2020

Borehole Water and Sachet Water Production in Southeast Nigeria

Joseph Emerenini
Walden University

Walden University

College of Health Sciences

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Joseph Emerenini

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Review Committee
Dr. David Anderson, Committee Chairperson, Public Health Faculty
Dr. Daniel Okenu, Committee Member, Public Health Faculty
Dr. Mary Garbowski, University Reviewer, Public Health Faculty

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Sue Subocz, Ph.D.

Walden University
2020

Abstract

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MS, Walden University 2013

BS, University of Detroit Mercy, 2007

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health

Walden University

November 15, 2020

Abstract

Drinking water is potable and safe if it is free from physical, chemical, and microbiological contaminants. Despite the Nigerian government's interventions to alleviate water contamination, a considerable number of Nigerians are still without safe potable water. The purpose of this quantitative cross-sectional study was to examine whether the level of contamination of drinking water sourced from boreholes and sachet packaged water in Owerri City, Southeast Nigeria was in compliance with World Health Organization (WHO) standards, and to examine the relationship between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet packaged water The conceptual framework for this study was the activated health education model. Data were collected from 68 water samples from 17 district wards of Owerri. The water pollution index revealed that 65% of the samples tested were polluted. Results of a one-sample *t*-test revealed poor compliance with the WHO standard. A binary logistic regression to evaluate whether physical and chemical parameters could predict bacterial contamination showed that turbidity of the water sample had 27 times increased odds for predicting bacterial contamination of the water source. However, this finding was not statistically significant. Results may provide the needed data to local authorities to enforce WHO standards for drinking water and promote public health.

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Dedication

This work is dedicated to the 1.1 billion people who do not have access to clean drinking water, particularly to the people of Owerri who are exposed to public health hazards. Also, to my lovely wife, Sabina Emerenini, for being a supportive wife and a loving mother of our lovely five children whom the Almighty God has blessed us with.

Acknowledgments

I would like to thank the people in Owerri whom I worked with, including the owners and vendors who contributed to this study. I would like to express my gratitude to the Almighty God for his infinite mercies, strength, grace, guidance, and protection throughout this study.

I am also profoundly grateful to the team at Walden, particularly to my chair, Dr. Anderson, and my committee member, Dr. Okenu, whose scholarly guidance, constructive comments, and critical revision of the drafts made it possible for me to complete this dissertation journey. I am also grateful to the university research reviewer team at the Walden College of Health Sciences to assist me in this work.

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Chapter 1: Introduction to the Study.

Unregulated borehole production and sachet water production are public health issues requiring attention because of their effects on general health and productivity of those affected (Amaechi, 2016; Emenike, Tenebe, Omeje, & Osinubi, 2017). Due to authorities' inability to provide safe water for communities, cities in Nigeria struggle to provide adequate clean water to meet citizens' needs (Akpen, Kpohal & Oparaku, 2018). The need for safe water has led to the escalation of unregulated drilling of boreholes and sachet water production. A borehole is a narrow hole drilled down through the earth to reach water (Daniel & Daodu, 2016). Sachet water is commercially packaged water bagged in 250 ml polyethylene bags meant for drinking. Sachet water came into the Nigerian retail market in 1990 (Stephen, 2015). The borehole and sachet water production was meant to bridge the gap in drinking water status/quality and access to clean drinking water. Despite the aim to provide safe drinking water through borehole and sachet water production, there are many people without safe drinking water in Nigeria (Wright, Dzodzomenyo, & Wardrop, 2016). Chapter 1 provides the study's background, problem statement, the purpose of the study, research questions and hypotheses, nature of the study, theoretical framework, assumptions, limitations of the study, delimitations, significance, and a summary of the chapter.

Background

Water is a transparent fluid that forms streams, lakes, oceans, and rain and is the major constituent of organisms' fluids. Water is an inorganic, odorless, tasteless, transparent, and nearly colorless substance made up of hydrogen and oxygen existing in gaseous, liquid, and solid states (Zumdahl, 2020). Water covers 71% of the earth's surface and is vital for all known forms of life. The instant development of developing nations includes having a more significant population of people who can improve water and improve health. However, 1.2 billion people worldwide do not have access to clean, safe water, and most of these people are in developing countries (Amaechi, 2016 and Jidawna et al.,2014).

Eighty percent of diseases and deaths in developing nations are attributed to unsanitary water (Daniel & Daodu, 2016). Therefore, clean drinking water is crucial in promoting good health. The water supply is not reliable in Nigeria, accounting for some of the people's ill health (Khan et al., 2017; Oludairo & Aiyedun, 2015). Studies have reported the negative impact of poor hygiene and unclean drinking water on the overall health of surrounding communities (Aroh et al., 2013; D. M. Musa; Garba, Yousuf & Ishag, 2018). The current study outcomes may improve the quality of drinking water sourced from borehole and sachet water.

In Nigeria, borehole and sachet water are significant sources of drinking water. However, these sources are not entirely safe as they may have contaminants that may be dangerous to health (Amaechi, 2016). A study conducted in 72 towns and cities in Edo-State, Nigeria, Idogho, Yahaya, and Dagona (2014) found sweeping typhoid occurrences resulting from unhealthy water and poor sanitation. In a similar study in Mozanbique, Gonzalez-Gomez, Lluch-Frechina, and Guardiola (2013) found a connection between unsafe water and sanitation and diarrhea in children.

The water supply in the Imo State of Nigeria is inadequate to meet the needs of the population (Amaechi, 2016). As an alternative to obtaining clean water, water bagging industries in Nigeria have created sachet water popularly known as “pure water” Across the world, studies have indicated the effects of unsanitary water on the overall health of surrounding communities (Wright et al., 2016). In Nigeria, despite the involvement of the World Bank, African Development Bank, and United Nations Children’s Educational Fund (UNICEF) to improve drinking water quality, accessing safe water is still a challenge (Ajayi, Sridhar, Adekunle, & Oluwande, 2008).

Drinking water, regardless of its source, is usually subjected to safety and quality tests. Ishaku, Majid, Ajayi, and Haruna (2011) stated that the water supply in rural areas in Nigeria is a public health dilemma as over 70% of the households do not have access to clean drinking water. Gregory and Victor (2018) confirmed this by reporting the need to examine issues arising from the increase in boreholes dug in Nigeria and concerns regarding groundwater contamination. Oyedeji et al. (2009) reported violations of international water quality standards of the sachet and bottled water sold in the Nigerian markets. Boreholes and sachet-packaged water have become the most common alternatives for getting drinking water for the average Nigerian. However, reports indicated that most of these sources might not meet acceptable water quality for consumption purposes (Amaechi, 2016).

Emenike et al. (2017) and Omalu et al. (2010) stated that sachet water produced in developing nations might be sold without adequate monitoring and that water treatment may be subject to contamination. A significant number of Southeast Nigerian villages have no access to safe water, which may expose them to unsanitary water and diseases such as trots, typhoid, and cholera (Wright et al., 2016). Drinking unsafe water or untreated borehole water is a significant cause of death in children (WHO/UNICEF, 2012). Findings from the studies of Kumpel, Cock-Esteb, Duret, De-Waal, and Khush (2017) and Ishaku et al. (2011) aligned with those from Gregory and Victor (2018), who reported a need to examine borehole and sachet water sold in developing nations like Nigeria.

The gap in the literature was the inadequate monitoring and quality control of borehole and sachet water production. Fisher et al. (2015), in a microbiological assessment of packaged water in Sierra Leone, stated that very few studies had addressed the quality of packaged sachet water despite the consumption rate, which has become substantial. Likewise, in Uganda, Halage et al. (2015) advocated for regular quality assessment of packaged water as they have become a popular consumer product; therefore, their demand may encourage the production of substandard and counterfeit products. According to Gangil, Tripathi, Patyal, Dutta, and Mathur (2013), due to the "astronomical increase in the consumption of packaged waters especially bottled and sachet drinking water" (p. 27) in India, the safety of water had become a matter of significant concern. The current study addressed this gap by identifying the levels of physical, chemical, and bacteriological contamination of drinking water sourced from borehole and sachet packaged water as a means of providing awareness for the situation report in the Owerri municipal area of Imo State, Nigeria. The results may provide authorities with guidelines for ensuring safe borehole and sachet water and monitoring strategies for the people's benefits in Imo State, Nigeria.

Problem Statement

The need to access safe water has forced many developing nations to opt for providing safe drinking water from boreholes and sachet packaged water (Atta, 2017). Most of the sachet-packaged water produced in Nigeria is sold without sufficient treatment and monitoring and may not be free from physical, chemical, and bacteriological contamination (Emenike et al., 2017; Omalu et al., 2010). In some instances, the borehole and sachet water production companies' storage tanks and pipes are not well maintained to ensure good quality and safety of water stored in them (Daniel & Daoda, 2016). According to Omalu et al. (2010), the physical assessment of some sachet water in Nigeria is necessary. There is an increasing understanding that contaminated water consumption is responsible for several health-related disorders such as waterborne infections like diarrhea and typhoid fever (Aroh et al., 2013; D. M. Musa et al., 2018).

The proliferation of unregulated boreholes and the sachet portable water production in Owerri and its surrounding environment has raised concerns about water quality and suitability for safe drinking and other domestic purposes in line with regulatory standards. Waterborne diseases account for 80% of developing nations' illnesses, killing a child every 8 seconds (Akpen et al., 2018; Ibrahim, Umaru, & Akinsorji, 2007). Dada (2009) and D. A. Shigut et al. (2017) described the weaken of monitoring and production quality of borehole water and sachet water packaging and the treatment process. Dada (2009) recommended the need for more research, as most water sources were inadequately regulated.

Purpose of the Study

Access to safe drinking water is one of the major challenges of the 21st century (Halage et al., 2015). Unhygienic water is a global public health concern, putting people at risk for a host of diarrheal diseases and chemical intoxication (Emenike et al., 2017). Although disease outbreaks due to contaminated packaged water are not common, any potential contamination may lead to an epidemic because of the high demand and consumption of this form of water (Halage et al., 2015). The purpose of the current quantitative study was to examine the level of physical, chemical, and bacteriological contamination of borehole and sachet water in Owerri municipal local government area of Imo State, Nigeria. I also examined the correlation between the physical, chemical, and bacteriological parameters of drinking water sourced from the borehole and sachet-packaged water.

Research Questions

The following research questions (RQs) were used to guide this study:

RQ1: Are the levels of water quality from sachets and boreholes in Owerri municipal area of Imo State, Southeast Nigeria, in compliance with the WHO/UNICEF standards?

H_o1: The levels of water quality from sachets and boreholes in Owerri municipal area of Imo State, Southeast Nigeria, comply with the WHO/UNICEF standards.

H_a1: The levels of water quality from sachets and boreholes in Owerri municipal area of Imo State, Southeast Nigeria, do not comply with the WHO/UNICEF standards.

RQ2: Is there an association between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area of Imo State, Southeast Nigeria?

H_o2: There is no association between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area of Imo State, Southeast Nigeria.

H_a2: There is an association between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area of Imo State, Southeast Nigeria.

RQ3: What is the relationship between the physical and chemical parameters of drinking water sourced from borehole and sachet-packaged water in the Owerri metropolitan area and the presence of bacteriological contamination?

H_o3: The physical and chemical parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area predict the bacteriological contamination of the water.

H_a3: The physical and chemical parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area do not predict the bacteriological contamination of the water.

Conceptual Framework

The conceptual framework for this study was the activated health education model (AHEM). Historically, health education models are an adaptation of models from other disciplines. According to Dennison and Golazewski (2002), the AHEM is not an exception but is rather a behavioral model developed from a review of successful health education interventions including operant conditioning, self-care, health belief model, and value clarification. The AHEM, also known as the success-based curricular model, was developed as the foundation for other relevant models in behavior-based health education interventions (Dennison & Golazewski 2002).

The AHEM is a three-phase curricular model designed to improve healthy behavior. These phases are experiential, awareness, and responsibility (Dennison & Golazewski, 2002). The experiential phase engages the participants to be conscious of their health behavior to place or assess their behavior on a scale of wellness. This phase encourages people to take responsibility and subsequently supports receptibility for related health information in improving their health status. The awareness phase draws attention that makes people aware of the information regarding the targeted water quality concern. An essential component in this phase is the awareness of possible susceptibility to disease or deformity or the consequences of inappropriate behavior. The benefits from personal actions must be emphasized, and the potential hindrances to behavior change must be eliminated to encourage a shift in behavior. The last phase, which is the responsibility phase, pushes for the change process by clarifying the water contamination level, which enables a customized plan for behavior change (Dennison & Golazewski, 2002).

The AHEM has been used in many settings, including the reduction of disruptive and dangerous alcohol drinking behaviors of university students, improving student’s dental health behavior, and improving nutritional educational behavior for high school health classes (Dennison & Golazewski, 2002). Though other models provide health education guidelines in planning intervention programs, the AHEM delivers a framework of what to do and when to do it, thereby promoting higher efficiency and maximum output (Dennison & Golazewski, 2002).

The application of this model in the current study followed the three phases of the model. Testing the water samples for impurities to learn about the bacteriological parameters, chemical parameters, and other contaminants served as the experiential phase. The results will be provided to the government to increase awareness of possible susceptibility to disease or deformity or the consequences of consuming contaminated water (awareness phase). The provided information can then be used to address drinking water quality concerns. In the AHEM's responsibility phase, the government must pass new regulations or enforce existing regulations to ensure clean borehole and sachet water quality and monitoring. The education on borehole and sachet water quality started with water analysis, and dissemination of results may promote healthy behaviors as change is the goal of a health behavior or health promotion (see Glanz, Rimer, & Viswanath, 2015).

The study's goal was that borehole and sachet water testing would help reduce the concomitant illnesses and diseases associated with the consumption of unsanitary water or prevent things that can cause health injury. I adopted information from the experiential phase to determine the relationships between variables based on the research questions and hypotheses. Data collection was formed by the hypothesized mechanisms as well as contextual conditions that activated the hypothesized mechanisms. The hypothesized mechanisms were the framework and test tools to facilitate testing parameters and promote contamination level awareness.

