	0.473	0.500	0.350	0.351	0.146	0.250	0.220
October	1.600	0.500	0.350	0.288	0.310	0.146	0.241	0.200
November	1.650	0.551	0.312	0.241	0.283	0.350	0.228	0.219
December	1.900	0.563	0.162	0.254	0.217	0.421	0.230	0.237

Table AII.5b: Nitrate concentration of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	NITRATE CONCENTRATION (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	2.200	0.624	0.170	0.166	0.140	0.342	0.240	0.245
February	2.342	0.480	1.161	0.164	0.161	0.508	0.252	0.253
March	2.303	0.570	0.268	0.200	0.200	0.517	0.228	0.260
April	1.251	0.568	0.338	0.218	0.222	0.200	0.238	0.225
May	1.752	0,520	0.449	0.320	0.356	0.147	0.234	0.226
June	1.750	0.517	0.450	0.341	0.366	0.131	0.252	0.202
July	1.760	0.460	0.518	0.356	0.377	0.144	0.303	0.252
August	1.810	0.460	0.520	0.360	0.482	0.145	0.308	0.245
September	1.818	0.550	0.470	0.367	0.362	0.150	0.251	0.226
October	1.640	0.560	0.372	0.300	0.330	0.152	0.245	0.201
November	1.721	0.571	0.330	0.262	0.300	0.361	0.234	0.226
December	2.003	0.570	0.168	0.278	0.220	0.426	0.241	0.243

Table AII.5c: Nitrate concentration of well and stream water samples from communities in Etche Local Government Area, Rivers State

	NITRATE CONCENTRATION (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	2.176	0.600	0.158	0.158	0.140	0.419	0.225	0.216
February	2.300	0.412	1.161	0.157	0.150	0.451	0.231	0.230
March	2.185	0.451	0.232	0.182	0.178	0.478	0.210	0.242
April	2.200	0.450	0.302	0.200	0.210	0.190	0.221	0.220
May	1.700	0.441	0.400	0.301	0.321	0.152	0.219	0.211
June	1.720	0.432	0.424	0.311	0.330	0.120	0.230	0.232
July	1.730	0.406	0.453	0.322	0.351	0.131	0.264	0.240
August	1.770	0.421	0.500	0.333	0.382	0.135	0.380	0.220
September	1.791	0.454	0.500	0.341	0.342	0.141	0.251	0.215
October	1.700	0.487	0.341	0.267	0.300	0.150	0.238	0.189
November	1.600	0.520	0.300	0.220	0.261	0.300	0.220	0.208
December	1.802	0.541	0.160	0.232	0.211	0.373	0.225	0.230

Table AII.5d: Mean nitrate concentration of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean nitrate concentration, mg/l)		
January	0.581	0.607	0.609
February	0.782	0.803	0.772
March	0.652	0.676	0.618
April	0.607	0.466	0.592
May	0.562	0.605	0.553
June	0.568	0.593	0.556
July	0.582	0.603	0.566
August	0.604	0.630	0.590
September	0.605	0.620	0.595
October	0.532	0.559	0.541
November	0.565	0.591	0.534
December	0.586	0.611	0.553

Table AII.5e: Mean nitrate concentration of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean nitrate concentration, mg/l)		
January	0.232	0.243	0.221
February	0.242	0.253	0.231
March	0.236	0.244	0.226
April	0.223	0.232	0.221
May	0.216	0.230	0.215
June	0.245	0.227	0.231
July	0.265	0.278	0.252
August	0.266	0.277	0.300
September	0.235	0.239	0.233
October	0.221	0.223	0.214
November	0.224	0.230	0.214
December	0.234	0.242	0.228

Table AII.6a: Biological oxygen demand (BOD) of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	BOD (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.26	2.06	1.47	5.57	10.15	9.70	4.51	4.36
February	7.20	1.3	1.40	5.31	10.15	9.71	4.43	4.40
March	5.52	1.3	1.40	3.10	6.40	8.45	4.44	4.47
April	9.22	8.21	8.10	7.40	8.10	7.36	4.50	4.51
May	10.31	10.30	8.32	10.05	8.30	8.50	9.10	7.43
June	10.42	10.43	8.46	10.21	8.40	8.57	9.20	8.32
July	11.27	10.50	8.60	10.47	9.30	8.60	9.16	9.30
August	11.35	10.61	8.72	10.51	11.08	8.66	9.13	9.24
September	10.50	9.18	8.58	10.70	11.22	9.83	10.53	10.36
October	9.42	7.10	5.38	9.50	11.41	10.36	9.66	9.21
November	8.60	5.20	3.41	8.60	10.36	9.53	4.40	4.10
December	8.31	4.10	2.30	6.10	10.11	9.6	4.22	4.33

Table AII.6b: Biological oxygen demand (BOD) of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	BOD (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.46	2.10	1.55	5.68	10.30	10.1	4.60	4.51
February	7.31	1.4	1.53	5.2	10.31	10.1	4.5	4.48
March	5.70	1.5	1.30	3.19	6.53	8.71	4.5	4.58
April	9.40	8.40	8.13	8.34	8.34	7.52	9.22	7.61
May	10.50	10.42	8.58	10.17	8.58	8.51	10.30	8.52
June	10.60	10.50	8.64	10.40	8.33	8.60	10.21	9.33
July	11.33	10.57	8.71	10.62	9.67	8.67	10.42	9.40
August	11.44	10.72	8.80	10.80	11.20	8.76	10.60	10.35
September	10.63	9.20	8.63	9.74	11.41	10.72	11.16	11.20
October	9.56	7.30	5.40	8.52	11.64	10.80	10.78	9.70
November	8.72	5.50	3.60	8.20	10.50	10.3	4.52	4.20
December	8.43	4.10	2.71	6.50	10.20	10.6	4.41	4.51

