Chapter

Bacteriological Quality of Borehole and Sachet Water from a Community in Southeastern Nigeria

Ogueri Nwaiwu, Chiugo Claret Aduba and Oluyemisi Eniola Oni

Abstract

Water from boreholes and packaged commercial sachet water from different areas in a community in southern Nigeria was analyzed with membrane filtration for a snapshot of heterotrophic count and coliforms. Two boreholes out of the 20 analyzed had counts of over 500 Cfu/mL and 7 boreholes indicated the presence of coliforms. Sixteen samples out of 20 sachet water brands analyzed showed a regulatory product registration code, whereas 4 samples had no number or code indicating that they were not registered. The heterotrophic count of all sachet water was well within the limit for all samples analyzed, and coliform was detected in only two samples. The overall quality of borehole water in the community studied was rated D (65%), whereas the sachet water was rated C (90%) according to the World Health Organization (WHO) surveillance guidelines. Improvements in water quality structure in the community studied are required to help achieve WHO sustainable development goals on water sanitation. The etiology, virulence properties, epidemiology, and pathogenicity of bacteria associated with borehole and sachet water are also discussed.

Keywords: bacteria, borehole, sachet water, coliforms, heterotrophic count

1. Introduction

Up to 2.1 billion people worldwide lack access to safe, readily available water at home according to a WHO/UNICEF report [1]. The report emphasized that majority of the people without good quality water are from developing countries and the lives of millions of children are at risk every day, with many dying from preventable diseases caused by poor water supply. The importance of good quality water is the reason why clean water and sanitation have been included as goal number 6 out of the 17 proposed sustainable development goals (SDGs) of the United Nations [2]. The proposal is that the SDGs will be the blueprint to achieving a better and more sustainable future for humanity by 2030.

In Nigeria, the public water supply is in a state of comatose in most towns and villages and dry taps without any hope of water running through the taps soon affect millions of homes. This has forced individuals and institutions to resort

to self-help by using water from boreholes as the only source of water supply for drinking and general use. Use of borehole is a simple way of obtaining potable water from the aquifer below the ground, after which the water can be pumped into storage tanks before distribution.

Many people that went into borehole drilling business, which reduced the price of new boreholes, aided the proliferation of boreholes in Nigeria, and many citizens were ready to pay more money in rent for houses, which had boreholes. Furthermore, the dependence on groundwater, which is believed to be purified, is on the increase due to the increasing contamination of the surface water [3]. It is known that properly designed and constructed borehole both ensures the success of the borehole as an adequate supply of water and minimizes the risk of local pollution affecting the source [4]. If a borehole facility is not properly managed, contamination may occur in the process through the accumulation of physical, chemical, and biological agents in the pipelines and storage tanks of a distribution system or water packaging company. One direct use of boreholes is in the production and packaging of drinking water in sachets made from low-density polyethylene sheets. These products are popularly known as "pure water" in Nigeria. From the early 1990s, the production of sachet water increased exponentially and provided jobs for producers and sellers of the product. There is hardly any community in Nigeria without a sachet water facility. It is possibly the most widely consumed commercial liquid in Nigeria, and no sophistication is required for production. The quest for a cheap, readily available, and inexpensive source of potable water contributed to the emergence of sachet water [5], and it is far better and safer than the hand-filled, hand-tied packaged water in polyethylene bag [6] sold in Nigeria in the past. In developing countries, production and consumption of sachet water are rapidly on the rise [7], and many unregulated producers exist.

Packaged drinking water like the sachet water could be water from any potable source such as tap, well, and rain, which may be subjected to further treatments like decantation, filtration, demineralization, remineralization, and other methods to meet established drinking standards [8, 9]. Packaged water is susceptible to microbial and chemical contamination regardless of their source [10]. Researchers have previously performed microbial analysis of sachet water in Nigeria using different laboratory techniques and found different bacteria and fungi. Occurrence of bacteria could lead to different disease conditions such as gastroenteritis, typhoid fever, cholera, bacillary dysentery, and hepatitis [11]. It has been reported [12] that waterborne diseases account for 80% of illnesses and diseases in developing countries, which leads to the death of several children every 8 seconds. In Nigeria, like most developing countries, various factors predispose packaged sachet water to contamination, and these include poor sanitation and source of raw material for food or water production [13]. Long storage of sachet under unfavorable environmental conditions and lack of good manufacturing practices (GMP) in general also contribute to contamination.