Nature of the Study

The nature of the study was quantitative with a descriptive design. Test analyses were carried out to determine possible physical, chemical, and bacteriological contamination of drinking water sourced from borehole and sachet water. Also, secondary quantitative data were collected to examine borehole and sachet water against the WHO standard. This study addressed the current state of borehole and sachet water contamination in Owerri municipal area of Imo State, Southeast Nigeria; a total of 68 samples were tested. Fifty-one bags of sachet water and 17 samples of borehole water were collected and examined. The related physical attributes were tested: temperature, color, appearance, odor, turbidity, and total dissolved solids (TDS). For chemical parameters, the following attributes were checked: alkalinity, calcium hardness, total hardness, chloride level, and pH. Assessment of bacteriological contamination included fecal coliform count, total coliform count, number of colony-forming organisms, Citrobacteria, and *Salmonella* bacteria.

The analysis of the water samples was done using the lab and the Tap Score tests. The data were analyzed using SPSS software Version 23. The analysis included descriptive and inferential statistics.

Definitions

This section includes defined terms used in the study:

Borehole: A narrow shaft bored in the ground to extract water (WHO/UNICEF, 2015).

Borehole water: A borehole water supply source is water drilled from the ground and then sent to the bagging operations (Aboh, Giwa & Giwa, 2015)

Byproduct: The process of making one thing result in a second product; that second thing is called a byproduct. For instance, byproducts result when chlorine reacts with naturally present compounds in the water. The formation of these products takes place during reactions in which organic substances, such as humid acid and fulvic acid, form a joint production process (Miller-Keone &Toole, 2003).

Citrobacter proteus: Bacteria associated with diarrhea and secondary infections in debilitated persons occasionally causing primary septicemia. The bacteria can be found in soil, water, and the human intestine (Miller-Keone & Toole, 2003).

Hardness: High mineral content in water.

Iron: Mineral from groundwater that gives an unpleasant metallic taste.

Sachet water: Water bagged in a 250 ml synthetic polyethylene plastic bag inside an industrial compound's operation site, which is affordable to the public (Kumpel et al., 2017).

Salmonella infection (salmonellosis): A common bacterial disease that affects the intestinal tract. Humans become infected most frequently through contaminated water or food. People with salmonella infection usually have symptoms such vomiting, diarrhea, fever, and abdominal cramps within 72 hours (Kumpel et al.,2017).

Tap Score: A Tap Score kit is a laboratory water testing kit for testing hundreds of contaminants. Attributes measured include pH, alkalinity, TDS, coliform counts, color, order, iron, calcium, hardness, and others.

Water pollution index (WPI): The sum ratio of the measured average values of samples tested.

Assumptions

The central assumption in this study was that all water quality measurements would be valid and reliable. It was also assumed that borehole and sachet water production quality in Owerri, Imo State, Nigeria, was devoid of adequate local authorities' monitoring, making water contamination a significant public health concern. Lastly, it was assumed that borehole and sachet-packaged water were the primary sources of potable drinking water for the residents of Owerri, Nigeria.

Scope and Delimitations

The scope of this study was Owerri metropolis in Nigeria. Findings from this study may not be reflective of the entire state of Imo and may not be generalizable to Nigeria. Also, within Owerri, not all of the available portable water sources were included in the study. The local government also produces water, albeit epileptically, which is piped to people’s homes. Some people consume bottled water, which has a slightly different production pattern compared to sachet water.

Limitations

Due to the potential cost and logistics in this study, all of the available borehole water sources and sachet-packaged water brands in Owerri were not included. This study was an examination of a sample of the different sources available. Also, there are many physical, chemical, and bacteriological analyses that could have been done. This study was restricted to the major ones due to limited resources.

Significance

This study's findings will be provided to the authorities to promote water quality standards for safe drinking water. Unsafe water is a global public health concern. The findings may help with designing a program of mandatory, periodic testing of boreholes and sachet water to ensure bagging operation sites comply with the rules and regulations of the WHO for safe water operating procedures (see WHO, 2018). The implementation of periodic water testing and monitoring may have a dramatic effect on the quality of drinking water and an eventual reduction in the attendant effects of contaminated water among the Nigerian people.

Summary

Water is an inorganic, odorless, tasteless, transparent, and nearly colorless chemical substance made up of hydrogen and oxygen existing in gaseous, liquid, and solid states (Zumdahl, 2020). About 1.2 billion people worldwide do not have access to clean, safe water, and most of them are in developing countries (Amaechi, 2016). Unsafe water quality is a global public health issue. There is concern that sachet water produced in developing nations may be sold without adequate monitoring, and that water treatment may be subject to contamination. The purpose of this quantitative study was to examine the level of contamination of drinking water sourced from boreholes and sachet-packaged water in Owerri city, Southeast Nigeria. Local officials may utilize this study's results to develop a standard that can improve the quality of commercially packaged sachet and borehole water for drinking purposes. The next chapter provides a review of the literature on the challenges and recommendations for borehole and sachet water production.

Chapter 2: Literature Review

The purpose of this quantitative study was to examine the level of physical, chemical, and bacteriological contamination of borehole and sachet water in Owerri municipal local government area of Imo State, Nigeria. This study also addressed the relationships between the physical, chemical, and bacteriological parameters between drinking water sourced from borehole and sachet-packaged water. Sachet water is packaged water bagged in a 250 ml polyethylene bags (Stephen, 2015). A borehole is a narrow hole drilled down into the earth to reach water (Daniel & Daodu, 2016).

In Nigeria, the composition of borehole and sachet water varies with local ambient conditions. Neither borehole nor sachet water has ever been chemically pure because water contains small amounts of gases, minerals, and organic matter of natural origin (Khan & Young, 2012). Forecasts indicated that this trend will continue for the foreseeable future (Ishaku et al., 2015). Research in the area of borehole and sachet water contamination has followed several avenues. Early work by D. M. Musa et al. (2018) addressed the bacteriological, physical, and chemical contamination of borehole and packaged water production. In Nigeria, packaged water is easy to get, and the price is affordable, but people still worry about its purity (Kumpel et al., 2017). Successful regulation of the packaged water industry remains a challenge to the national agency established to enforce compliance with international standards (Dada, 2009). Nigeria’s government was providing potable water to the communities and at the local level until 1980 (Kumpel et al., 2017).

The Ministry of Works in Nigeria that oversees water production and supply was overwhelmed due to the increasing population, poor planning, and corruption (Kumpel et al., 2017). Due to the Ministry of Works, Nigerians resorted to digging water boreholes and producing sachet water. Policymakers supported this practice as the public water system failed to meet Nigerians' needs (Khan & Young, 2012). Some borehole water samples were exposed to pathogens and pollutants such as *E-coli* and other contaminants that can produce diarrhea and massive loss of fluids (Khan & Young, 2012). Borehole and sachet water production and consumption are increasing in Imo State, and the government agencies are unable to regulate the safety and quality of water sold in the market (Fisher et al., 2015).

In the current study, water quality referred to the bacteriological, physical, and chemical characteristics of the borehole and sachet-packaged water. The monitoring of water quality has been neglected in Nigeria, making it a public health risk (D. M. Musa et al., 2018). The level of bacteriological, chemical, and physical parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal local government area of Imo State, Southeast Nigeria was analyzed. This study's results may be implemented during policy implementation, program planning, and clean water development.

Summary of Literature Establishing Relevance

Fisher et al. (2015) found that 58% of Nigerians consumed between two and four 250 ml sachet water bags per day, and the products are prone to microbiological contamination. Drinking water (borehole and sachet water), which may have immediate health consequences, is considered a public health risk (D. M. Musa et al., 2018). According to a study conducted in Jigawa State, Nigeria, the status and potential threats of groundwater quality have not been examined on a large scale in developing nations, which puts people at serious health risks (D. M. Musa et al., 2018). Amaechi (2016) stated that about 1.2 billion people around the world do not have access to clean water, and about 2.5 billion people do not have adequate sanitation. Clean water is vital in promoting healthy living; however, international water quality standards in developing countries are a major public health concern.

One of the research questions in the current study addressed whether water quality levels from sachet and boreholes comply with the WHO/UNICEF standards (see WHO, 2018). This question required the analysis of borehole and sachet water bacteriological contaminants. Borehole and sachet water are available and affordable, but there are concerns regarding its purity (D. M. Musa et al., 2018). Borehole and sachet water contamination has been a global issue, and it has attracted many studies and discussions on diseases such as typhoid fever. Cholera continues to be among the major health problems in developing nations (D. M. Musa et al., 2018).

The current study also addressed whether there was an association between the physical, chemical, and bacteriological contamination from borehole and sachet-packaged water in the Owerri municipal local government area of Imo State, Southeast Nigeria. Emenike et al. (2017) and Wright et al. (2016) conducted studies in Ado Odo Ata, Southwest Nigeria, and found the possibility of water contamination. Findings indicated that most of the community's existing water could be contaminated, which posed a public health threat (Wright et al., 2016). Based on these studies' findings, analysis of borehole and sachet water quality in the Imo State was necessary and appropriate.

Fisher et al. (2015) reported a decline in water quality for sachet water in Nigeria and other West African countries. People who live in developing nations or middle- or low-income countries are at risk, and about 3.8% of deaths have been credited to unclean water (Umma, 2010; WHO/UNICEF, 2012). The boreholes that provide drinking water in Southeast Nigeria are considered public health risks because there are tendencies for contamination with bacteria and heavy metals (Emenike et al., 2017). According to Kumpel et al. (2017), there has been a deterioration in water quality, which highlights the need to investigate all boreholes water and sachet water in Nigeria. The availability of quality drinking water has been an urgent problem because waterborne disease poses severe threats to families and communities around the world (Maduke et al., 2014).

Safe and clean drinking water supplies in Nigeria are inadequate despite government efforts because most of the country’s drinking water comes from boreholes and sachet water (Akpen et al., 2018; D. M. Musa et al., 2018). Other water quality production assessments indicated that some sachet water producers do not adequately treat raw water before packaging (Emenike et al., 2017; Umma, 2010). If the trends continue, about 2.4 billion people will lack access to safe drinking water, and multiple studies have indicated the effects of unclean drinking water on the overall health of surrounding communities (Akter, Ali, & Dey, 2014; Gonzalez-Gomez et al., 2013; Idogho, et al., 2015). The impact of microbiological contamination and the deterioration of water borehole and sachet water production quality along the supply chain suggest the need to improve sachet water quality (Fisher et al., 2015).

Borehole and sachet water production sites need precise requirements for establishing a site licensing and transparent bagging process (Emenike et al., 2017). Across the world, researchers found that water from boreholes has not been treated effectively before packaging inside the sachet, and they also reported that the problems of untreated water affect the health of surrounding communities (Akter et al., 2014; Ezeokpube, Obiora, & Phil-Eze, 2014; Idogho et al., 2015). Amaechi (2016) found that the storage and packaging method is more prone to frequent contamination, as in most cases, it is difficult to clean the borehole water storage tank after emptying it correctly. In a similar study, Garn et al. (2018) found a connection between untreated water and a diagnosis of trachomatous inflammation folliculitis (a waterborne disease) in people. All health-related issues reported came from the consumption of contaminated water (Emenike et al., 2017). Emenike et al. (2017) further stated that sachet water does not qualify as safe drinking water in West Africa.

Sachet water and untreated borehole water can impose health risks, and Justin, Okorie, and Nkwocha (2019) recommended further study of adequate water quality control measures in Nigeria. Ngwi et al. (2010) and Emenike et al. (2017) reported that sachet water could not be free from contamination because monitoring and regulatory agencies have not ensured that the sachet water bagging operations follow WHO clean water guidelines. Amaechi (2016) examined the link between handling practices and microbial quality and reported that water storage is more prone to contamination because it is difficult to clean a water reserve tank properly. This can allow micro-organisms to grow in the water tank and contaminate water (Usman, Gerber, & Pangaribowo, 2016). Omalu et al. (2011) reported the tendencies of contamination of sachet or bottled water in Nigeria. Omalu et al. and Emenike et al. reported that sachet water quality and other health concerns are a serious public health concern in Nigeria.

The most recommended sources of water in Nigeria are borehole and sachet water. However, the quality and the unwholesomeness of it is still a concern because regulation remains a challenge for the National Agency for Food and Drug Administration and Control (Amaechi, 2016). In Nigeria, the supply of drinking water is not reliable and has affected Nigerians' health (Amaechi, 2016; Omalu et al., 2010). Water-related diarrhea is the most prevalent disease among citizens after malaria, promoting the need for safe drinking water (Fisher et al., 2015). Gonzalez-Gomez et al. (2013) looked at untreated water and sanitation when it comes to diarrhea in children. Gonzalez-Gomez et al. collected data from 334 households and reported that families or individuals who do not practice hygiene, such as washing hands before touching foods, are more likely to experience diarrhea. Gonzalez-Gomez et al. also reported a relationship between certain habits and infrastructure that likely influences the rate of waterborne diseases such as diarrhea and typhoid in children below 5 years old.

Khan et al. (2011) adopted cognitive and focus group interviews of 429 households in a split sample study. Khan et al. used mixed methods and indicator cluster surveys that indicated that 80% of respondents agreed to water quality testing, given the reported health incidence associated with unsafe water in Belize. In a longitudinal study conducted in low-income urban areas in Bangladesh, Akter et al. (2014) sampled 30,000 households and found that untreated water and hygiene negatively affect community health and development. In a similar study conducted in 72 towns and cities in Edo State in Nigeria, Idogho et al. (2014) found instances of widespread typhoid resulting from unsanitary water and sanitation. As such, water must be continually assessed for the protection of public health (Daniel & Duodu, 2016)

Production, sales, and consumption of borehole and sachet water are growing in most countries of the world, and there is tremendous public health concern associated with the drinking of microbial contaminated packaged water (Oludairo & Aiyedun, 2015). Some studies stated that about 80% of all diseases and over 30% of deaths were a result of poor quality of drinking water, and this issue has not been addressed to an acceptable standard (Akpen et al., 2018; Ibrahim et al., 2007). In most cases, borehole and sachet water analysis were not taken seriously due to the high poverty rate in Nigeria (D. M. Musa et al., 2018). As borehole water and sachet water production are increasing in Nigeria, packaged water, no matter their sources are susceptible to microbial, toxic organic and inorganic contamination (Anyamene & Ojiagu, 2014; Oldairo & Aiyedun, 2015). Unfortunately, very little research has been conducted in geographical Southeast Nigeria to ensure proper water quality and improved clean water production (Okoji & Isah, 2014). The lack of safe water treatment, quality control, and diseases remains a troubling issue in Nigeria, especially in Imo state.