Table AII.6c: Biological oxygen demand (BOD) of well and stream water samples from communities in Etche Local Government Area, Rivers State

	BOD (mg/l)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.20	2.01	1.38	5.40	10.12	9.52	4.43	4.30
February	7.16	1.2	1.39	5.30	10.00	9.60	4.43	4.32
March	5.48	1.3	1.36	3.42	6.32	9.00	4.54	4.40
April	9.00	8.10	8.00	7.10	8.01	8.10	8.00	4.43
May	10.09	10.12	8.15	10.00	8.22	8.00	9.03	7.00
June	10.21	10.23	8.21	10.08	8.29	8.37	9.11	8.10
July	11.11	10.35	8.37	10.18	9.00	8.43	9.13	9.08
August	11.20	10.40	8.42	1-.26	10.31	8.50	10.36	9.16
September	10.31	9.05	8.42	10.40	10.58	9.20	10.45	10.21
October	9.23	7.12	5.40	10.40	11.00	10.01	9.42	9.11
November	8.32	5.13	3.32	8.50	10.30	9.33	4.30	4.20
December	8.08	4.12	2.26	6.70	10.19	9.3	4.18	4.24

Table AII.6d: Mean BOD of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean BOD, mg/l)	
January	6.04	6.20	5.94
February	5.85	5.98	5.78
March	4.36	4.49	4.48
April	8.07	8.36	8.05
May	9.30	9.46	9.10
June	9.42	9.51	9.23
July	9.79	9.93	9.57
August	10.16	10.29	9.77
September	10.00	10.06	9.66
October	8.86	8.87	8.86
November	7.62	7.80	7.48
December	6.75	7.09	6.78

Table AII.6e: Mean BOD of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean BOD, mg/l)	
January	4.44	4.56	4.37
February	4.42	4.49	4.38
March	4.46	4.54	4.47
April	4.51	8.42	6.22
May	8.27	9.41	8.02
June	8.76	9.77	8.61
July	9.23	9.91	9.11
August	9.19	10.48	9.76
September	10.45	11.18	10.33
October	9.44	10.24	9.27
November	4.25	4.36	4.25
December	4.28	4.46	4.21

Table AII.7a: Salinity of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	SALINITY (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	22.31	19.41	17.48	10.55	10.01	11.15	12.31	13.1
February	60.42	32.5	19.26	29.41	8.41	17.51	18.43	16.25
March	54.1	35.33	64.3	16.33	20.32	24.21	30.4	38.33
April	55.11	36.1	65.47	16.7	20.4	24.2	20.46	40.09
May	60.45	45.27	50.21	12.6	24.56	17.3	18.5	35.41
June	29.3	37.3	27.32	10.16	10.17	12.46	10.11	25.36
July	14.21	36.4	17.41	11.21	8.5	11.1	8.21	21.47
August	9.65	13.4	12.4	9.02	7.4	7.33	8.16	19.26
September	10.71	12.49	11.24	11.06	7.61	6.2	8.3	18.21
October	10.23	12.61	12.46	11.23	8.04	7.19	8.35	19.03
November	11.38	10.53	10.9	10.14	9.12	8.4	11.1	20.21
December	14.26	11.32	11.7	11.2	10.14	10.58	11.43	20.45

Table AII.7b: Salinity of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	SALINITY (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	24.25	20.02	18.53	11.33	10.04	11.22	12.63	13.34
February	62.64	34.7	20.45	31.24	8.1	19.4	19.6	16.43
March	56.2	37.61	67.4	18.31	22.41	26.33	32.3	40.2
April	57.14	38.23	68.52	18.66	22.6	26.45	32.51	42.31
May	62.66	48.32	52.1	13.21	26.72	19.46	19.58	37.6
June	31.1	41.41	29.11	10.22	10.2	13.52	10.17	26.41
July	15.19	39.8	19.21	11.44	8.08	11.05	8.4	21.68

August	10.03	14.21	13.3	9.05	7.53	7.41	8.13	18.5
September	11	13.56	12.12	11.11	7.77	6.21	8.1	18.5
October	10.3	13.63	13.2	11.36	8.09	7.23	8.21	19.08
November	12.28	11.4	11.51	10.22	9.2	10.16	11.19	21
December	15.12	12.2	12.6	11.3	10.19	10.88	11.8	21.32

Table AII.7c: Salinity of well and stream water samples from communities in Etche Local Government Area, Rivers State

	SALINITY (mg/L)							
	WELL						STREAM	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	21.2	18.52	17.27	10.12	10.1	11	11.25	12.3
February	58.31	30.36	19.16	29.3	9.21	16.33	17.23	15.1
March	51.22	32.08	60	16	19.13	22.1	28.3	36.21
April	52.2	33.19	61.31	16.21	19.35	22.1	27.61	36.41
May	56.34	40.2	56.58	12.44	22.06	17	17.83	31.53
June	27.4	34.31	27.11	11.01	10.06	12.01	10	22.42
July	13.18	34.01	16.6	11.09	8	11	8.09	20.34
August	9.43	13.22	12.14	10.81	7.22	7.5	8.09	18.1
September	10.5	12.36	12	11.11	7.46	7.3	8.31	18.17
October	10.5	12.55	12.3	11.2	8.01	7.01	8.33	18.5
November	11.2	10.3	11	10.08	9.11	9	10.67	19.01
December	13.1	11.24	11.5	11.01	10.12	10.41	11.03	19.34