It has been found that the microbiome dynamically changes during different stages of water treatment distribution and the main important group in the past and present are fecal-associated bacterial pathogens like *Escherichia coli* [14]. However, opportunistic bacteria like *Legionella* and process-related bacteria, which form biofilms, are also a cause for concern [15, 16]. A review [17] elucidated that drinking water comprises a complex microbiota that is influenced by disinfection and that members of the phylum *Proteobacteria* represent the most frequent bacteria in drinking water. It was also pointed out that their ubiquity has serious implications for human health and that the first step to address the persistent nature of bacteria in water would be to identify and characterize ubiquitous bacteria. The manifestation of bacterial contamination in drinking water can become known when

outbreaks occur, and surveillance data provides insights on the microbial etiology of diseases and process failures that facilitated the outbreak [18]. Sometimes it can also be detected from laboratory results especially when water treatment facility is contaminated by bacterial biofilms [19, 20].

In Nigeria, regulatory oversight is inadequate due to limited resources. Surveillance of bacteria in drinking water from boreholes and sachet water is necessary for the benefit of public health; hence, periodic surveys can help establish trends and identify where water quality of boreholes and sachet water is deficient. This chapter reports a survey, explores reports of bacteria associated with water from borehole and sachet water in Nigeria, and compares data found with WHO water standards. The organisms associated with boreholes and sachet water are discussed.

2. Methods

Water samples from boreholes were collected on different days using Whirl-Pak sampling bags (Nasco, Wisconsin, USA) and analyzed within 2 hours after collection. Twenty private boreholes and 20 different brands of commercial sachet water sold in four areas of a community were analyzed on different days. Sachet water was purchased (five each) from the different areas and were inspected for the inscription of an approved product registration code from the National Agency for Food and Drug Administration and Control (NAFDAC), the Nigerian national regulatory body. It was ensured that the same brand was not purchased twice from one area. The human population of the community (all 4 areas) was estimated to be over 5000 but less than 100,000.

Heterotrophic plate and total coliform count of bacteria were carried out using standard membrane filtration performed previously [21]. A slight modification of the method was introduced. Instead of using factory-made ready to use nutrient media sets, plate count agar (Oxoid, United Kingdom, CM0325) and violet red bile lactose agar (Oxoid, CM0107) for coliforms were prepared and used according to manufacturer's instructions. Briefly, the filtration process involved placing of 100 ml of water sample in a sterile multibranched stainless steel manifold and filter holder system. A 0.45 μm membrane filter was fitted into the filter system after which water was drawn through to retain bacteria on the membrane. The membrane filter was placed on the media prepared and then incubated at 32°C over 48 h for membrane filters placed on plate count agar, whereas incubation at 30°C for 48 h was used for filters grown on violet red bile lactose agar. The heterotrophic count was noted, and estimated coliform results obtained for boreholes and sachet water were compared to WHO quality guidelines for drinking water [22].

3. Results

3.1 Heterotrophic and total coliform count of borehole samples

This survey was carried out to have an overview of the bacterial load in water quality of some boreholes in the community surveyed. The borehole owners were apprehensive and thought they were being investigated for possible closure. To allow sample collection, it was agreed that the name of borehole owners and their location should remain anonymous when the findings were published. Results showed that borehole samples from area "C2" had the highest heterotrophic aerobic count. Two boreholes had counts of over 500 Cfu/mL, which is above the

recommended heterotrophic limit [21]. All the other samples were below 500 Cfu/mL. Seven boreholes indicated the presence of coliforms because purple-pink colonies, which were 1–2 mm in diameter surrounded by a purple zone, were formed on the plates after incubation. Samples C2a, C2b, C2c, C2d, and C2e had coliform count of 17, 15, 9, 6, and 5 Cfu/mL, respectively, whereas samples C3b and C4b had coliform count of 4 and 2 Cfu/mL. The rest of the samples had no coliform on the plate used after incubation. A definitive trend was that samples with the highest heterotrophic count had the most coliform count (**Figure 1**).