In another study, Emenike et al. (2017) and Gern et al. (2018) described the connection between untreated water and people diagnosed with trachomatous inflammation folliculitis. Emenike et al. (2017) study informed that other health issues might result from contaminated borehole and sachet water consumption. The study further stated that sachet water provision does not qualify as safe drinking water in West Africa (Edema & Atayese, 2009; Emenike et al., 2017).

Sachet water and untreated boreholes still impose health risks, which support Orisalene et al. (2016) recommendation for water quality control in Nigeria. Ngwi et al. (2010) and Emenike et al. (2017) reported that sachet water in Imo State is not is free from contamination as monitoring and regulatory agencies have not ensured that the sachet water bagging operations follow World Health Organization clean water guidelines. Omalu et al. (2010) reported the tendencies of contamination of sachet water as the source of drinking water in Nigeria. Omalu et al. and Emenike et al. reported that sachet water quality and other health concerns are a serious public health concern in Nigeria.

In most cases, quality control and treatment processes were downplayed due to Nigeria's high poverty rate. Unfortunately, very little research has been conducted in geographical Southeast Nigeria to ensure proper water quality and improve clean water awareness. In Nigeria, low coverage of improvements on borehole and sachet water is caused by the fact that the monitoring program does not exist. Over half of Nigeria’s population is using unregulated borehole and sachet water. In a research conducted in Oyo State in southwest Nigeria, Itama, Olascha, and Spiridaha (2017) reported that the community's primary drinking water source was found to be contaminated. However, researchers have not examined the level of sachet water contamination and bagging operations sites in Nigeria.

Idogho, Yahaya, and Dagona (2014) conducted a study in 18 local government areas in Edo State, Nigeria; the results described widespread water and sanitation diseases associated with unsafe water. Idogho et al. (2014) stated a high incidence of schistosomiasis (134,361:43%); typhoid (81,981: 27%); cholera (62,191: 20%) and diarrhea (29,893: 10%), respectively. The results indicated a need to study private boreholes and sachet water production. From the literature review, there is a gap in the area of the borehole and sachet water quality and regulations in Southeast Nigeria.

Clean drinking water is the most basic for life in all kinds of organisms, but if it is not adequately protected during bagging and handling, it could be a public health issue (Halage et al., 2015; Musa et al., 2018). It has been reported by Itama et al. (2007) that the groundwater is contaminated. According to Garn et al. (2018), appropriate hygiene could prevent diseases or public health problems. However, in the developing nations, drinking water or sachet water is assumed not treated or deemed to be partially treated, which is a public health concern.

Preview of Major Sections of the Literature Review

This chapter established the relevance of this study. This chapter's remaining sections cover the literature search strategy, the theoretical framework for the study, a review of bacteriological, chemical, and physical parameters of borehole and sachet water contaminants. The literature review helped analyze borehole and sachet water contaminant levels, bacteriological parameters, relationships, and microbial quality.

There is a need to create public awareness of the bacteriological, chemical, and physical levels of borehole and sachet water because of its potential danger. FONT

Literature Search Strategy

The databases used to find pertinent articles and topics include: the SAGE research methods online database, Google Scholar, African Journals Online (AJOL), CINAHL Plus database, the CINAHL Plus provide journals and ebooks database. (Walden University Library, n.d), ProQuest ABI/INFORM Collection database, and PsycArticle that contains peer-reviewed scholarly and scientific articles. Library databases provide access to journals, articles, and books (Walden University Library). Key search terms used for this research were: unsanitary water, bottled water, bacteriological parameters, boreholes in Nigeria, chemical parameters, drinking water, heavy metal, package water, sachet water, microbiological quality in Nigeria. The scope of the literature review focused on articles and books that were less than 5 years old.

Conceptual Framework

The activated health education model (AHEM), developed by Dennison Golazewski (2002), provided this research framework. The activated health education model is an adaptation of models from other disciplines, including operant conditioning, self-care, health belief model, and value clarification. The AHEM, also known as the "success-based" curricular model, was developed as the foundation for other relevant models in behavior-based health education interventions (Dennison & Golazewski 2002).

According to Dennison Golazewski (2002), the activated health education model works on the three-phase model. This research's long-term value lies in examining the bacteriological, chemical, and physical parameters of a borehole and sachet water upon which the purpose of the AHEM rests (Justine, Okorie & Nkwocha, 2019; Nieto 2010). The framework model assumption was that borehole, and sachet water testing/analysis is useful, and therefore, not testing reflects poorly on people (experimental phase). This study also tested hypotheses based on assessing relationships and predictive abilities between the independent and dependent variables and the strength of such relations. The results will be given to the local government to identify a problem area (awareness phase) and provide information that can be used to improve borehole and sachet water regulations.

In the AHEM's responsibility phase, the local government must pass and enforce regulations that will assist in promoting healthy behaviors. For example, the education of borehole and sachet water contamination will start with water analysis that can lead to the promotion of safe water development. In every conceptual framework, change is the ultimate aim of a health promotion that can reduce health disparities (Allensworth, 2015; Glanza et al., 2015).

Borehole and sachet water testing, as well as awareness on the levels of physical, chemicals and bacteriological contamination, can reduce morbidity and mortality or prevent circumstances that can cause health injury (Glanza et al., 2015). The activated health education approach provided information in the experiential phase to determine the relationships between variables and create awareness given the research questions and hypotheses for this study. The framework adopted in this study will guide in collecting and analyzing water samples. This study will provide the local government and program planning results that will motivate them to implement and enforce clean water regulations. In this final phase, management strategies were introduced that provided the local government with the opportunity to develop a clean water program or regulations. The practical theory of the activated health education model phase is that when the local government fails to improve water quality, this will continue to create health problems and affect health development (Edema & Ataysi, 2009).

The second phase of the framework is the awareness phase, which presents data derived from the experiential phase to create awareness of quality control and monitoring. The benefit of people being aware of the issue is to rise above the stereotyped situations in their everyday lives. According to Glanza et al. (2015), changes in people’s behavior or attitude is the optimum focus of health promotion and behavior change. The awareness phase is where the individual accepts to act to reduce the possibility of contracting a disease or being sick through drinking unsanitary water. Many stakeholders agree that health or event mitigation's main success lies in creating awareness (Khan & Young, 2012).

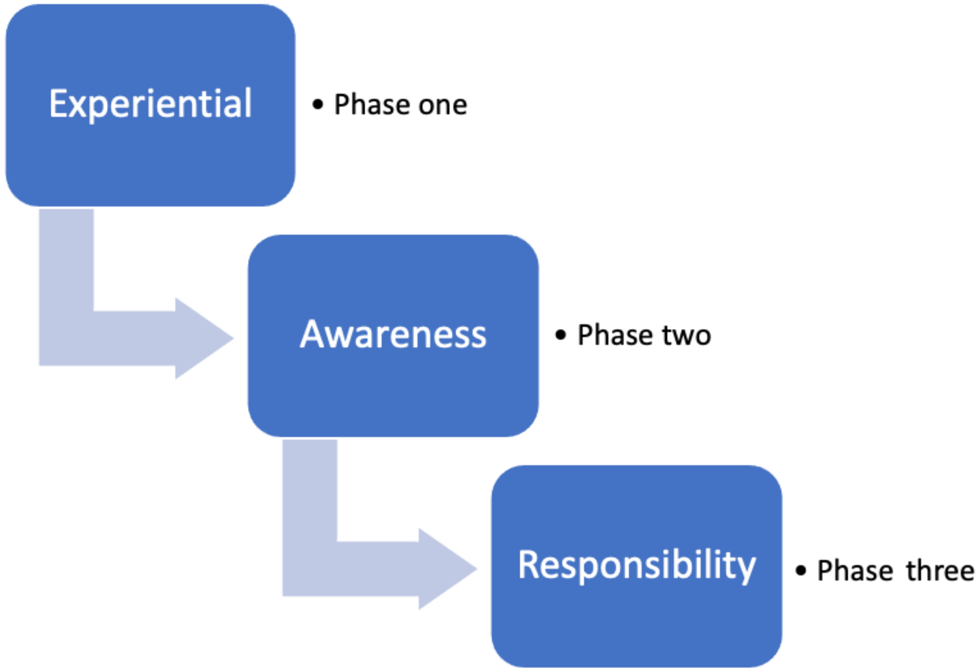

Figure 1. Activated health education model phases diagram.

Figure 1 schematically displays the activated health education model based on Dennison & Golazewski's (2002) interventions. Phase 1 identifies behavior determinants of the borehole and sachet water is used to achieve research goals. Phase 2 promotes awareness of the bacteriological parameters of groundwater and sachet water (Justine, Okorie & Nkwocha, 2019). Phase 3 requires action to be taken based on the experiential outcome of the research analysis of the bacteriological, chemical, and physical parameters of borehole and sachet water.

Figure 1 demonstrated how a series of activities are carried out to communicate research. The figure concluded that point one advances the other level, which controls point two and points three in the study. The experiential phase (assessment) commits researchers in analyzing borehole and sachet water bacteriological, chemical, and physical contamination through laboratory testing. Through assessment, researchers will become aware of the targeted microbial contaminants and other impurities. According to Soriano (2016), and evaluation conducted helped assess drinking water contamination from boreholes and sachet packaged water in Imo state, southeast Nigeria. The phase established baseline measures and identified conditions for future goals set. The presented information presented knowledge or rationale for experiential activities and created an understanding of the targeted borehole and sachet water bacteria level. The responsibility phase activities controlled or managed the results of the study. The phase must be adequate, positive, and provided a solution to the health behavior that improved the community's lives and beyond. The last stage described the process that actualized the intent to change or accept water production change and continue observing unsanitary behavior. Decisions need to be made and carried out regarding borehole water and sachet water production quality and monitoring the quality of water sold in the market. The activated health education model was used to control unsafe water production and achieve optimum health (Dennison & Golaszewki, 2002).

There are some underlying assumptions upon which AHEM operates. The first is that the experiential phase should precede the other phases and independently organized; the second is that the awareness phase should progressively decrease time and effort. At the same time, the third assumption states that the responsibility phase must utilize personal experience and knowledge to incorporate the behavior change into a participant’s lifestyle (Dennison & Golaszewki, 2002).

The model had been used in many settings, including the reduction of the disruptive and dangerous alcohol drinking behaviors of university students, improving student's dental health behavior, the effectiveness of a training workshop using the AHEM, and a nutritional educational behavior for high school health classes. Though other models provide health education guidelines in planning intervention programs, AHEM provides educators with a practical framework of what to do and when to do, thus assisting with higher efficiency and maximum output (Dennison & Golaszewki, 2002).

Summary and Transition

Successful regulation of the packaged water industry remains a challenge to the national agency established to enforce compliance with international standards (Dada, 2010). More than half of Nigerians consume between two to four sachet packaged water per day. This is because packaged water is easy to get, and the price is affordable, though they are prone to microbiological contamination, and people still worry about its purity (Fisher et al. 2015; Kumpel et al., 2017). Neither borehole nor sachet water has ever been chemically pure since water contains small amounts of gases, minerals, and organic matter of natural origin (Khan & Young, 2012). Many studies conducted in Nigeria had revealed widespread water and sanitation diseases associated with unsafe water. The activated health education model (AHEM) provided the framework for this research. It was developed as the foundation for other relevant models in behavior-based health education interventions (Dennison & Golazewski, 2002). The literature review showed a gap in the quality control borehole and sachet water quality and regulations, especially in Southeast Nigeria. Chapter 3 discussed the research methods employed for this study.

Chapter 3: Research Method

Water is essential for sustenance of life, and it needs to be available, accessible, and affordable in its purest form. Borehole and sachet water may seem clean, but they may contain potentially harmful contaminants from aging pipes and production processes. Drinking water is potable and safe for drinking if it is free from physical, chemical, and microbiological contaminants (Ogoko, 2017). Despite the Nigerian government's interventions to alleviate water contamination, a considerable number of Nigerians are still without potable water (Shigut, Liknew, Irge & Ahmad, 2017). Less than half (48%) of residents in semi-urban and urban areas and 39% of rural dwellers have access to potable water in the country (Onyenechere & Osuji, 2012).

Safe water is vital for human developmental processes. There can be no state of adequate or good health without safe water. It is not appropriate for water to be adequate in quantity only; it should also be adequate in quality (Onyenechere & Osuji 2012). This study is a quantitative research that examined the level of contamination of drinking water sourced from boreholes and sachet-packaged water in Owerri city, Southeast Nigeria. The level of borehole and sachet water contamination was done by assessing the physical, chemical, and bacteriological parameters in line with the standards stipulated by the WHO (2018). Because the sale of the borehole and sachet-packaged water has increased, both borehole and sachet water must meet the highest quality standards. This study will provide findings to the local government to enforce hygienic standards that meet the Nigerian National Agency for Foods Drugs Administration and Control Agency (NAFDAC) standards or guarding (Umma, 2010).

This chapter includes the research design for this quantitative study and the rationale for its choice. A description of the study setting and how samples were collected is also included. The chapter also includes a description of the study instruments, data collection methods, and how the data were analyzed. Potential threats to internal and external validity are discussed, and ethical concerns are addressed. The chapter ends with a summary of the research methods and the transition to the next chapter.

Research Questions and Hypotheses

The following research questions (RQs) were used to guide this study:

RQ1: Are the levels of water quality from sachets and boreholes in Owerri municipal area of Imo State, Southeast Nigeria in compliance with the WHO/UNICEF standards?