Table AII.7d: Mean salinity of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean salinity, mg/l)	
January	15.15	15.90	14.70
February	27.92	29.42	27.11
March	35.77	38.04	33.42
April	36.33	38.60	34.06
May	35.07	37.08	34.10
June	21.12	22.59	20.32
July	16.47	17.46	15.65
August	9.87	10.26	10.05
September	9.89	10.30	10.12
October	10.29	10.64	10.26
November	10.08	10.80	10.12
December	11.53	12.05	11.23

Table AII.7e: Mean salinity of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean salinity, mg/l)	
January	12.71	12.99	11.78
February	17.34	18.02	16.17
March	34.37	36.25	32.26
April	30.28	37.41	32.01
May	26.96	28.59	24.68
June	17.74	18.29	16.21
July	14.84	15.04	14.22
August	13.71	13.32	13.10
September	13.26	13.30	13.24
October	13.69	13.65	13.42
November	15.66	16.10	14.84
December	15.94	16.56	15.19

Table AII.8a: Chloride concentration of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	CHLORIDE CONCENTRATION (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	12.60	9.40	8.43	5.00	4.21	5.10	5.30	6.15
February	33.10	17.12	10.51	15.20	3.61	10.58	10.40	7.10
March	29.15	18.01	34.10	8.40	11.00	12.20	14.00	8.00
April	29.10	18.00	34.11	8.41	11.00	12.18	14.01	8.01
May	35.00	24.00	27.00	6.00	13.01	10.50	10.41	5.12
June	15.20	20.00	13.60	5.10	4.20	7.00	4.10	5.00
July	6.21	19.41	8.04	5.40	3.41	5.00	3.31	5.10
August	5.00	7.00	6.41	4.20	3.40	3.10	3.56	4.30
September	5.20	6.20	6.00	5.10	3.61	2.41	3.45	4.20
October	5.21	6.10	6.30	5.21	3.80	3.37	3.54	4.20
November	6.10	5.00	5.20	4.20	4.00	4.00	5.10	5.10
December	7.20	7.00	6.00	5.15	5.00	4.10	5.20	7.80

Table AII.8b: Chloride concentration of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	CHLORIDE CONCENTRATION (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	13.42	10.30	9.51	5.15	4.30	5.12	5.60	6.20
February	35.0	19.01	11.0	17.0	3.80	11.0	11.01	7.40
March	31.10	20.00	36.20	9.60	12.2	14.30	16.20	8.10
April	31.2	20.01	36.20	9.61	12.1	14.29	16.20	8.15
May	37.00	26.00	29.00	7.00	15.00	11.01	11.30	5.20
June	16.30	22.20	15.80	5.20	4.40	7.03	4.20	5.01
July	7.71	21.10	10.02	5.75	3.60	5.04	3.60	5.15
August	5.00	7.20	6.64	4.70	3.42	3.20	3.80	4.60
September	5.42	6.41	6.10	5.05	3.58	2.65	3.51	4.50
October	5.40	6.38	6.50	5.28	3.70	3.40	3.61	4.50
November	6.20	5.05	5.20	4.40	4.10	4.10	5.20	5.20
December	7.62	7.06	6.20	5.10	5.02	4.30	5.40	6.01

Table AII.8c: Chloride concentration of well and stream water samples from communities in Etche Local Government Area, Rivers State

	CHLORIDE CONCENTRATION (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	11.40	9.01	7.30	5.15	4.10	5.00	5.00	6.00
February	30.60	16.10	9.20	13.10	4.00	9.10	9.20	6.00
March	28.10	17.00	31.10	7.15	10.10	11.15	12.10	7.01
April	28.08	17.02	31.00	7.10	10.10	11.20	11.80	7.01
May	31.01	22.01	26.01	5.80	12.15	9.70	9.20	5.00
June	14.10	19.02	12.20	5.00	4.10	6.60	4.00	3.30
July	7.00	18.20	7.30	5.30	4.00	5.10	3.30	5.00
August	5.02	6.81	6.10	4.10	3.30	3.00	3.41	4.00
September	5.10	6.00	5.80	5.10	3.50	3.10	3.20	4.10
October	5.15	6.05	6.20	5.15	4.00	3.20	3.50	4.00
November	6.00	5.00	5.75	4.10	4.10	3.81	5.00	5.00
December	6.40	6.10	6.00	5.10	5.10	4.00	5.15	6.00

Table AII.8d: Mean Chloride concentration of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Chloride concentration, mg/l)		
January	7.46	7.97	6.99
February	15.02	16.14	13.68
March	18.81	20.57	17.43
April	18.80	20.57	17.42
May	19.25	20.84	17.78
June	10.85	11.82	10.17
July	7.91	8.87	7.82
August	4.85	5.03	4.72
September	4.75	4.87	4.77
October	5.00	5.11	4.96
November	4.75	4.84	4.79
December	5.74	5.88	5.45

Table AII.8e: Mean Chloride concentration of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Chloride concentration, mg/l)		
January	5.73	5.90	5.50
February	8.75	9.21	7.60
March	11.00	12.15	9.56
April	11.01	12.18	9.41
May	7.77	8.25	7.10
June	4.55	4.61	3.65
July	4.21	4.38	4.15
August	3.93	4.20	3.71
September	3.83	4.01	3.65
October	3.87	4.06	3.75
November	5.10	5.20	5.00
December	6.50	5.71	5.58