3.2 Heterotrophic and total coliform count of sachet water samples

Periodic analysis of sachet water is important to public health because millions of people in Nigeria consume it. An ideal situation would be to analyze every borehole water from which sachet water is produced to establish water treatment effectiveness. Enquiries made to sachet water producers for access to their source of water for production were not successful. To refuse access some companies gave information and advice that they do not have a borehole and their water for production is sourced from the supply by water tankers. Hence, commercial samples of sachet water were purchased from different locations with unknown source of initial water for production of sachet water on sale. Sixteen samples out of the 20 analyzed showed a NAFDAC product registration code, whereas 4 samples had no number or code indicating that they were not registered. The heterotrophic count was well within the limit for all samples analyzed, and coliform was detected in only two samples. Sample SC1c and SC3c had a coliform count of 2 Cfu/mL each (**Figure 2**).

3.3 Comparisons with WHO guidelines

The WHO standards and guidelines are usually used to monitor water quality. The WHO categorizes drinking water systems based on population size and quality rating to prioritize actions. A quality score from A to D is awarded (quality decreases A to D) based on the proportion (%) of samples negative for *E. coli*. However, the samples under study were assessed for total coliforms and not *E.coli*; the scoring was carried out with the presumption that samples with high coliform count may contain *E. coli*. Total coliforms serve as a parameter to provide basic

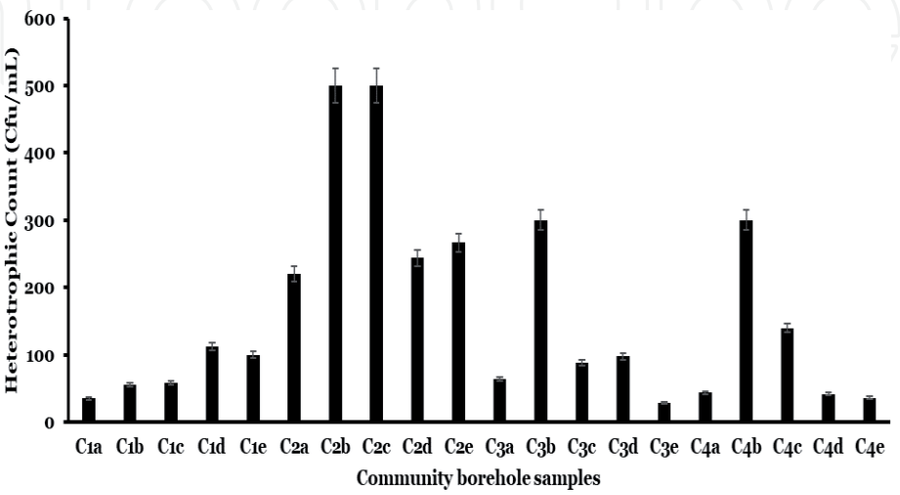

Figure 1.
Heterotrophic plate count of borehole water sourced from different areas of the community studied (C1–C4). The letters a to e represent different samples.