H_o1: The levels of water quality from sachets and boreholes in Owerri municipal area of Imo State, Southeast Nigeria, comply with the WHO/UNICEF standards.

H_a1: The levels of water quality from sachets and boreholes in Owerri municipal area of Imo State, Southeast Nigeria, do not comply with the WHO/UNICEF standards.

RQ2: Is there an association between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area of Imo State, Southeast Nigeria?

H_o2: There is no association between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area of Imo State, Southeast Nigeria.

H_a2: There is an association between the physical, chemical, and bacteriological parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area of Imo State, Southeast Nigeria.

RQ3: What is the relationship between the physical and chemical parameters of drinking water sourced from borehole and sachet-packaged water in the Owerri metropolitan area and the presence of bacteriological contamination?

H_o3: The physical and chemical parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area predict the bacteriological contamination of the water.

H_a3: The physical and chemical parameters of drinking water sourced from borehole and sachet-packaged water in Owerri municipal area do not predict the bacteriological contamination of the water.

The physical parameters examined were:

- temperature
- color,
- appearance,
- odor,
- turbidity, and
- total dissolved solids.

The chemical parameters were

- alkalinity,
- calcium hardness,

- total hardness,
- chloride level, and
- pH.

The bacteriological parameters were

- fecal coliform count,
- total coliform count,
- *Citrobacter*, and
- *Salmonella* bacteria.

Research Design and Rationale

This quantitative study addressed the contamination of drinking water sourced from boreholes and sachet-packaged water from Owerri municipal local government (OMLG) in Imo State, Southeast Nigeria. The dependent variables were the contaminants in the boreholes and sachet water. The independent variables were the physical, chemical, and bacteriological parameters. The third research question addressed the association between the physical and chemical parameters of the bacteriological parameters of drinking water sourced from borehole and sachet water.

A quantitative methodology was appropriate for this study because I tested hypotheses based on assessing relationships and predictive abilities between the independent and dependent variables and the strength of such relations. A cross-sectional design was used for this study. Because this study was observational, both exposure and outcome were measured simultaneously. The cross-sectional design is a snapshot of the study population at a given time. The study's research questions required a single evaluation of the samples of drinking water; therefore, a nonexperimental design was adopted for this study.

Given the research questions and hypotheses for this study, the borehole and sachet water analyses addressed the samples' water quality parameters and the relationships between the independent and dependent variables. The study did require a comparison of two or more groups to assess an intervention's effects as would have been appropriate for the experimental or quasi-experimental design. An advantage of the cross-sectional design is that it can be conducted in a natural setting, thereby increasing the findings' external validity. A cross-sectional study has the advantage of immediate outcome assessment; therefore, there is no attrition or loss to follow up. A cross-sectional design is also ideal for samples of research subjects, especially those scattered over a wide geographical area.

Methodology

Study Area

Owerri municipal LGA was the study setting. Owerri metropolitan is one of the three LGAs in Owerri, the capital of Imo State, Southeast Nigeria. The other LGAs are Owerri North and Owerri West. Owerri has an approximate land mass of 100 square kilometers with coordinates 5°29 ′06″N, 7°02 ′06″E/ 5.485°N and is located 159 meters above sea level (Ogoko, 2017). Owerri municipal is composed of 17 wards. All of these wards served as the sampling frame, especially for the collection of borehole water. A sample from each of the boreholes was collected from each of the wards. A list of the wards was obtained from the Imo State Electoral Commission. Owerri municipal has a population of 125,337 inhabitants, with a population growth rate of 3.2%. The city is experiencing a rapid rate of urbanization (Onyenechere & Osuji, 2012). The city is poorly planned with layouts, which have hindered the provision of basic amenities and infrastructures. Water provision is currently inadequate in Owerri city. Some residents are connected to the public water supply, but this connectivity is irregular, leading residents to find alternative water sources (Onyenechere & Osuji, 2012),

Owerri's primary water sources are the Imo State Water Corporation, community-based water supply, water kiosks, water peddlers, self-provision, and the municipal council. The community-based water supply is the borehole water source. This can be either commercial water and other private establishments for those in the neighborhood and the general public (Onyenechere & Osuji, 2012). The water peddlers are those who sell water using water storage tanks, while water kiosks are the retailers for the sachet-packaged water and bottled water. Due to the urbanization and challenges with the Owerri city layout, the Imo State Water Corporation's services are inadequate, causing people to learn more about using alternative drinking water sources. Figure 2 is a map showing the location of Owerri municipal LGA and surrounding LGAs of the Imo State.

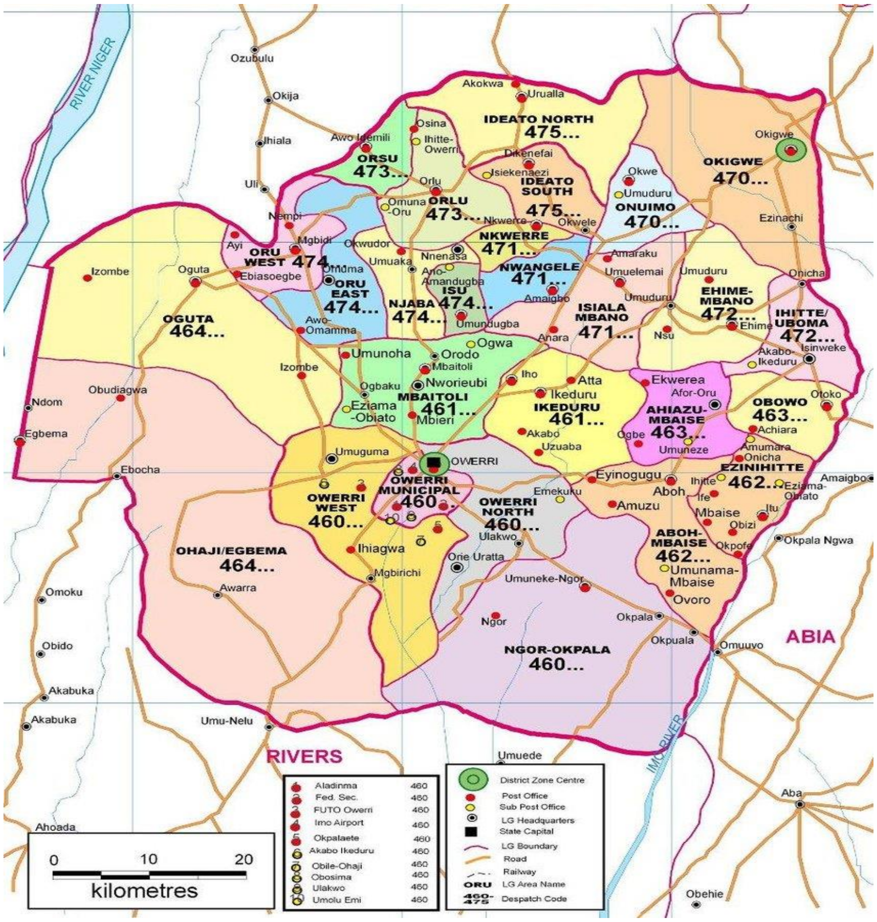

Figure 2. Map of Imo State of Nigeria showing all 21 LGAs. Owerri municipal area is circled on the map. Source: Nigeria Zip Code Map.

Sample Size Analysis

The research sample size was comparable with the quantitative methods and quality control requirements of the study. For this study, 68 water samples were obtained from the 17 wards that make up the Owerri area. These water samples included 51 bags of sachet packaged water (three each from the 17 wards) and 17 samples of borehole water. A list of the wards was obtained from Imo Independent Electoral Commission, as indicated in Figure 3 and Table 1. The water analysis cost for the different water samples and the time constraints accounted for the number of water samples included in this study.

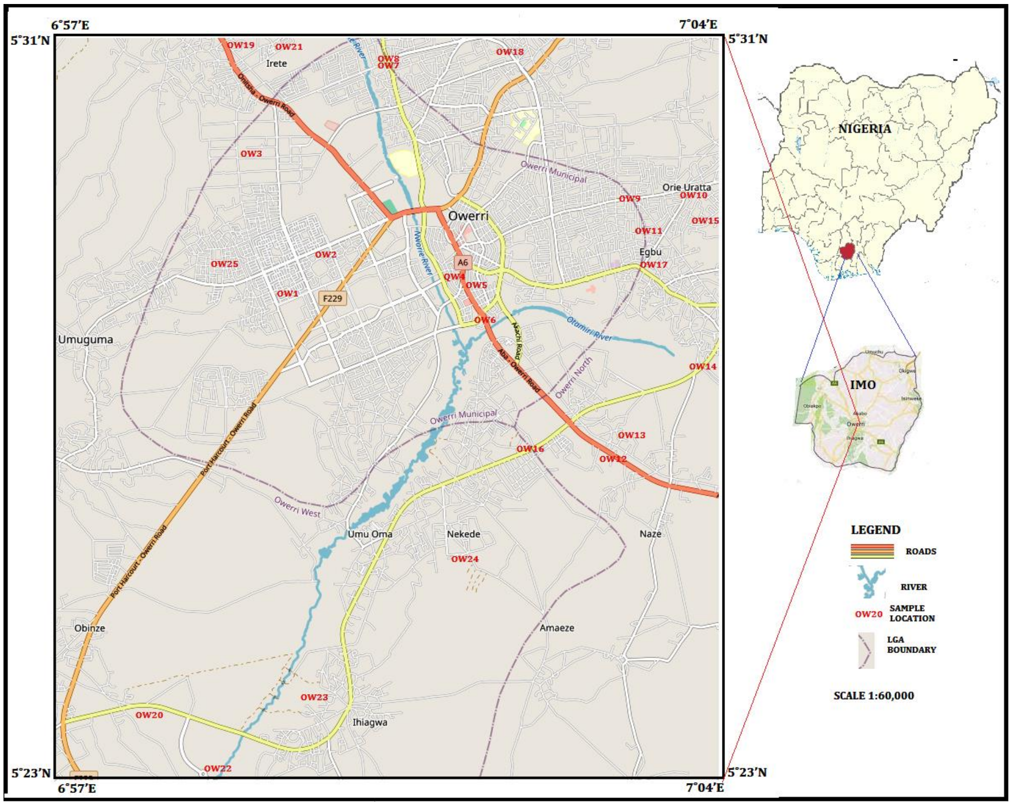

Figure 3. Map of the study area showing sampling locations.

Table 1

Sample Location, GPS, and Map Code

Sample location	Latitude	Longitude	Elevation	MAP CODE
DanBridge Table Water	N05° 28.485	E007° 00.078	129.8ft	OW1
Claret Table Water	N05° 28.913	E007° 00.503	235.5ft	OW2
Ce-Mercy Table Water	N05° 28.740	E007° 01.770	177.4ft	OW4
Liola Table Water	N05° 28.659	E007° 02.072	125.6ft	OW5
Kenpas Table Water	N05° 28.214	E007° 02.168	198.7ft	OW6
Macafran Table Water	N05° 31.000	E007° 01.084	210.7ft	OW8
Chipa Table Water	N05° 29.211	E007° 03.955	159.0 ft	OW11
Linkmore Table Water	N05° 26.851	E007° 03.535	242.6ft	OW12
Mr. Ben Table Water	N05° 27.043	E007° 03.696	230.7ft	OW13
Munachi Table Water	N05° 29.489	E007° 05.364	407.0ft	OW15
Pahenss Table Water	N05° 26.851	E007° 02.652	226.5ft	OW16
Iroko Table Water	N05° 32.261	E007° 59.101	242.6ft	OW19
Voss Table Water	N05° 24.078	E006° 58.453	222.0ft	OW20
Gosil Table Water	N05° 31.439	E006° 59.739	225.0ft	OW21
Futo Table Water	N05° 23.606	E006° 59.140	191.2ft	OW22
Chilec Royal Table Water	N05° 24.321	E007° 00.346	189.7ft	OW23
Apex Table Water	N05° 28.930	E006° 59.496	197.0ft	OW25

Sample Collection

In this research, a total of 68 water samples were collected from all the 17 wards that covered the study locations. Fifty-one bags of sachet and borehole water were collected, and 17 samples of water from 17 boreholes. Water samples were collected in triplicates from 17 different boreholes randomly selected from the community/commercial boreholes in each of the 17 wards in Owerri municipal metropolis, i.e., a borehole per district ward. Figures 4 and 5 show the pictures of a non-commercial and commercial borehole in Owerri. The water samples were collected in new 250ml polyethylene plastic containers. To obtain water samples with constant temperature and pH, water from the boreholes ran for 2 minutes before collection. Samples of water were collected directly from the borehole faucet during the working hours (8:30 am to 12:30 pm). The faucets were sterilized using a lighter before sample collection. Also, triplicate batches of each brand of identified sachet packaged water were purchased randomly from local markets, shops, and street vendors within Owerri city. Both the borehole and sachet samples were marked for easy identification. The collected samples were stored at 4°C in clean ice coolers and transported to the new concept analytical laboratory within 8 hours after collection. For the analysis, each product was carefully opened that avoided contaminating the water samples. Figure 6 is an image of a sachet water production site, while Figure 7 are some images of some of the sachet water sampled. For bottled borehole water, the cap of each bottle was carefully removed to prevent touching the opening. In the case of sachet water, an edge of the package was cut with sterilized scissors and discharged the contents into culture tubes.

Figure 4. Picture of a noncommercial borehole.

Figure 5. Picture of a private borehole.

Figure 6. Sachet water production site.

Figure 7. Images of some of the sachet water sampled and analyzed.

Sample Analysis

All quantitative analyses were performed using Tap Score and lab tests. Tap Score kit is a laboratory water testing kit for testing hundreds of contaminants. Quantitative data from the experiment were analyzed using descriptive statistics. The Tap Score and laboratory were used to test for water hardness, iron, alkalinity, pH, chloride level, and calcium level. Bacteriological analysis was done within one day after collection, and chemical analysis was carried out within two days of sampling. The hypothesis and the research questions guided the study. The standard methods were followed during sample collection. Analysis of the samples was done according to the standard methods for the examination of water and wastewater (APHA, 2005). The following physical attributes: appearance and odor were evaluated subjectively using the standard operating procedure (SOP) on water analysis specified by Nigeria National Agency for Foods Drugs Administration and Control Agency (NAFDAC) laboratory manual. The average of the three readings for each water quality parameter from each borehole water source or sachet packaged water was recorded. The study analysis samples were refrigerated at 4 C within 8 hours of collection. As such, samples were collected in batches and avoided possible delays in the laboratory.