Table AII.9a: Iron concentration of well and stream water samples from communities in Ikwerre Local Government Area, Rivers State

	IRON CONCENTRATION (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0.002	0.610	0.218	0.003	1.620	0.600	0.49	0.070
February	0.003	1.513	0.201	0.004	2.414	1.316	0.063	0.060
March	0.004	0.800	0.122	0.004	1.240	1.200	0.040	0.041
April	0.003	0.104	0.050	0.046	0.430	0.120	0.210	0.062
May	0.003	0.110	0.060	0.065	0.360	0.300	0.231	0.137
June	0.002	0.127	0.011	0.117	0.213	0.231	0.210	0.234
July	0.012	0.410	0.014	0.164	1.020	0.513	0.409	0.300
August	0.018	0.427	0.026	0.170	1.115	0.300	0.220	0.211
September	0.015	0.450	0.104	0.225	1.106	0.321	0.160	0.100
October	0.017	0.440	0.320	0.431	1.207	0.224	0.051	0.050
November	0.013	0.410	0.241	0.320	1.119	0.423	0.103	0.060
December	0.004	0.689	0.232	0.280	1.205	0.600	0.130	0.051

Table AII.9b: Iron concentration of well and stream water samples from communities in Emohua Local Government Area, Rivers State

	IRON CONCENTRATION (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0.003	0.614	0.210	0.003	1.645	0.613	0.52	0.075
February	0.004	1.540	0.200	0.003	2.245	1.331	0.074	0.062
March	0.004	0.811	0.124	0.005	1.264	1.210	0.030	0.047
April	0.002	0.100	0.052	0.050	0.532	0.126	0.242	0.073
May	0.003	0.112	0.065	0.071	0.214	0.302	0.263	0.148
June	0.002	0.130	0.014	0.120	0.286	0.260	0.219	0.259
July	0.010	0.412	0.016	0.172	1.042	0.544	0.418	0.309
August	0.021	0.430	0.030	0.174	1.130	0.314	0.241	0.242
September	0.016	0.452	0.108	0.230	1.010	0.332	0.163	0.104
October	0.020	0.410	0.363	0.462	1.214	0.256	0.062	0.054
November	0.014	0.400	0.270	0.322	1.123	0.551	0.100	0.061
December	0.005	0.700	0.228	0.300	1.208	0.605	0.136	0.042

Table AII.9c: Iron concentration of well and stream water samples from communities in Etche Local Government Area, Rivers State

	IRON CONCENTRATION (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0.002	0.600	0.210	0.002	1.530	0.0512	0.41	0.061
February	0.003	1.510	0.117	0.003	1.810	1.214	0.052	0.052
March	0.003	0.715	0.120	0.003	1.401	1.114	0.050	0.040
April	0.002	0.100	0.046	0.038	0.400	0.114	0.200	0.051
May	0.002	0.106	0.054	0.060	0.320	0.260	0.220	0.120
June	0.001	0.120	0.030	0.101	0.200	0.224	0.200	0.212
July	0.010	0.360	0.034	0.140	1.011	0.430	0.387	0.281
August	0.016	0.410	0.020	0.150	1.10	0.270	0.210	0.200
September	0.012	0.431	0.100	0.217	1.100	0.310	0.151	0.102
October	0.015	0.410	0.290	0.400	1.200	0.200	0.50	0.47
November	0.010	0.400	0.230	0.301	1.108	0.380	0.100	0.050
December	0.003	0.601	0.230	0.262	1.200	0.550	0.121	0.046

Table AII.9d: Mean Iron concentration of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Iron concentration, mg/l)		
January	0.509	0.515	0.399
February	0.909	0.887	0.776
March	0.562	0.570	0.559
April	0.126	0.144	0.117
May	0.150	0.128	0.134
June	0.117	0.135	0.113
July	0.356	0.366	0.331
August	0.343	0.350	0.328
September	0.370	0.358	0.362
October	0.440	0.454	0.419
November	0.421	0.447	0.405
December	0.502	0.508	0.474

Table AII.9e: Mean Iron concentration of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Iron concentration, mg/l)		
January	0.280	0.298	0.236
February	0.062	0.068	0.052
March	0.041	0.039	0.045
April	0.136	0.158	0.126
May	0.184	0.206	0.170
June	0.222	0.239	0.206
July	0.355	0.364	0.334
August	0.216	0.242	0.205
September	0.130	0.134	0.127
October	0.051	0.058	0.485
November	0.082	0.081	0.075
December	0.091	0.089	0.084

Table AII.10a: Total dissolved solids in water samples from well and stream in communities in Ikwerre Local Government Area, Rivers State

	TOTAL DISSOLVED SOLIDS (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	280	68	71	55	24	265	132	10,100
February	279	130	128	88	40	601	480	12,400
March	235	54	91	60	26	280	132	10,600
April	34	35	28	11	10	10	17	5,000
May	50	36	41	17	18	17	17	6,100
June	50	38	43	16	18	18	16	6,200
July	47	39	28	12	11	18	18	5,100
August	60	40	23	17	14	16	19	5,000
September	65	19	26	22	19	16	20	5,100
October	70	25	28	16	17	17	45	5,200
November	94	37	29	21	20	34	85	6,800
December	118	70	58	36	38	42	100	7,000

Table AII.10b: Total dissolved solids in water samples from well and stream in communities in Emohua Local Government Area, Rivers State