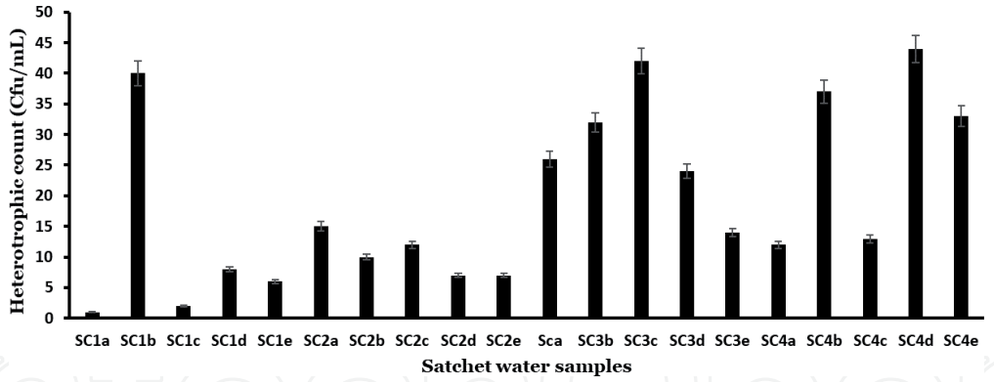

Figure 2.
Heterotrophic plate count of sachet water (S) sourced from different areas of the community studied (C1–C4). Letters a to e represent different samples.

information on water quality [23]. On this basis, the overall quality of borehole water in the community studied (all areas combined) was rated D (proportion of samples negative for coliform =13; 65%), whereas the sachet water was rated C (18 = 90%).

4. Discussion

4.1 Bacteria associated with boreholes in Nigeria

Pathogenic bacteria often occur in borehole water systems especially in developing nations [24–26]. Coliforms found in this study and other Gram-negative bacteria have been isolated from boreholes in different parts of Nigeria by many investigators [27–34]. The organisms mentioned in these studies include *Enterobacter aerogenes*, *Escherichia coli*, *Klebsiella aerogenes*, *Klebsiella* sp., *Klebsiella pneumoniae*, *Klebsiella variicola*, *Proteus* sp., and *Proteus vulgaris*. Other bacteria isolated are *Providencia sneebia*, *Pseudomonas aeruginosa*, *Salmonella paratyphi*, *Salmonella* sp., *Salmonella typhi*, *Staphylococcus aureus*, and *Vibrio cholera*.

The prevalence of the aforementioned species and genera may be due to the classical microbiological methods used for isolation. In most cases, MacConkey media was used for *E.coli* and coliform identification with no molecular studies that included 16S or whole-genome sequencing essential for establishing the actual prevalent bacteria species and strains in boreholes. An opportunity exists for regular molecular characterization of bacteria found in boreholes to help differentiate between harmless coliforms, fecal coliforms, and the deadly *E. coli* strain O157: H7. Borehole operators are required to deliver safe and reliable drinking water to their customers. If a community consistently consumes contaminated water, they may become unwell. Hence, regular monitoring and assessment of borehole water sources help maintain quality and provide data on groundwater management [35–38].

4.1.1 Bacteria contamination of groundwater

In Africa, many people rely on water from a borehole, but the purity of the drinking water from this source remains questionable [39, 40]. The high heterotrophic count found in Area "2" of the community studied suggests that the groundwater of that area may be contaminated. The corresponding increased coliform count observed is consistent with the findings of Amanidaz et al. [41], which showed that

when the concentration of coliforms and fecal *Streptococci* bacteria increased in a water network system, there was also an increased concentration of heterotrophic bacteria. These contrasts with the work of others [42] where it was shown that high heterotrophic count inhibits coliform proliferation. Despite increased heterotrophic count and coliforms in the study of Amanidaz et al. [41], it was concluded that no correlation exists, and increased numbers could be due to variability in nutrient composition [43]. Another factor could be biofilm formation because it has been shown that attached bacteria in biofilms of a water system are more metabolically active than the ones that are free-living [44]. Groundwater is susceptible to contamination by both organic and inorganic contaminants [45–48]. Contamination could happen through natural processes, such as geological weathering and dissolution of numerous minerals beneath the earth's surface, which results in low natural concentrations of contaminants in groundwater [49]. Anthropogenic sources, such as seepages from agricultural wastewaters, domestic sewages, mining activities, and industrial effluents, can also affect the quality of groundwater in many parts of the world [50–52]. Other reports showed that borehole contamination may occur through domestic wastewater and livestock manure [53] industrialization and urbanization [54] and leakages from septic tanks [55] or pit latrines [56]. Seasonal environmental conditions may also contribute to increased bacteria count from borehole water because other investigators [57, 58] have demonstrated that higher bacterial count in borehole water occurs during the rainy season. This has been attributed to flooding which may allow floodwater to get into borehole systems that are not properly constructed.