Borehole and sachet water temperature, pH, and dissolve solid were measured using a multimeter and total dissolved (TDS) with electrical conductivity. Total hardness was determined by titrimetric method, appearance, the odor was observed. The bacteriological were measured in the lab.

Instrument

Laboratory tests and Tap Score kits were used for data collection. A recording leaflet developed was used to record the laboratory findings of the water analysis. Appendix A is a copy of the recording leaflet.

Types of Variables and Measurement

The variables of interest in this study were dependent and independent. Depending on the research question, any of the variables can either be the independent or dependent variable. Variables considered in this study include the physical water parameters comprising temperature, color, appearance, odor, total dissolved solids, and turbidity. In this study, the chemical parameters are alkalinity, calcium hardness, total hardness, chloride levels, and pH. Bacteriological parameters are the fecal coliform count, total coliform count, Citrobacter, and *Salmonella* bacteria, and the number of colony-forming organisms. Table 2 shows the variables of interest and their operationalization.

Table 2

Variables and Operationalization

Variables	How variable is measured	Measurement scale
Source of water	Borehole or Sachet	Nominal
Temperature	Centigrade (°C)	Ratio
Color	Hazen unit (Hu)	Ratio
Appearance	Clear/Not clear	Nominal
Taste	Objectionable/Not objectionable	Nominal
Odor	Inoffensive/Offensive	Nominal
Turbidity	Nephelometric Turbidity Units (NTU)	Ratio
Total dissolved solids	Mg/L	Ratio
Alkalinity	Mg/L	Ratio
Calcium hardness	Mg/L	Ratio
Total hardness	Mg/L	Ratio
Chloride level	Mg/L	Ratio
pH	Units	Ratio
Fecal Coliform Counts	CFU/100ml	Ratio
Total Coliform Counts	CFU/100ml	Ratio
Citrobacter Bacteria	CFU/100ml	Ratio
Number of colonies forming organisms	Counts/Frequency	Ratio
Salmonella bacteria	CFU/100ml	Ratio

Data Analysis Plan

After collection and cleaning (verification of retrieved recording leaflets) of laboratory analysis, the data were entered into the computer and analyzed with statistical package for social scientists (SPSS) software version 25. The analysis was based on research questions, measurement scale of data collected, and the research hypothesis. Frequency distributions were run on the database to check for missing fields, omissions, entry errors, and double entries. Where such was found, the source leaflet(s) was traced, and such errors were corrected to reflect what was obtained in the leaflet form.

Research question one (RQ1) was analyzed using descriptive statistics, and tables and figures (frequency distribution) were used to represent the data. For those parameters with the nominal measurement scale, frequency distribution, tables, and bar charts were used to represent data values. On the other hand, for those continuous data on a ratio measurement scale, measures of central tendencies were used to describe the data. For the comparison of the physio-chemical parameters with the standard values, a one-sample t-test was done for those parameters measured as continuous variables.

Research question two (RQ2) was about the relationships between the physical, chemical, and bacteriological parameters of drinking water sourced from boreholes and sachet packaged water. The quantitative data were analyzed using Pearson's Correlation for the continuous variables and Pearson's Chi-Squared test for the nominal variables. An independent sample t-test was used to check conformity between the means of the two independent groups, i.e., the parameters from the boreholes and those from the sachet packaged water.

Research question three (RQ3) assessed the predictive abilities of both the physical and chemical parameters of drinking water sourced from boreholes and sachet packaged water in determining the bacteriologic contamination. According to Oludairo and Aiyedun (2015), the presence of coliform in potable water was used as an indication of water contamination. Therefore, bacteriological contamination is a dichotomous variable. RQ3 analyzed samples using logistic regression. Logistic regression is a type of regression in which the outcome variable is categorical (as in the case of bacteriological contamination in the question), and the predictor (or independent) variables are continuous or categorical. The prediction was on an outcome dichotomous categorical variable. Binary logistic regression was used in modeling outcomes for the dependent variable using the independent variables stated in RQ3.

Threats to Validity

Threats to External Validity

A threat to external validity in this study was the possibility of some prevalent sachet packaged water not being involved in the study either because they are not sampled or inability to include them within the sample due to financial and time constraints. Findings from such samples could also impact significantly on the outcome variables as the eventual sachet water samples may not reflect the full range of diversity of the sachet packaged water in Owerri municipal area. The same applies to the borehole water samples. There are two types of borehole: the private borehole and the public borehole water sample. The hygienic conditions for the different kinds of boreholes differ, thus affecting the generalization of the findings included in all the borehole water samples.

Threats to Internal Validity

Allowing for the study's validity consists of transferability, confirmability, and credibility (Sousa, 2014). Through the test, detailed values obtained added to the confirmability of this study. To achieve confirmability, I used the lab and Tap Score to improve the research's accuracy, credibility, validity, and transferability (Yin, 2018). The risks of internal validity in this study are measurement errors arising from varied sources such as measuring the wrong attributes, duplicate data entry, differences in the study setting, different administration of study instruments, and lack of uniformity in coding. For different aspects of measurements, three basic types of validity are usually mentioned: content validity, empirical validity, and construct validity. Content validity was checked by the review of the recording leaflet and ascertained that the proposed measurement reflects or covers all the attributes intended for measurement. Empirical validity is also known as instrument validity, or criterion validity was checked by ensuring that the physio-chemical and bacteriological parameters' analysis conforms with the proposed standard methods for examining water and wastewater by the American Public Health Association (2005).

Furthermore, to address construct validity and other possible threats to internal validity, the laboratory and Tap Score readings of the sample parameter values were recorded for each water sample for their respective sources. This assisted with validating the measurements and accuracy of data entry/tests. The water sample collection was completed in batches; all the samples were analyzed in the same referenced laboratory and handled the same way.

Ethical Concerns

The study proposal was approved by Walden University's Institutional Review Board (IRB). Approval number IRB# 04-17-20-0138576. The confidentiality of the water sample sources was maintained by collecting data without traceable identifiers. Codes were used to represent the names of the location (wards), where the borehole water was sampled. The codebook was kept with the researcher. Data from the recording leaflets were entered into a personal computer that is password protected. This ensured that only the investigator has access to the entered data. The paper leaflets were kept in a filing cabinet and locked. The results would be held with me for upwards of 5 years, after which they can be shredded. The chapter concluded how ethical issues were addressed. Chapter 4 described the findings from the study.

Chapter 4: Results

Water is one of the indispensable resources for the continued existence of living things, including humans. An adequate supply of fresh and clean drinking water is a basic need for all human beings (Edema et al., 2011). In nature, all water contains impurities; as water flows in streams and accumulates in lakes and filters through layers of soil and rock in the ground, it dissolves or absorbs substances it comes in contact with, which may be harmful or harmless (Ogoko, 2017). One of the significant problems in most developing countries is the provision of adequate and safe drinking water to their populace (Kitawaki, 2002).

Drinking water that is safe and palatable is a matter of high priority to Standard of WHO and other regulatory agencies in Nigeria and is expected to meet the WHO standard. Furthermore, drinking water that is fit for human consumption is expected to meet the WHO standard and be free from physical and chemical substances as well as microorganisms in an amount that can be hazardous to health (Denloye, 2004). No single method of purification can eliminate 100% of contaminants from drinking water. However, water can be made safe for consumption within acceptable limits (Denloye, 2004).

Sachet water is commercially treated water that is manufactured, packaged, and distributed for sale in sealed food grade polyethylene and intended for human consumption. However, there are concerns that some sachet water may not be properly treated as studies have indicated some type of contamination in sachet water (Itama & Olascha, 2015; Seltenrich, 2016; Zumdahl, 2020). The production of sachet water in

Nigeria started in the late 1990s, and today the advancement in scientific technology has made sachet water production one of the fastest-growing industries in the country (Idogho et al., 2014). Water consumers are frequently unaware of the potential health risks associated with exposure to waterborne contaminants, which has led to diseases like diarrhea, cholera, dysentery, typhoid fever, legionnaire's disease, and parasitic diseases (Omalu et al., 2011). The continuous increase in the sale and indiscriminate consumption of packaged drinking water in cities like Owerri is of public health concern because the prevalence of water-related diseases in most developing countries is determined by the quality of their drinking water (Ezeokpube, Obiora & Phil-Eze, 2014, Justin et al., 2019).

The assurance of drinking clean water in poor and deprived communities has been in jeopardy in the last decade due to the introduction of refuse and sewage into sources of water supply (Guzman & Stoller, 2018). The consumption of unsafe water could have devastating effects on health as unsafe drinking water is a crucial determinant of many microbial diseases with severe complications in immune-competent and immune-compromised individuals (Daniel & Daodu, 2016). The introduction of sachet water aimed to provide safe, hygienic, and affordable drinking water to the public and curb the magnitude of water-related infections in the country (Ezokpub, Obiora & Phil-Eza, 2014).

Sachet water is colorless, odorless, and tasteless, with high boiling and melting points as well as high heat of vaporization. Pure water can be slightly ionized reversibly to yield hydrogen and hydroxyl ions. Therefore, water is not only a solvent in which the chemical reactions of the living cell occur (Parashar, Bresee & Glass, 2003). The quality of drinking water is made up of components (Ngwai et al., 2010). The quality of drinking water is evaluated based on its chemical components. This is done by assessing the odor, pH, hardness, total alkalinity, dissolved oxygen, carbon dioxide, heavy metals, and organic constituents (Denloye, 2004).

This chapter presents the results of the study. Water quality was determined by measuring physical, chemical, and bacteriological parameters. Water quality guidelines are numerical values that define the average measure value of physical, chemical, or bacteriological parameters, which indicate a safe level for consumption (WHO/UNICEF, 2012). The samples collected from borehole and sachet water production in Imo State, Southeast Nigeria, were analyzed for physical, chemical, and bacteriological parameters contamination based on each parameter's threshold values.

Data Collection

Sampling of Sachet and Borehole Water

Before receiving approval from Walden IRB (approval number # 04-17-20-0138576), I identified study areas in 17 wards in Owerri. A total of 17 sites were identified. These sites are water-packaging factories that use boreholes as their water source. Data collection started June 10, 2020 and lasted until June 30, 2020. The data collected were first sorted. Fifty-one sachet and 17 borehole water samples from different drinking water brands, making a total of 68 water samples from different manufacturers, were used for this study. These are the most consumed brands in Owerri. Each brand's triplicate batches were purchased randomly from local markets, shops, and street vendors within Owerri metropolis. Each brand was from an individual ward in Owerri. The samples were marked for identification and transported to New Concept Analytical Laboratory, Owerri, for analysis. The laboratory used was different from the proposed laboratory due to travel restrictions. The samples were examined physically, and information on the packages was recorded. Each product was carefully opened to avoid contamination. In the case of sachet water, an edge of the package was cut with sterilized scissors and carefully placed in a sterilized beaker. The physical, chemical and bacteriological parameters were determined by taking water directly from the original package (sachet) or bottle (for borehole samples) and tested. Each sachet brand was tested in triplicates, and the average score was recorded as the value of the parameter.

Determination of Physical Qualities

In this study, borehole and sachet water samples were analyzed. The temperature was checked using the WHO standard. The laboratory test and fieldwork were completed using a multipurpose pH meter (EZ9902 pH meter, USA) adjusted for temperature in degrees Celsius as provided in standard methods for the examination of water and wastewater (American Public Health Association [APHA} 1998). The color and order value pollution index were determined using the WHO Standard: Spectrophotometric Method, with an ultraviolet spectrophotometer (EZ9908, USA.) expressed in Hazen units, according to standard methods for the examination of water and wastewater (APHA, 2005). The turbidity was measured using the WHO Standard Method: Nephelometric Method by turbidimeter (EZ9909, USA) in nephelometric turbidity units (NTU), as explained in standard methods for the examination of water and wastewater (APHA, 2005). Conductivity was determined using Standard Method 2510 B: Laboratory Method via a conductivity meter (EZ9908, US) in micro-Siemens per centimeter, as detailed in standard methods for the examination of water and wastewater (APHA, 2005). Total dissolved solids (TDS) and total suspended solids (TSS) were completed using WHO standard methods: TDS dried at 103-105°C and 2540 D, and TDS dried at 103-105°C, respectively. The units were expressed in mg/L according to standard methods for the examination of water and wastewater (APHA, 2005).

Determination of Chemical Qualities

In this study, alkalinity was measured based on the WHO Standard Method: Titration Method in mg/L, as explained in standard methods for examining water and wastewater (APHA, 2005). Total hardness and calcium hardness were determined using the WHO Standard Method: EDTA Titrimetric Method and Standard Method Titrimetric Method, respectively, as detailed in standard methods for examining water and wastewater (APHA, 2005) expressed in mg/L. Chloride was analyzed using Standard Method 4500-Cl–B: Argentometric Method in mg/L, and pH was measured using Standard Method 4500-H+ B: Electrometric Method, by a multipurpose pH meter (EZ9902 EC/pH-03, USA), according to standard methods for the examination of water and wastewater (APHA, 2005). Total coliform and fecal coliform organism numbers were determined using Standard Method 9221 B: Standard Total Coliform Fermentation Technique. Heterotrophic bacteria were measured using WHO Standard Method: Spread Plate Method, according to WHO standard methods for the examination of water and wastewater (APHA, 2005). Appendix B shows the physical and chemical properties of the sampled borehole and sachet-packaged waters.