	TOTAL DISSOLVED SOLIDS (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	285	70	73	58	27	280	130	10,000
February	282	131	130	91	45	800	501	13,100
March	240	56	95	62	28	302	131	11,200
April	38	37	30	12	10	9	18	5,400
May	52	38	44	18	19	18	18	6,300
June	50	40	46	17	18	20	16	6,500
July	48	40	30	12	12	19	19	5,400
August	67	42	25	19	15	16	20	4,800
September	70	20	28	24	20	17	21	5,100
October	73	28	30	18	19	18	50	5,400
November	101	41	31	23	23	37	92	7,100
December	122	74	60	38	40	45	110	7,300

Table AII.10c: Total dissolved solids in water samples from well and stream in communities in Etche Local Government Area, Rivers State

	TOTAL DISSOLVED SOLIDS (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	270	61	68	56	22	240	128	9,700
February	275	129	130	83	47	550	420	11,100
March	230	52	90	54	24	271	130	10,200
April	31	32	26	13	11	9	15	5,200
May	47	33	37	15	16	16	15	5,800
June	48	36	40	15	17	17	16	6,000
July	45	37	26	13	10	17	16	5,700
August	55	41	24	16	13	15	17	4,900
September	60	21	26	20	17	15	18	5,000
October	65	22	30	20	19	16	40	5,100
November	90	35	32	22	19	30	81	6,600
December	110	72	60	30	33	40	93	6,900

Table AII.10d: Mean Total Dissolved Solids (TDS) in water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean TDS, mg/L)	
January	127.2	132.2	119.5
February	211.0	246.5	202.3
March	124.3	130.5	120.2
April	21.3	22.7	20.3
May	29.8	31.5	27.3
June	30.5	31.8	28.8
July	25.8	26.8	24.7
August	28.3	30.7	27.3
September	27.8	29.8	26.5
October	28.8	31.0	28.7
November	39.2	42.7	38.0
December	60.3	63.2	57.5

Table AII.10e: Mean TDS in water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
		(Mean TDS, mg/L)	
January	5116.0	5065.0	4914.0
February	6440.0	6800.5	5760.0
March	5366.0	5665.5	5165.0
April	2508.5	2709.0	2607.5
May	3058.5	3159.0	2907.5
June	3108.0	3258.0	3008.0
July	2559.0	2709.5	2858.0
August	2509.5	2410.0	2458.5
September	2560.0	2560.5	2509.0
October	2622.5	2725.0	2570.0
November	3442.5	3596.0	3340.5
December	3550.0	3705.0	3496.5

Table AII.11a: Turbidity of water samples from well and stream in communities in Ikwerre Local Government Area, Rivers State

	TURBIDITY (NTU)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	3.176	16.31	6.31	5.30	7.23	9.32	11.45	15.17
February	3.181	18.53	57.20	19.47	57.32	57.19	17.30	17.41
March	3.181	18.61	6.08	3.80	11.15	14.35	15.41	16.36
April	6.40	32.18	6.08	4.10	10.21	7.35	6.47	11.21
May	6.46	64.44	86.18	92.43	38.42	12.41	11.56	16.30
June	6.52	67.36	10.12	11.37	6.30	12.50	11.70	17.22
July	7.47	67.48	9.47	10.40	6.41	9.24	11.77	17.22
August	7.60	47.29	9.38	8.22	7.36	10.11	12.50	17.67
September	7.31	37.20	8.11	6.39	6.43	8.14	10.27	18.36
October	6.25	49.34	7.07	6.20	7.16	6.10	11.10	17.40
November	2.008	42.10	4.25	5.38	10.13	11.10	9.19	14.60
December	1.812	16.37	6.41	5.46	6.60	10.30	12.21	16.51

Table AII.11b: Turbidity of water samples from well and stream in communities in Emohua Local Government Area, Rivers State

	TURBIDITY (NTU)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	3.200	17.22	6.45	5.20	7.19	9.40	12.26	17.21
February	3.160	19.31	59.26	21.00	59.40	59.50	19.19	19.20
March	3.180	19.46	6.10	4.07	11.20	15.21	16.20	17.40
April	6.51	34.50	6.06	4.05	10.32	7.42	6.32	11.12
May	6.58	66.02	88.03	94.58	40.37	13.46	11.71	18.35
June	6.62	69.21	10.14	11.53	6.11	13.58	12.09	19.27
July	7.73	69.33	10.10	10.47	6.36	9.31	12.17	19.20
August	7.91	49.34	9.30	8.34	7.44	10.20	13.44	18.40
September	7.24	38.12	8.16	6.20	6.58	8.20	10.33	19.30
October	6.30	51.52	7.10	5.74	7.20	6.07	11.19	18.42
November	3.110	44.11	4.36	5.51	10.21	11.18	9.28	15.51
December	2.002	18.21	6.51	5.74	6.66	10.37	13.30	18.05

Table AII.11c: Turbidity of water samples from well and stream in communities in Etche Local Government Area, Rivers State

	TURBIDITY (NTU)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	2.200	16.20	6.24	4.45	7.20	9.27	11.20	14.33
February	2.106	17.31	55.30	17.32	55.45	55.22	16.40	16.40
March	3.00	17.42	6.03	3.51	11.00	14.01	14.61	15.20
April	6.10	30.20	6.07	4.02	10.10	7.30	7.01	11.10
May	6.10	60.31	80.20	90.11	36.21	11.56	11.26	15.51
June	6.32	63.42	10.00	11.20	7.10	11.60	11.43	15.10
July	7.20	64.00	9.36	10.51	7.22	9.18	11.65	15.12
August	7.20	45.10	9.20	9.12	7.30	10.00	12.10	15.00
September	7.22	36.30	9.01	6.43	6.31	9.20	11.16	17.01
October	6.20	47.40	8.00	6.26	7.13	7.01	11.00	15.20
November	2.00	40.18	2.11	5.18	10.09	11.02	10.00	14.40
December	1.800	16.00	6.21	5.32	7.01	10.21	12.00	15.30