4.2 Cases of sachet water contamination in Nigeria

Postproduction improper handling [59] and compromising safety and quality for profit during production [60] are factors that can affect sachet water contamination in Nigeria. Sachet water producers are expected to be food safety conscious in order not to jeopardize the health of the public. A large number of sachet water-producing companies in Nigeria are not registered and do not practice good manufacturing practices or follow international quality standards of water treatment [61] despite the efforts of NAFDAC to improve standards. Up to 25% of samples analyzed in this study had no regulation or expiration date code as recommended previously [62]. However, the fact that 75% of sachet water analyzed had date codes is a remarkable improvement from what was the norm (0%) when sachet water production started in the country. Unlike a previous study with larger sample size [11], which reported isolation of bacterial species in 54 out of 720 (7.5%) from 6 different brands of sachet water in northern Nigeria, all the samples in this study (100%) showed heterotrophic growth that were within permissible limits (<500 Cfu/mL).

Sachet water analysis from other parts of Nigeria has shown different levels of contamination. In this study, 10% (2 out of 20) of samples contained coliforms. In other studies carried out on samples sourced from Aba in the southeast, an analysis of 20 sachet water samples showed that 32% of the samples reportedly tested positive for *Staphylococcus* spp., 23% for *Pseudomonas*, 20% for *Klebsiella* spp., 15% for *Proteus*, and 10% for *Enterobacter* [59]. Another study in the same region reported a contamination in 8 out of the 10 sachet water samples analyzed, isolated microorganisms included *E. coli*, *Klebsiella* spp., *Pseudomonas* spp., *Bacillus* spp., *Proteus* spp., and *Staphylococcus* spp. [5]. Also 66% and 73% prevalence of pathogens have been reported [63] in this region after two batches of 30 sachet water samples were analyzed. In Oyo, which is situated in the southwest of Nigeria, *E. coli* (13.3%), *Pseudomonas aeruginosa* (39.9%), and *Enterobacter aerogenes* (53.3%) were isolated

from commercially sold sachet water [64]. Another report in this region [26] highlighted that all brands of sachet water (100%) analyzed had the presence of coliforms.

4.3 Compliance with world standards

A recent SDGs progress report [3] shows that between 2000 and 2017, the proportion of the global population using safely managed drinking water increased from 61 to 71%. The report highlighted that despite the increase, water stress affects people on every continent, requiring immediate and accelerated collective action to provide billions of people with safely managed drinking water. The quality score for the boreholes and sachet water from the community studied showed that the water needs improvement to achieve the desired "A" rating. In this study, the borehole water quality in Area "2" is a source of concern, and the owners in that area were advised to boil and filter the water before drinking. It is common knowledge in Nigeria that some boreholes are not deep enough to produce clean water from the aquifer; hence, such boreholes are used for other domestic purposes but not for cooking food or drinking. Owners of such boreholes normally boil and filter the water for drinking.

Water quality specifications may depend on the particular use, but the presence of coliforms in drinking water indicates that disease-causing organisms could be in the water system and may pose an immediate health risk to the water consumers. When coliforms and other bacteria are found, it is always recommended [65] that an investigation should be carried out to establish the sources of contamination. This confirmation will enable risk assessment and identification of solutions that will eliminate or reduce the risk of waterborne disease within a large population [66].