Water Pollution Index

The water pollution index (WPI) is the sum ratio of the measured average values of the selected physical, chemical, and bacteriological parameters and each parameter's threshold values based on WHO. The values summary was carefully tabulated and shown in Table 3, Figure 8, and Figure 9. The importance of the WPI is that it helps classify and describe the safety of the water for drinking from very pure to heavily impure. The combined physical-chemical index makes it possible to compare the water quality of various water bodies independent of pollutants' presence (Filatov et al., 2005). The WPI has wide application and is used as the indicator of the quality of ground and river water, as well as of drinking water (Filatov et al., 2005; Fisher et al., 2015; Lylko et al., 2001). The WPI represents the sum of the ratio between the observed parameters and regulated standard values:

$$WPI = \sum_{n=1}^{n} \frac{\mathrm{Ai}}{\mathrm{T}} \times \frac{1}{\mathrm{n}}$$

The WPI is calculated as the sum of the ratio of the measured average value Ai and the standard threshold values for each parameter, divided by the number of used parameters (n). The standard threshold values for all parameters used are the WHO Standard

WQI = Water Quality Index

Ai = average measured value of each parameter

T = threshold values for each parameter.

Table 3

Water Quality Class Based on Water Pollution Index

Class	Description	WPI
I	Very pure	≤ 0-.3
II	Pure	0.3-1.0
III	Moderately Polluted	1.0 – 2.0
IV	Polluted	2.0 – 4.0
V	Impure	4.0 – 6.0
VI	Heavily impure	> 6.0

Results of Analysis

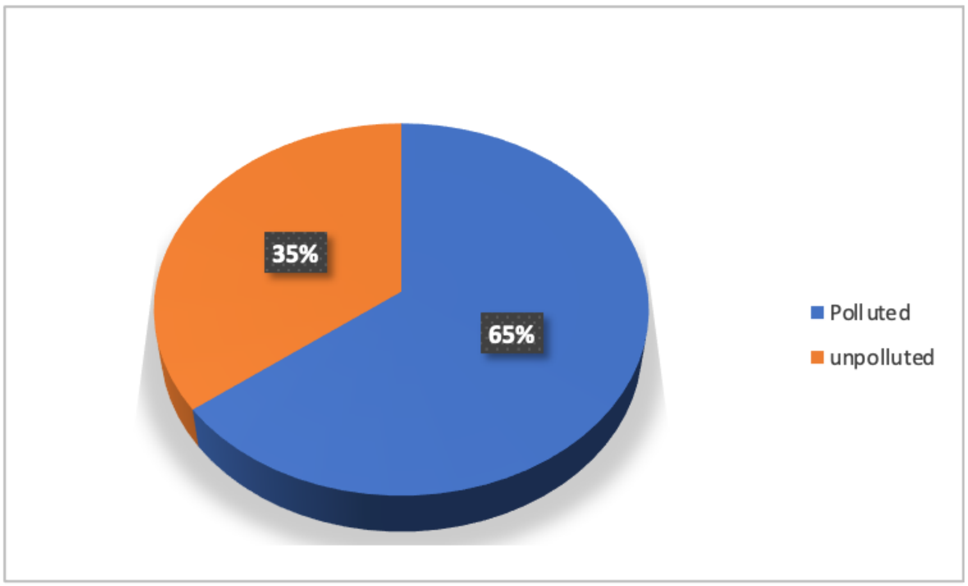

Figure 8. Overall pollution of water samples.

The following parameters were taken into consideration: odor, turbidity, TDS, conductivity, total hardness, chloride, pH, nitrate, nitrite, calcium, mg/l, iron, TSS, total bacterial count, and total coliform count. Overall, 65% of both water sources were polluted, and 35% were unpolluted (see Figure 8). The water comparison results in

Figure 9 showed both the borehole and the sachet analyzed samples levels ranging from pure to moderately impure for consumption (see Figure 9).

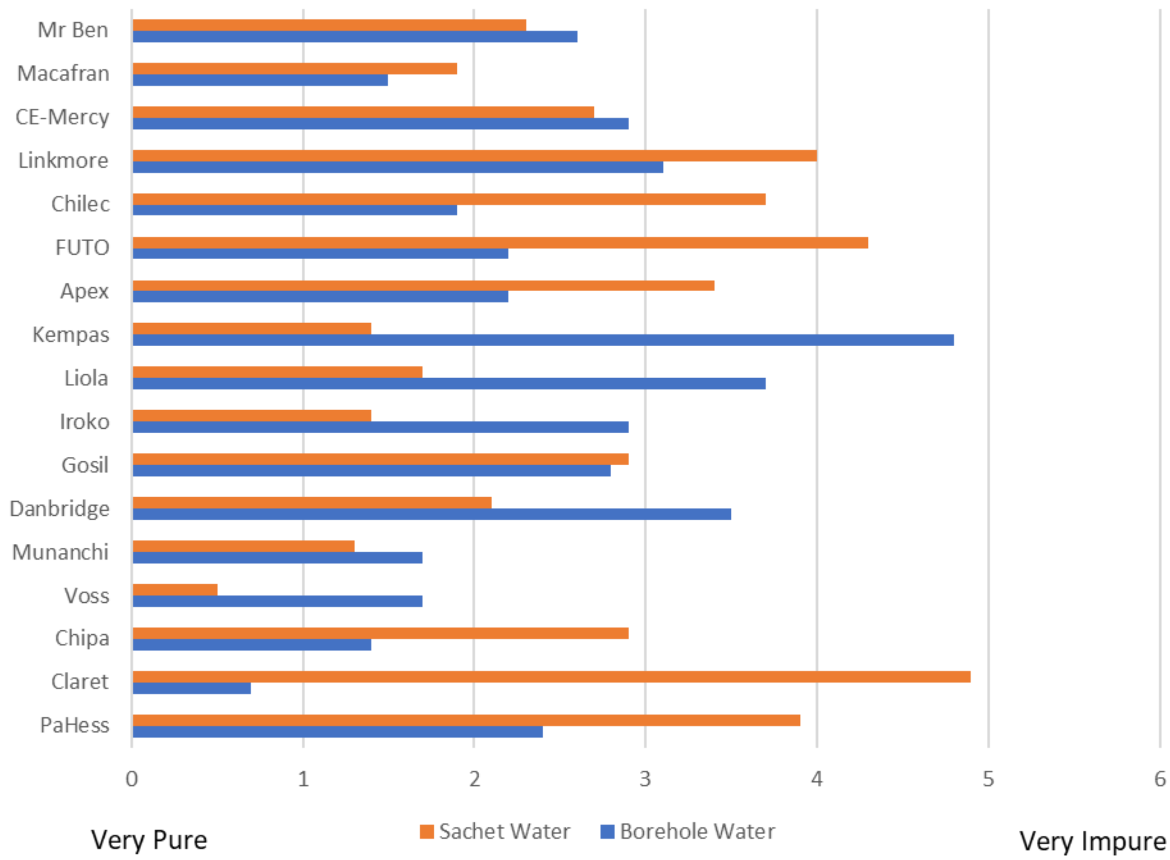

Figure 9. Comparison of results of water pollution index for water samples.

The analysis in Table 4 shows that all the chemical and bacteriologic parameters of the water samples from the boreholes significantly deviate from the WHO standards apart from the total fecal count and total bacteria count ($p > 0.05$). A similar result is also seen for the sachet packaged water in Table 5. Here, in addition to the total fecal count and the total bacteria count, the total Citrobacter count hypothesis testing does not differ significantly from the WHO standard.

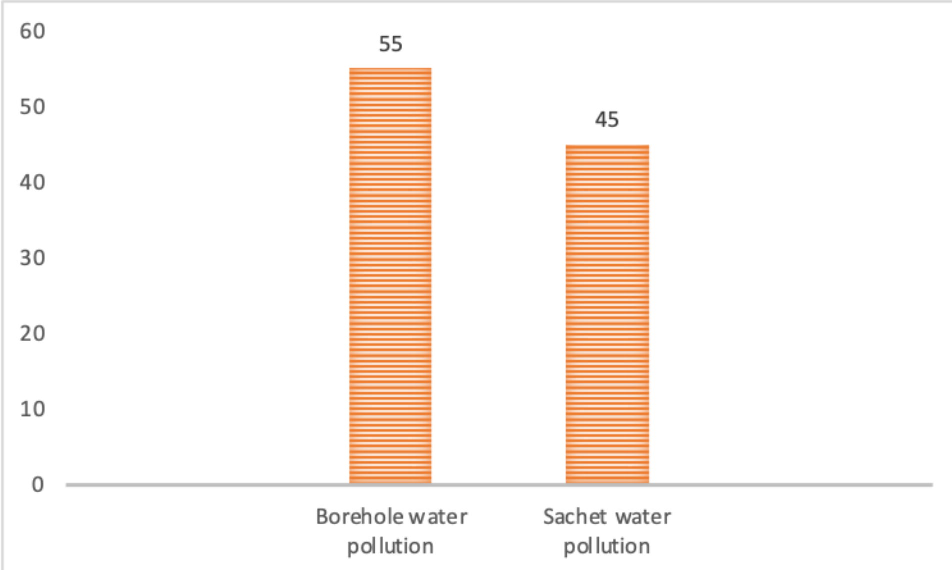

Figure 10. Pollution of water samples in comparison with the WHO standard.

Table 4

Relationships Between the Chemical and Bacteriologic Parameters of Borehole Water Samples with the WHO Standard

Parameters	WHO Standard	Mean ± SD	*t*	*p*
Color	15	0.12 ± 0.11	-126.50	.000
Turbidity	5	1.12 ± 1.02	-15.53	.000
Total dissolved solids	500	83.94 ± 43.03	- 9.67	.000
Alkalinity	200	32.94 ± 28.01	- 24.59	.000
Calcium hardness	150	16.76 ± 6.10	- 21.83	.000
Total hardness	150	27.57 ± 6.57	- 18.64	.000
Chloride	250	51.87 ± 42.42	- 19.26	.000
Total fecal coliform	0	7.59 ± 3.7	2.04	.057
Total citrobacter	0	7.12 ± 3.1	2.29	.036
Total coliform count	10	0.35 ± 0.20	- 46.16	.000
Total *Salmonella*	0	10.06 ± 4.17	2.41	.028
Total bacteria count	30	35 ± 22.02	.929	.367

Research Question 1: Results

This question addressed if the quality of water from sachet and boreholes complies with the WHO standards. The parameters assessed were the physical, chemical, and bacteriologic properties. A physical assessment of the water qualities for both the sachet and the ones sourced from boreholes showed conformity with the WHO standard (Appendix B). The appearance, color, and odor were similar to the WHO standard. The mean temperature for the water from sachet statistics output 26.97 ± 1.82 ^{o}C, and the one from borehole 27.83 ± 1.32 was between the reference range of the WHO, which is 20 – 30 ^{o}C. Likewise, the mean pH for the water from sachet statistics output 6.58 ± 0.35, and the ones from borehole 6.11 ± 0.87 were within the acceptable standard of 6.50 – 8.50. A one-sample t-test was done for the other parameters; both samples from the boreholes and sachet used the WHO values as the standard.

Table 5

Relationships Between the Chemical and Bacteriologic Parameters of Sachet Packaged Water Samples with the WHO Standard

Parameters	WHO Standard	Mean ± SD	*t*	*p*
Color	15	-	-	-
Turbidity	5	1.72 ± 1.12	-12.03	.000
Total dissolved solids	500	25.92 ± 23.41	- 91.15	.000
Alkalinity	200	49.29 ± 31.83	- 20.03	.000
Calcium hardness	150	12.80 ± 9.22	- 83.68	.000
Total hardness	150	26.66 ± 18.85	- 37.91	.000
Chloride	250	32.46 ± 7.60	- 118.11	.000
Total fecal coliform	0	0.29 ± 0.20	1.43	.172
Total citrobacter	0	1.53 ± 0.80	1.92	.073
Total coliform count	10	0.18 ± 0.09	- 103.08	.000
Total *Salmonella*	0	2.29 ± 1.17	2.41	.028
Total bacteria count	30	22.47 ± 16.38	1.96	.068

Research Question 2: Results

This question addressed an association between the physical, chemical, bacteriological parameters of drinking water sourced from borehole and sachet packaged water. A Pearson correlation analysis was done. The analysis showed a positive correlation (correlation coefficient [*r*] was between 0.027-.002 for turbidity of the borehole water samples with total salmonella count, and total Citrobacter count in the sachet water ($p < 0.05$). However, the borehole water samples' turbidity had a statistically significant negative correlation with total dissolved solids in the sachet water samples ($r = -.55$). Likewise, the higher the borehole water's total hardness, the higher the sachet water's calcium hardness and vice versa (r = .94 and .91, *p* = .000). Alkalinity in the borehole samples also positively correlated with the calcium hardness and total hardness of the sachet water samples (r = .70 and .69, *p* = .020). Lastly, the higher the borehole water samples' pH, the lower the chloride levels in the sachet water, *r* = -.72, *p* = .000.