Table AII.11d: Mean turbidity of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Turbidity, NTU)		
January	7.94	8.11	7.59
February	35.48	36.94	33.78
March	9.53	9.87	9.16
April	11.05	11.48	10.63
May	50.06	51.51	47.42
June	19.03	19.53	18.27
July	18.41	18.88	17.91
August	14.99	15.42	14.65
September	12.26	12.42	12.41
October	13.69	13.99	13.67
November	12.49	13.08	11.76
December	7.83	8.25	7.76

Table AII.11e: Mean turbidity of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Turbidity, NTU)		
January	13.31	14.74	12.77
February	17.36	19.20	16.40
March	15.89	16.80	14.91
April	8.84	8.72	9.06
May	13.93	15.03	13.39
June	14.46	15.68	13.27
July	14.50	15.69	13.39
August	15.09	15.92	13.55
September	14.32	14.82	14.09
October	14.25	14.81	13.10
November	11.90	12.40	12.20
December	14.36	15.68	13.65

Table AII.12a: Calcium concentration of water samples from well and stream in communities in Ikwerre Local Government Area, Rivers State

	Calcium concentration (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.220	6.300	5.300	2.000	1.705	1.907	1.300	120.100
February	7.101	8.421	3.200	2.230	2.160	2.010	1.201	130.106
March	5.416	8.400	3.412	2.300	2.100	2.160	1.244	132.410
April	4.200	6.000	3.400	1.206	2.004	2.160	1.285	27.316
May	4.421	4.880	3.560	1.128	2.010	2.182	1.400	35.215
June	5.100	5.100	3.400	1.200	2.017	2.190	1.312	39.512
July	7.220	6.210	4.400	2.423	2.027	2.516	1.402	68.360
August	5.430	6.009	4.530	2.670	2.206	4.300	1.550	47.140
September	5.211	4.600	3.320	1.300	2.220	4.240	1.402	38.310
October	8.100	4.541	3.210	1.201	2.110	6.167	1.341	34.200
November	8.100	5.330	3.750	2.240	2.006	3.168	1.276	70.103
December	8.301	7.210	4.800	2.130	2.018	2.121	1.200	102.414

Table AII.12b: Calcium concentration of water samples from well and stream in communities in Emohua Local Government Area, Rivers State

	Calcium concentration (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	7.543	6.650	5.260	2.100	1.911	2.007	1.310	120.610
February	7.222	8.710	3.210	2.310	2.300	2.000	1.206	141.420
March	5.602	8.710	3.512	2.378	2.103	2.200	1.260	136.300
April	4.203	5.003	3.370	1.100	2.002	2.118	1.300	29.101
May	4.731	4.864	3.310	1.105	2.018	2.201	1.425	38.412
June	5.200	5.300	3.432	1.201	2.022	2.200	1.530	41.210
July	2.311	6.135	4.515	2.601	2.030	2.702	1.640	70.340

August	5.660	6.001	4.700	2.720	2.200	4.420	1.702	50.006
September	5..432	4.670	3.600	1.301	2.100	4.300	1.400	40.410
October	8.200	4.600	3.100	1.220	2.008	6.203	1.345	45.320
November	8.318	5.401	4.201	2.330	2.000	3.202	1.304	71.220
December	8.520	7.420	4.868	2.000	2.022	2.130	1.211	104.604

Table AII.12c: Calcium concentration of water samples from well and stream in communities in Etche Local Government Area, Rivers State

	Calcium concentration (mg/L)							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	7.002	6.100	5.001	2.010	1.610	1.810	1.361	119.201
February	7.000	7.670	4.302	2.106	2.401	1.960	1.300	128.344
March	5.111	8.100	3.520	2.210	2.002	2.150	1.312	130.611
April	4.160	5.701	3.332	1.168	2.000	1.168	1.330	26.400
May	4.301	5.411	4.001	1.139	2.000	2.179	1.382	33.540
June	5.212	5.102	3.386	1.139	2.010	2.181	1.313	37.600
July	6.520	6.200	4.102	2.400	2.018	2.414	1.330	66.711
August	5.220	6.001	4.500	2.516	2.200	4.210	1.500	45.23
September	4.700	4.312	3.100	1.401	2.201	2.200	1.400	36.61
October	7.640	4.220	2.910	1.313	2.100	5.340	1.302	40.810
November	7.640	5.300	3.518	2.101	2.012	3.210	1.264	69.00
December	7.451	6.655	4.460	2.121	2.111	2.130	1.205	100.100

Table AII.13a: Magnesium concentration of water samples from well and stream in communities in Ikwerre Local Government Area, Rivers State