Research Question 3: Results

Research question 3 sought to see if the physical and chemical parameters of drinking water sourced from borehole and sachet packaged water could predict the bacteriological contamination in those water samples. The bacteriological parameters tested in the research include fecal coliform count, total coliform count, Citrobacter, and *Salmonella* bacteria. However, bacterial contamination is defined as fecal coliform in portable water (Oludairo & Aiyedun, 2015). Figure 12 shows the bacterial contamination of the sampled water. Table 6 shows the results of the binary logistic regression done for the water samples from boreholes. However, the logistic regression analysis for the sachet packaged water samples could not be done as there was no predicted contamination value for the total fecal coliforms. The logistic regression results show that only the water sample's turbidity has 27 times increase the probability of bacterial contamination of the water source. However, this finding is not statistically significant. The independent variables did not predict the possibility of bacterial contamination of the water source from the (coefficients output), with χ^2 (7) = 8.825, ($p > 0.05$), and Cox and Snell R^2 = .40. (from the model summary output)

Table 6

The Relationship Between Chemical and Physiologic Parameters in Borehole Water Samples and Bacteriologic Contamination of the Water Source

	B	SE	Wald	df	*p*	e^B	95% CI of e^B	
							LL	UL
Turbidity	3.302	2.158	2.341	1	.126	27.180	.395	1868.104
TDS	.005	.008	.470	1	.493	1.005	.990	1.021
Alkalinity	.010	.063	.024	1	.877	1.010	.893	1.141
Calcium Hardness	.226	.280	.653	1	.419	1.254	.724	2.169
TH	-.201	.207	.943	1	.331	.818	.545	1.227
Chloride	.020	.022	.768	1	.381	1.020	.976	1.066
pH	.213	1.153	.034	1	.853	1.237	.129	11.853
Constant	-2.996	7.800	.148	1	.701	.050		

Note. SE = Standard Error, LL = lower level, UL = upper levels and CI = confidence interval, e^B = Exponential of B

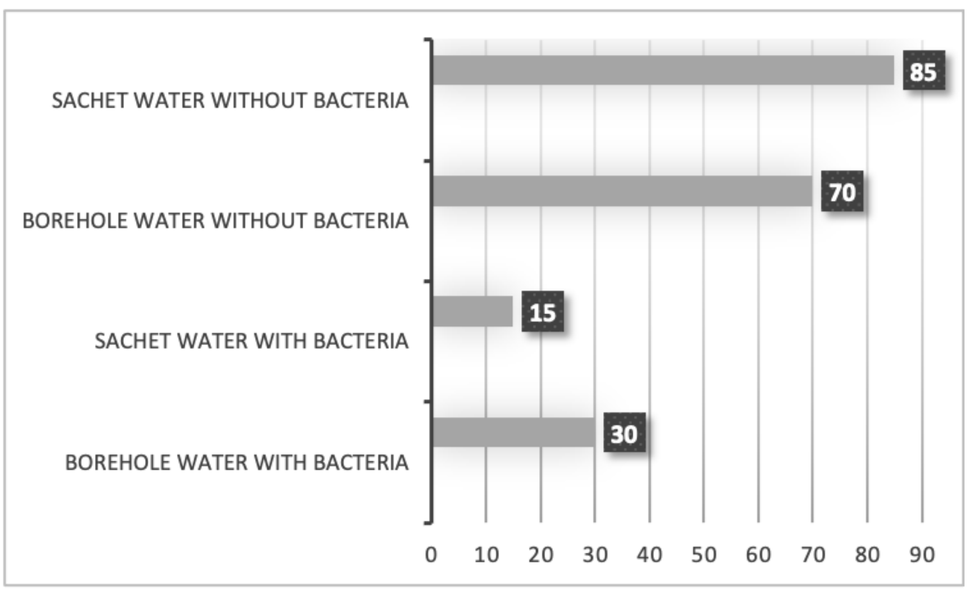

Figure 11. Bacterial contamination of water samples.

Summary

This chapter gave a flow of how data collected and the results of data analysis. The findings to the three research questions were also enumerated. RQ1 showed that both water samples are not entirely in conformity with the WHO standard. For RQ2, there was a positive correlation between turbidity of the borehole water samples with total *Salmonella* count and total Citrobacter count in the sachet water. However, turbidity in the borehole water samples negatively correlated with total dissolved solids in the sachet water samples. The results of the binary logistic regressions for RQ3 show that the water sample's turbidity has 27 times increase the probability of bacterial contamination of the water source. In all, the result of the water pollution index calculation showed that 35% of both the sachet water and the borehole water samples are very pure to moderately pure for consumption, and 65% of the samples tested are polluted (Figures 9). Figure 12 indicates that 30% of borehole samples analyzed had bacteria contamination; 70% of borehole water samples did not have bacteria contamination, 15% of sachet water samples had bacteria and 85% of sachet water samples analyzed had no bacteria contamination. This study's findings are similar to studies conducted in India, Iran, Kampala, and Ghana. Those studies show 70% of water samples analyzed showed growth for total coliform/total coliform count above the acceptable levels set by WHO standards (Anyamene & Ojiagu, 2014; Halage et al., 2015; Yidana et al., 2014). However, this finding is not statistically significant. The meaning of these results and other outcomes are provided in Chapter 5.

Chapter 5: Discussion, Conclusions, and Recommendations

The physical, chemical and bacteriological state of borehole and sachet water is the most component in drinking water that should be observed by all the members of the public. The samples for this study were sachet-packaged waters procured from vendors and borehole water sampled from the 17 wards of Owerri municipal in Imo State, Southeast Nigeria. All samples were analyzed for physical, chemical, and bacteriologic parameters according to the standard methods for the examination of water and wastewater (APHA, 2005). Owerri's drinking waters can be considered very pure or impure for human consumption as far as the measured parameters presented in the pollution index (see Figures 5 and 6). Some samples can be regarded as impure due to the absence of chlorine, and the public should be aware of this category of water.

Interpretations of Findings

Physical parameters of temperature, appearance, color, turbidity, and total dissolved solids are particulate matters in the water, which sometimes interfere with water quality; each was given quantitatively in unit. Odor and color tests were performed, and nothing was detected/unobjectionable (UO). From the results collected from the samples, temperature derived from borehole water samples ranged from 26.00 to 29.00^{o}C, and that from sachet water samples ranged from 25.01 to 31.20^{o}C. The results indicated that the sachet water's average temperature was higher than that of the borehole water. The temperature indicated that the borehole and sachet water were not higher than the WHO/NAFDAC standard of 25 to 32.4^{o}C and were statistically within range of the WHO/NAFDAC required values for drinking water. The high temperature in water tends to promote the development of undesirable taste and odor in water with time and bacterial growth.

The WHO and NAFDAC standards specify 15 right color units for color after filtration. From the results shown in Table 2, values for borehole drinking water and sachet water samples were between zero/clear. All of the borehole and sachet water samples had color below the detection limit, with zero values that were in the range of the WHO/NAFDAC standard. This means that all of the water samples were free from the dissolved substances.

Turbidity is a vital physical parameter for water quality. Turbidity is known to affect water's odor and color (Ngwi et al., 2010). The turbidity values for the borehole water analyzed were between 0.00 and 5.00 NTU (averaging 5 NTU limit). The sachet-packaged water values ranged from 0.65 to 3.89 NTU (average 0.30 NTU), as shown in Appendix B. The highest turbidity was recorded in the borehole water samples, and the lowest turbidity was recorded in most of the sachet water samples. Some of the samples tested were found below limits prescribed by WHO/NAFDAC standards (1-5 NTU). As the results indicated, the borehole water was slightly higher in turbidity as compared with the sachet water. The slightly higher turbidity suggests that there may be the presence of contamination in the borehole water tested. The consumption of highly turbid water may cause health risks, such as gastrointestinal diseases (U. Musa et al., 2014). The results indicated that the turbidity level was below acceptable limits for consumption and domestic use.

In this study, total solids for the borehole water ranged from 6.5 to 118 mg/L, and the sachet water values were between 1 and 71.00 mg/L as compared to the acceptable limit of 1000mg/L. However, comparatively borehole water is not a good standard for the conductivity limit. The TDS analysis revealed that all of the sachet water was in the range of 250mg/L, which is below the acceptable limit, while the borehole water sold in Owerri municipalities showed a value of 757mg/L, which is above the recommended standard 500mg/L recommendation by the WHO and NAFDAC. The water pollution index revealed that 25% of the sachet water samples and 10% of the borehole water samples were pure and fit for consumption, while 65% of the samples tested were polluted. Physical quality was reported as very pure and impure, as suggested in the pollution index in Figures 8 and 9. Package water, particularly in developing countries, has affected a more significant part of the world and has severe public health concerns (Anyamene & Ojiagu, 2014). The results were consistent with Amaechi's (2016) views that some water samples are not sufficiently potable to meet the population's needs in Owerri.

The analysis of the chemical parameters was done by adopting the WHO standards. Appendix B shows the results of alkalinity, calcium, total hardness, chloride, and pH level. The alkalinity level, as indicated in the pollution index, showed the level of pollution. The average alkalinity values range from 0 to 50mg/L were recorded for borehole water, and the 20 to 41 range were recorded for sachet water samples analyzed, which were below the acceptable limit of 200mg/L recommended by the WHO. The sachet samples had a pH range of 4.62 to 7.10, while that of borehole water samples was

4.40 to 6.40. All of the water samples analyzed were within the scope of 6.5 to 8.5 recommended by the WHO and NAFDAC.

In general, the calcium hardness, as indicated in Table 4, showed that the borehole water samples were between 79.99 and 81.02 mg/L, and sachet water had values between 8.0 mg/L and 34.0 mg/L. The alkalinity of sachet water samples was between 44 and 60 mg/L, and borehole water samples were within a range of 40 to 100 mg/L. Although the sachet water values of alkalinity were below those of borehole water, all were below the WHO/NAFDAC standard of 200 mg/L. Similarly, the borehole and sachet water samples' chloride content was below the WHO/NAFDAC standard of 150 mg/L. The sachet water samples had lower chloride content from the test results than the bottled samples, with average values of 36.98 mg/L and 42.96 mg/L, respectively.

Total hardness analysis indicated that borehole water was very hard with values ranging from 119.0 to 121.20 mg/L (average 100-200mg/L). The variable hardness obtained for the sachet water was between 10.08 and 34.00 mg/L, which was slightly soft. Both were below the 200mg/L guideline value of the WHO. The chloride level from borehole and sachet water was between 13.0 and 22.0, which was below the 250mg/L guideline value of the WHO. The pH of water samples from the borehole water source was found to be slightly acidic and above the maximum permissible limit, as indicated in Table 3. The high concentration of alkalinity and calcium in four boreholes and two sachet water packages exceeded the maximum permitted limit by the NAFDAC and WHO. However, sachet water sources were found to be better for drinking than borehole water sources.

The minimum and maximum pH values in the borehole and sachet water samples were 6.33 and 6.38, and 6.33 and 7.89. Turbidity was 4.084-38 NTU and 3.3- 3-7 NTU, TDS was 6.50-75750 and 355.34-352.68 mg/L, and TSS was 14.84 and 14.00-12.09 mg/L, respectively. Total hardness, both calcium and chlorine concentration, was 64.62 - 65.63 and 31.45-39.75 mg/L, respectively. From the results, four of the water samples analyzed were slightly acidic and found to exceed the maximum permissible limit set by NAFDAC and WHO. However, the TDS in one of the borehole samples was slightly higher than the acceptable limit. The TDS in any drinking water depends on the amount of particulate matter in the water, which sometimes interferes with the intensity of drinking water contamination (Musa et al., 2018).

The pH value refers to the intensity of the acid or alkaline condition of the solution. The pH values of water samples were found to vary from 6.35 to 7.89. The lowest pH values of 4.40-7.40 were recorded in the borehole water sample, while the maximum values of 6.1-7.4 were recorded in the sachet water. Both the borehole and sachet water ranges were below 6.50-8.50mg/L, the WHO's guideline value. From the results, four of the water samples analyzed were slightly acidic and found to be above the maximum permissible limits set by the NAFDAC and WHO. Long-term exposure to pH above the allowable limits affects the membrane of cells. The results indicated that some water samples were inadequate to meet the population's needs in Owerri (see Amaechi, 2016).

Results obtained in this study indicated that 70% of the sachet and borehole water samples analyzed were free from microbiological contaminants, as shown in Tables 4 and

5. The presence of total coliform in treated drinking water is a measure of its overall sanitary quality. In contrast, the indication of fecal contamination is measured by the presence of fecal coliform count. The WHO standards are that none should be detected in drinking water (WHO, 2011). Tables 4 and 5 provide total fecal count, and the bacterial count was significantly different at $p < 0.05$, which did not differ much from the *Citrobacter* count from the WHO standard. The results supported Dada's (2009) recommendation to fortify total coliform monitoring on packaged water products. Most of the borehole and sachet water samples in the current study met the WHO and NAFDAC standards. However, about 30% were significantly impure for consumption.

In this study, a bacteriological analysis of the borehole and sachet water was conducted. Out of 68 samples, 15% of sachet water were unsatisfactory, as shown in Figure 11. The analysis revealed that 15% of sachet water analyzed had *Salmonella* counts, bacteria counts, and fecal counts and were unfit for human consumption per WHO standards. In addition, 30% of the borehole samples revealed the presence of bacteria such as *Salmonella* and *Citrobacter*; 45% of borehole and sachet water samples were observed with bacteriological parameters that did not meet the standards of the WHO. The bacteriological results in this study were consistent with those from a study in Jaipur, India, where 50% of the 20 sachets and bottled water samples analyzed were polluted, and 100% of the specimens tested indicated high coliform counts with 40% *E. coli* (Gangil, Tripachi, Patyal, Dutta, & Mathur, 2013; Parashar, Bresee, & Glass, 2003). In Rivers State, Nigeria, 40% of 10 brands of sachet water analyzed had fecal coliform count with *E-coli* as well (Akinde, Nwachukwu, & Ogamba, 2011). Tables 4 and 5 provide a correlation of total fecal count and bacterial count at $p < 0.05$. The correlation did not differ significantly from *Citrobacter* count at $p < 0.05$. However, the analysis in Table 5 showed a positive correlation coefficient at 1.72 ± 1.12 mean for turbidity water samples and 2.29 ± 1.17 mean *Salmonella* count and total *Citrobacter* count of sachet water at $p < 0.05$.

Implications for Positive Social Change

The study provided data that can enhance Nigeria's successful borehole and sachet water production regulations and ultimately improve society's health. The local regulatory agencies and the local public health agencies should exercise more surveillance programs and educate the producers of the need to look for safe drinking water. The study results provided new insight toward training site owners and providing after education awareness.

- One of the most important steps to contamination is to regularly test water for bacteria to make sure that the public has reliable water.
- Based on the results, the contamination level may provide new insights towards improving water facility cleanness and improving drinking water.
- Due to the level of sachet package water contamination, production facilities should be trained on proper operation and disinfection of sachet water
- The local regulatory agencies and the local public health agencies should exercise more surveillance programs and educate the producers of the need for potable drinking water.