	Magnesium concentration (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0.820	1.330	0.751	0.206	0.340	0.306	0.0700	25,200
February	0.631	1.620	0.452	0.280	0.321	0.101	0.060	27,400
March	0.710	0.840	0.520	0.120	0.118	0.130	0.064	30,000
April	0.600	0.410	0.400	0.032	0.031	0.321	0.032	26,750
May	0.610	0.420	0.400	0.045	0.025	0.610	0.010	28,600
June	0.622	0.581	0.510	0.064	0.056	0.500	0.018	33,400
July	0.710	0.772	0.870	0.051	0.130	0.710	0.030	48,000
August	0.520	0.710	1.060	0.068	0.190	0.800	0.120	50,500
September	0.618	1.030	1.000	0.107	0.321	1.102	0.131	44,300
October	1.715	1.121	0.650	0.130	0.522	1.130	0.120	33,620
November	1.620	1.010	0.900	0.126	0.520	0.306	0.110	30,400
December	1.715	1.323	1.202	0.160	0.517	0.216	0.071	32,200

Table AII.13b: Magnesium concentration of water samples from well and stream in communities in Emohua Local Government Area, Rivers State

	Magnesium Concentration (mg/L)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	0.840	1.366	0.790	0.200	0.360	0.310	0.072	26,000
February	0.654	1.656	0.480	0.308	0.342	0.100	0.066	28,100
March	0.720	0.888	0.560	0.122	0.123	0.142	0.070	31,210
April	0.601	0.442	0.410	0.038	0.054	0.355	0.036	27,000
May	0.620	0.440	0.391	0.050	0.047	0.620	0.010	29,420
June	0.631	0.600	0.520	0.070	0.071	0.5.10	0.020	34,200
July	0.711	0.800	1.000	0.066	0.152	0.741	0.034	50,000

August	0.530	0.720	1.106	0.075	0.200	0.900	0.125	52,000
September	0.621	1.080	0.687	0.110	0.343	1.100	0.140	45,200
October	1.720	1.133	0.430	0.153	0.540	1.110	0.200	34,410
November	1.621	1.020	0.850	0.140	0.541	0.310	0.130	29,220
December	1.800	1.375	1.300	0.171	0.520	0.200	0.082	31,100

Table AII.13c: Magnesium concentration of water samples from well and stream in communities in Etche Local Government Area, Rivers State

	Magnesium concentration (mg/L)							
	WELL						**STREAM**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
January	0.800	1.300	0.730	0.200	0.321	0.290	0.667	24,600
February	0.627	1.600	0.421	0.251	0.316	0.100	0.056	26,100
March	0.700	0.801	0.500	0.120	0.105	0.121	0.060	28,600
April	0.600	0.391	0.380	0.030	0.021	0.300	0.020	25,200
May	0.610	0.400	0.391	0.041	0.020	0.520	0.011	27,300
June	0.618	0.560	0.500	0.060	0.050	0.470	0.016	31,100
July	0.680	0.720	0.800	0.048	0.124	0.680	0.025	45,200
August	0.520	0.700	0.940	0.060	0.180	0.740	0.116	47,300
September	0.600	1.010	1.030	0.102	0.300	1.100	0.120	41,200
October	1.700	1.118	0.530	0.124	0.401	1.218	1.117	30,150
November	1.600	1.009	0.715	0.120	0.431	0.225	0.100	28,100
December	1.700	1.300	1.119	0.140	0.500	0.200	0.060	31,300

Table AII.13d: Mean Magnesium concentration of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Magnesium conc., mg/L)		
January	0.626	0.644	0.607
February	0.568	0.590	0.553
March	0.406	0.426	0.391
April	0.299	0.317	0.287
May	0.352	0.361	0.330
June	0.389	0.378	0.376
July	0.541	0.578	0.509
August	0.558	0.589	0.523
September	0.696	0.657	0.690
October	0.878	0.848	0.849
November	0.747	0.747	0.683
December	0.856	0.894	0.827

Table AII.13e: Mean Magnesium concentration of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Magnesium conc., mg/L)		
January	12600.04	13000.04	12300.33
February	13700.03	14050.03	13050.03
March	15000.03	15605.04	14300.03
April	13375.02	13500.02	12600.01
May	14300.01	14710.01	13650.01
June	16700.01	17100.01	15550.01
July	24000.02	25000.02	22600.01
August	25250.06	26000.06	23650.06
September	22150.07	22600.07	20600.06
October	16810.06	17205.10	15075.56
November	15200.06	14610.07	14050.05
December	16100.04	15550.04	15650.03

Table AII.14a: Conductivity of water samples from well and stream in communities in Ikwerre Local Government Area, Rivers State

	Conductivity (μs/cm)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	61	52	46	40	29	31	29	15,800
February	74	60	31	23	25	20	12	15,600
March	65	63	35	28	24	19	15	9,100
April	56	41	30	15	13	12	11	6,000
May	68	42	36	11	20	15	12	6,100
June	42	39	32	12	20	19	13	6,700
July	41	31	40	12	18	20	9	5,600
August	43	38	30	10	18	19	10	5,800
September	50	40	25	17	21	21	11	5,800
October	61	42	22	17	22	22	15	6,100
November	55	46	35	21	26	25	16	7,000
December	69	55	40	29	30	32	18	14,600

Table AII.14b: Conductivity of water samples from well and stream in communities in Emohua Local Government Area, Rivers State

	Conductivity (μs/cm)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	63	50	46	40	50	32	31	16,000
February	76	61	30	24	26	21	13	16,300
March	66	65	37	29	25	20	17	9,400
April	57	44	30	14	14	12	12	6,000
May	70	45	38	12	20	16	14	6,500
June	41	40	30	13	21	20	13	7,100
July	43	32	42	12	18	19	9	4,200
August	42	40	31	11	17	18	9	5,600
September	53	41	26	18	22	22	12	5,100
October	64	43	22	17	21	24	17	6,000
November	57	47	36	22	24	27	18	7,200
December	70	56	41	30	31	34	19	15,300