Conclusions

The study assessed and compared results obtained from laboratory analysis of borehole and sachet water in the Owerri municipality, Nigeria. Results received from some of the physical, chemical, and bacteriological parameters of the selected samples are in the range of pure. Few are in the range of impure as summarized in the pollution index. As indicated in the borehole and sachet water quality index, the overall results suggest that 23% of the boreholes and 35% of the sachet water sold in Owerri do not conform with the WHO (2018) and NAFDAC standard. In terms of physical parameters such as color, odor, temperature, turbidity, total dissolved solids, they all met the WHO, and NAFDAC recommended standard. However, dissolved solids could be good if stored at room temperature, but Nigeria water sometimes is stored in outdoor temperature. Concerning chemical parameters, some sachet and borehole water samples met the WHO and NAFDAC recommended standard, and some of the samples are not. For the bacteriological parameters, as indicated in the pollution tables, some of the borehole and sachet water samples were contaminated with total coliform bacteria and *Salmonella* bacteria above acceptable limits.

The relationship between the water sample parameters in Tables 4 and 5 provided total fecal count and bacteria count at ($p < 0.05$), which does not differ significantly from the Citrobacter count from the WHO standard. The analysis shows a positive correlation between the borehole water samples' turbidity with *Salmonella* count and total Citrobacter count in sachet water samples. Alkalinity in the borehole samples positively associated with the calcium hardness and total hardness of the sachet water, as indicated by the Pearson Correlation analysis.

From the sources of water analyzed, it was discovered that though sachet water is of better quality with a large number of very pure than borehole water, both are not entirely free from pollutants as indicated in the pollution index figures.

Recommendations on Borehole and Sachet Water Production Quality

Potable drinking water is an essential source of good health. The results based on each parameter's measured indicated that the water production sector needs necessary policy implementation and regulation in Owerri and other parts of Nigeria. With the level of pollution identified in these water samples, further study should be done to check the prevalence of commercial water sold with Owerri's water-borne diseases. Since this study was restricted to sachet packaged water and borehole water samples, further research could explore bottled water to see if the spectrum of pollution is repeated in the bottled water. With the pollution index table and figures, the regulatory agencies should be mandated to intensify effort to monitoring borehole and sachet water production quarterly. Based on this result, there is a need to create drinking water awareness on the potential danger, and local sachet water production regulations. Finally, the NAFDAC needs to organize quarterly hygiene, water production, and sanitation programs.

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Appendix A: Recording Leaflet

Leaflet Code

Sample Source: ☐ Borehole ☐ Sachet packaged water

Sample Code: ☐

If the sample is borehole, Type of borehole: Private ☐ Commercial ☐ N/A ☐

<u>The physical parameters</u>:

- Temperature (°C) ………………………………………………… ☐
- Color (Hu)………………………………………………………….. ☐
- Appearance (Clear/Not clear), ☐
- N/A (Objectionable/Not Objectionable) ……………………………. ☐
- Odor (offensive/inoffensive) ……………………………………… ☐
- Turbidity (NTU)……………………………………………………. ☐
- Total dissolved solids (mg/l) ……………………………………… ☐

<u>The chemical parameters</u>:

- Alkalinity (mg/l) ………………………………………………….. ☐
- Calcium hardness (mg/l)………………………………………….. ☐
- Total hardness (mg/l) ……………………………………………. ☐
- Chloride level (mg/l) ……………………………………………… ☐
- pH (units) ………………………………………………………….. ☐

<u>The bacteriologic parameters</u>:

- Fecal coliform count (CFU/100ml) ………………………………. ☐
- Total coliform count (CFU/100ml) ………………………………. ☐

- Heterotrophic bacteria (CFU/100ml) ……………………………… ☐
- The number of colonies forming organisms (Units) ………………… ☐

Does the sample meet the WHO guideline for drinking water? Yes/No. ☐

Appendix B: Raw Data of Water Sample Analysis

Result of Physio-chemical and Biological Analysis of the Borehole and Sachet Water Samples (Set 1)

Parameters	PaHenss		Claret		Chipa		Voss		Munachi		DanBridge	
	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet
Temperature, ^{0}C	26.9	27.1	26.4	26.9	29	31.2	27.4	28.5	28.7	27.2	27.9	25.1
Color, PCU	0	0	0	0	0	0	0	0	0	0	0	0
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
N/A	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
Odor	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
Turbidity, NTU	0	0.72	0	1.15	0	0	0.65	0	1.17	1.76	0	2.77
Total dissolve solid, mg/l	757.5	46.8	104	11.7	71.5	42.25	6.5	9.1	25.35	33.8	40.95	33.8
Conductivity, µs/cm	810	72	160	18	405	65	10	14	39	52	63	52
Alkalinity, mg/l CaCO3	0	40	50	40	0	20	0	0	20	20	20	90
Total Hardness, mg/lCa/MgCO3	23.31	23.31	41.44	23.31	20.72	23.31	20.72	12.95	15.54	20.72	20.72	15.54
Calcium Hardness, mg/l CaCO3	15.54	7.77	31.08	10.36	15.54	10.36	10.36	10.36	10.36	10.36	5.18	12.95
Magnesium Hardness, mg/l	7.77	15.54	10.36	12.95	5.18	12.95	10.36	2.59	5.18	10.36	15.54	2.59
Chloride, mg/lCl^{-}	111	38	37.96	40.96	63.94	37.96	41.96	40.96	31.97	40.96	119.96	23.99
pH	5.5	6.4	6.2	6.6	4.4	6.1	6.3	7.1	5.5	6.4	7	6.6
Nitrate, mg/l NO-3	2.77	4.62	1.08	7.08	1.54	2.77	1.38	0.31	1.85	0	3.85	1.54

Nitrite, mg/l NO2	4.19	6.98	1.68	10.7	2.33	4.19	2.09	0.47	2.79	0	5.81	2.32
Phosphate, mg/l PO^{-3}	0.24	5.1	0.45	0.55	0.02	0.73	0.48	2.21	0.39	0.54	1.63	0.71
Sulphate, mg/l SO^{-2}	ND	5	5	ND	ND	ND	15	ND	ND	ND	ND	ND
Total Solid, mg/l	136	68	128	20	79	91	5	12	56	71	52	175
Magnesium, mg/ l Mg	1.89	3.78	2.52	3.15	1.26	3.15	2.52	0.63	1.26	2.52	3.78	0.63
Calcium, mg/l Ca	5.05	2.52	10.09	3.36	5.05	3.36	3.36	3.36	3.36	3.36	1.68	4.21
Iron, mg/l Fe	0	0.19	0.27	0.29	0.15	0.06	0.21	0.08	0	0.25	0.25	0.12
Total Suspended Solids, mg/l	12.5	21.2	24	8.3	7.5	48.75	5.5	2.9	30.65	37.2	11.05	141.2
Total Bacterial Count, cfu/100ml	56	60	40	8	2	10	24	10	32	0	13	29
Total Coliform Count, cfu/100ml	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Total *Salmonella shigella* bacteria,	20	NG	3	NG	NG	NG	NG	NG	3	1	NG	NG
Total Fecal Coliform count, cfu/100ml	2	NG	NG	NG	2	NG	NG	NG	2	3	NG	NG
Total *Citrobacter* count, cfu/100ml	5	NG	2	NG	NG	NG	NG	NG	1	NG	NG	NG

B/Hole- Borehole, **NS** –No Stated, **ND**- None Detected, **UO**- Unobjectionable, **NG –** No growth.

Result of Physio-chemical and Biological Analysis of the Borehole and Sachet Water Samples (Set 2)

Parameters	Gosil		Iroko		Liola		Kempas		Apex		FUTO	
	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet
Temperature, ^{0}C	28.1	25.2	29.2	25.4	28.7	25	29.4	25.2	25.8	24.9	29.3	27.2
Color, PCU	0	0	0	0	0	0	2	0	0	0	0	0
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
N/A	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
Odor	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
Turbidity, NTU	0.16	2.43	3.01	2.16	1.19	2.25	1.69	2.99	0	0	2.44	3.89
Total dissolve solid, mg/l	10.4	58.5	20.8	18.2	20.8	12.35	14.3	12.35	42.25	66.95	7.8	6.5
Conductivity, µs/cm	16	90	32	28	32	19	22	19	65	103	12	10
Alkalinity, mg/l CaCO3	40	40	60	90	20	100	50	30	30	100	30	0
Total Hardness, mg/lCa/MgCO3	12.95	20.72	20.72	20.72	25.9	15.54	15.54	18.13	15.54	15.54	15.54	44.03
Calcium Hardness, mg/l CaCO3	10.36	5.18	5.18	10.36	7.77	10.36	10.36	7.77	7.77	7.77	5.18	10.36
Magnesium Hardness, mg/l	2.59	15.54	15.54	10.36	18.13	5.18	5.18	10.36	7.77	7.77	10.36	33.67
Chloride, mg/lCl^{-}	20.99	22.99	20.99	30.99	17.99	22.99	21.99	19.99	158.95	26.99	29	37
pH	7.4	7.1	6.9	6.8	7.1	6.7	6.8	6.8	6.7	6.9	5.9	6.7
Nitrate, mg/l NO-3	3.54	1.69	2.62	0.77	3.18	1.85	5.85	0.92	4.15	6.46	1.85	2.15
Nitrite, mg/l NO2	5.35	2.56	3.95	1.16	4.65	2.79	8.84	0.92	4.15	6.46	2.79	3.26
Phosphate, mg/l PO^{-3}	1.27	0.61	0.43	0.2	0.68	0.26	0.26	0.42	1.21	0.24	0.15	1.06
Sulphate, mg/l SO^{-2}	ND	5	ND	ND	ND	ND	5	ND	ND	ND	ND	ND

Total Solid, mg/l	116	148	37	26	97	42	215	30	44	137	59	45
magnesium, mg/ l Mg	0.63	3.78	3.78	2.52	4.41	1.26	1.26	2.52	1.89	1.89	2.52	8.19
Calcium, mg/l Ca	3.36	1.68	1.68	3.36	2.52	3.36	3.36	2.52	2.52	2.52	1.68	3.36
Iron, mg/l Fe	0.12	0.1	0.29	0.1	0.21	0.02	0	0.02	0.1	0	0.08	0.15
Total Suspended Solids, mg/l	105.6	89.5	16.2	7.8	76.2	29.65	200.7	17.65	1.75	70.05	51.2	38.5
Total Bacterial Count, cfu/100ml	15	10	40	35	26	12	42	28	90	25	54	34
Total Coliform Count, cfu/100ml	NG	NG	NG	NG	NG	NG	NG	1	NG	NG	1	NG
Total *Salmonella shigella* bacteria,	NG	NG	20	15	1	NG	5	NG	69	NG	24	14
Total Fecal Coliform count, cfu/100ml	NG	NG	12	2	1	NG	4	NG	59	NG	9	NG
Total *Citrobacter* count, cfu/100ml	NG	NG	NG	10	NG	NG	4	2	50	NG	23	10

NS –No Stated, **ND**- None Detected, **UO**- Unobjectionable, **NG –** No growth.

Result of Physio-chemical and Biological Analysis of the Borehole and Sachet Water Samples (Set 3)

Parameters	Chilec		Linkmore		CE-mercy		Macafran		Mr. Ben		WHO/NAF-2015
	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	B/Hole	Sachet	
Temperature, ^0C	28.4	27.2	27.8	27.2	28.1	30.4	27.4	27.3	24.6	27.5	20-30.00
Color, PCU	0	0	0	0	0	0	0	0	0	0	15
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
N/A	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
Odor	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO
Turbidity, NTU	1.72	1.63	1.53	2.11	2.88	2.41	1.63	0.92	1.01	2.19	5
Total dissolve solid, mg/l	7.15	11.7	118.3	58.3	61.75	1	17.55	13	100.1	4.55	500
Conductivity, µs/cm	11	18	182	90	95	90	27	20	154	7	1000
Alkalinity, mg/l CaCO3	40	50	110	50	40	30	50	30	0	40	200
Total Hardness, mg/lCa/MgCO3	23.31	23.31	129.5	90.65	28.49	46.62	18.13	20.72	20.72	18.13	150
Calcium Hardness, mg/l CaCO3	12.95	18.13	111.37	46.62	12.95	15.54	5.18	12.95	7.77	10.36	150
Magnesium Hardness, mg/l	10.36	5.18	18.13	44.03	15.54	31.08	12.95	17.05	12.95	7.77	150
Chloride, mg/lCl^-	24	26	33	29	27	37	29	33	92	43	250
pH	5.7	6	6.3	6.5	6	5.9	5.9	6.8	4.3	6.8	6.50-8.50
Nitrate, mg/l NO-3	1.85	6.31	2.46	0.46	2.31	0	0.62	0.62	2.31	2.15	50
Nitrite, mg/l NO2	2.79	9.53	3.72	0.69	3.49	0	0.93	0.93	3.49	3.26	0.2
Phosphate, mg/l PO^{-3}	0.37	0.37	0.42	0.56	0.56	0.68	3.03	0.32	6.68	0.37	5

Sulphate, mg/l SO^{-2}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	100
Total Solid, mg/l	10	3	130	59	114	3	25	22	59	20	500-1000.00
Magnesuim, mg/ l Mg	2.52	1.26	4.41	10.71	3.78	7.56	3.15	4.15	3.15	1.89	0.2
Calcium, mg/l Ca	4.21	5.89	36.16	15.14	4.21	5.05	1.68	4.21	2.52	3.36	200
Iron, mg/l Fe	0		0.19	0.08	0	0.15	0.02	0.21	0.9	1.54	0.3
Total Suspended Solids, mg/l	2.85		17.7	0.7	52.25	2	7.45	9	8	15.45	<10.00
Total Bacterial Count, cfu/100ml	20	27	60	10	36	15	40	3	5	26	30
Total Coliform Count, cfu/100ml	NG	NG	2	1	NG	NG	3	1	NG	NG	10
Total *Salmonella shigella* bacteria,	12	2	10	NG	NG	6	4	1	NG	NG	NG
Total Fecal Coliform count, cfu/100ml	4	NG	31	NG	2	NG	1	NG	NG	NG	NG
Total *Citrobacter* count, cfu/100ml	7	2	5	NG	3	2	3	NG	NG	NG	NG

B/Hole – Borehole, NS –No Stated, **ND-** None Detected, **UO-** Unobjectionable, **NG –** No growth.