Table AII.14c: Conductivity of water samples from well and stream in communities in Etche Local Government Area, Rivers State

	Conductivity (μs/cm)							
	WELL						STREAM	
	1	2	3	4	5	6	7	8
January	58	50	43	38	27	28	27	15,000
February	70	55	30	21	24	19	12	15,000
March	60	60	33	27	22	19	14	9,000
April	52	40	28	16	12	11	12	5,900
May	62	41	32	10	17	13	13	6,000
June	41	41	30	11	18	16	14	6,200
July	41	30	37	12	18	18	13	6,200
August	42	35	30	13	20	18	10	5,300
September	46	38	24	15	21	19	10	5,300
October	50	40	23	16	23	20	14	6,000
November	53	43	33	20	18	22	15	6,700
December	62	50	34	27	25	30	16	14,200

Table AII.14d: Mean Conductivity of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Conductivity, μs/cm)		
January	43.17	46.83	40.67
February	38.83	39.67	36.50
March	39.00	40.33	36.83
April	27.83	28.50	26.50
May	32.00	33.50	29.17
June	27.33	27.50	26.17
July	27.00	27.67	26.00
August	26.33	26.50	26.33
September	29.00	30.33	27.17
October	31.00	31.83	28.67
November	34.67	35.50	31.50
December	42.50	43.67	38.00

Table AII.14e: Mean Conductivity of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Conductivity, μs/cm)		
January	7914.50	8015.50	7513.50
February	7806.00	8156.50	7506.00
March	4557.50	4708.50	4507.00
April	3005.50	3006.00	2956.00
May	3056.00	3257.00	3006.50
June	3356.50	3556.50	3107.00
July	2804.50	2104.50	3106.50
August	2905.00	2804.50	2655.00
September	2905.50	2556.00	2655.00
October	3057.50	3008.50	3007.00
November	3508.00	3609.00	3357.50
December	7309.00	7659.50	7108.00

Table AI.1d2: Mean heterotrophic bacterial population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Log_{10} THB population, cfu/ml)		
January	2.9800	3.8949	2.4742
February	2.8388	3.7684	2.4624
March	2.4281	3.5930	2.2856
April	2.8949	3.8314	2.3579
May	2.7427	3.7936	2.5079
June	2.9345	3.8250	2.5024
July	3.1265	4.2338	2.5315
August	2.9745	3.9986	2.5527
September	2.9533	3.7853	2.5052
October	2.8825	3.4914	2.4771
November	2.6561	3.9420	2.4914
December	2.5999	3.7443	2.3522

Table AI.1e2: Mean heterotrophic bacterial population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Log_{10} THB population, cfu/ml)		
January	2.5185	3.7782	2.5623
February	3.4624	4.3118	2.4393
March	3.0531	3.8779	2.4624
April	3.1775	3.8808	2.4771
May	3.2240	4.1399	2.5378
June	3.1508	3.9085	2.5855
July	3.2613	4.0719	2.4843
August	3.3043	3.9345	2.4983
September	3.2799	4.1021	2.5315
October	3.1987	4.3711	2.3522
November	2.5966	3.4393	2.4393
December	2.5740	3.6385	2.4150

Table AI.2d2: Mean fungal population of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Log_{10} Fungal population, cfu/ml)		
January	3.3457	3.3741	2.1809
February	3.3358	3.3457	2.1996
March	3.4393	3.2347	2.2041
April	*3.4150*	*4.1903*	*2.2788*
May	3.4960	4.3324	2.2900
June	3.4674	4.3522	2.3324
July	3.5074	4.1683	2.3711
August	3.4723	4.1513	2.4260
September	3.5420	4.2672	2.4260
October	3.4771	4.0852	2.3979
November	3.5141	3.3257	2.3222
December	3.4260	3.0969	2.1996

Table AI.2e2: Mean fungal population of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Log_{10} Fungal population, cfu/ml)		
January	3.4314	3.0212	2.2553
February	3.3892	3.0607	2.3118
March	3.4843	3.3324	2.3324
April	3.2041	4.0607	2.3711
May	3.3522	4.1139	2.3979
June	3.5502	4.1614	2.4232
July	3.5315	4.4065	2.4314
August	3.4914	4.0212	2.4624
September	3.6232	4.0792	2.4771
October	3.4914	4.0414	2.4150
November	3.4843	3.0212	2.3222
December	3.4914	3.1614	2.2900

Table AII.12d: Mean Calcium concentration of water from wells in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Calcium conc., mg/L)		
January	4.072	4.245	3.922
February	4.187	4.292	4.240
March	3.965	4.084	3.849
April	3.162	2.966	2.922
May	3.030	3.038	3.172
June	3.168	3.226	3.172
July	4.133	3.382	3.942
August	4.191	4.284	4.108
September	3.482	3.194	2.986
October	4.222	4.222	3.921
November	4.099	4.242	3.964
December	4.430	4.493	4.155

Table AII.12e: Mean Calcium concentration of water from streams in Ikwerre, Emohua, and Etche LGA of Rivers State

	Ikwerre	Emohua	Etche
	(Mean Calcium conc., mg/L)		
January	60.700	60.960	60.281
February	65.654	71.313	64.822
March	66.827	68.780	65.962
April	14.301	15.201	13.865
May	18.308	19.919	17.461
June	20.412	21.370	19.457
July	34.881	35.990	34.021
August	24.345	25.854	23.365
September	19.856	20.905	19.005
October	17.771	23.333	21.056
November	35.690	36.262	35.132
December	51.807	52.908	50.653