4.4 Etiology, virulence, epidemiology, and pathogenicity of bacteria associated with borehole and sachet water

From the studies reviewed, the organisms found in borehole water are well-known food- and waterborne bacteria that are constantly monitored by regulatory authorities in many parts of the world. Outbreaks can occur in a community and cause fatalities and economic losses. Hence, a constant review of the growth conditions that enable the bacteria to proliferate, the features that enable survival in different environments, infection mode, and prevalence pattern of these bacteria is important to reduce outbreaks.

4.4.1 Staphylococcus

The bacterium *Staphylococcus aureus* from the genus *Staphylococcus* is known for methicillin resistance of some strains. The bacterium is a major environmental contaminant of food and water, and the human skin and nose are known to be major sources of the organism. Nasal colonization [67, 68] and atopic dermatitis of the skin [69, 70] are considered risk factors. Environmental contamination may be the source of contamination in borehole water analyzed in this study, whereas humans or personnel involved in sachet water production are likely to be contributors to contamination. In Nigeria, sachet water producers are known to lack resources; hence, it is possible that respiratory protective equipment like nose masks are not worn during production in some facilities. Since it is possible to distinguish community-associated MRSA from healthcare-associated MRSA based on genetic, epidemiologic, or microbiological profiles [71], it would be beneficial to screen the strains found in this study to determine if they are methicillin resistant and community-related.

The pathogenicity, epidemiology, and virulence factors of *Staphylococcus* have been comprehensively reviewed [72]. It was highlighted that colonization is aided by biofilm formation that is housed in extracellular polymeric substance (EPS) found in many bacteria and that virulence factors are expressed with accessory gene regulator (agr) system in response to cell density [73]. To avoid formation of biofilms and EPS in the sachet water-producing environment, adequate personnel hygiene and good manufacturing practices that meet food safety standards must be implemented.

4.4.2 Pseudomonas

The genus *Pseudomonas* especially *P. aeruginosa* is known globally as endemic [74] and an opportunistic pathogen that causes several infections [75]. They are often isolated in clinics [76], and other sources may include residential, recreational, or surface water [77]. The colonies are usually heavily mucoid on solid media. It has been reported that mechanisms of antimicrobial resistance in *Pseudomonas* strains and most bacteria include multidrug efflux pumps and down-regulation of outer membrane porins, whereas virulence may include secretion of toxins and the ability to form biofilms [78, 79]. A natural property of *Pseudomonas* is the possession of multiple mechanisms for different forms of antibiotic resistance [80], and this may have facilitated its occurrence in boreholes and sachet water.

4.4.3 Klebsiella

Klebsiella causes many infections, which includes urinary tract infections, pneumonia, bacteremia, and liver abscesses [81]. The genus is associated with water, and this may be why it has been isolated in both borehole and sachet water. The organism is found in drinking water [82], rivers [83], and sewage water [84], which may encourage environmental spread. It has been reported that the organism has a variety of virulence and immune evasive factors, which contribute to uptake of genes associated with antimicrobial resistance and pathogenicity [85]. A report [86] suggested that the species *K. pneumoniae* acquired antimicrobial resistance genes independently and their population is highly diverse. An analysis of strains from human and animal isolates spanning four continents has shown convergence of virulence and resistance genes, which may lead to untreatable invasive *K. pneumoniae* infections [87].

4.4.4 Escherichia

The most studied species of the *Escherichia* genus is *E. coli*, a coliform bacteria used to verify hygiene status in food and water. Usually, the presence of various strains of pathogenic or nonpathogenic *E. coli* in food or water samples indicates fecal contamination [88]. It has been reported that [89] a comparative analysis show that avian and human *E. coli* isolates contain similar sets of genes encoding virulence factors and that they belong to the same phylogenetic groups, which may indicate the zoonotic origin of extraintestinal pathogenic *E. coli*.

A study of the prevalence of *E. coli* strain O157:H7 in England and Scotland showed that it has a seasonal dependency, with greater fecal shedding of the organism in the warmer months together with increased reporting of *E. coli* O157:H7 infection among hospitalized patients [90]. This finding is very worrying because it suggests that there could be high prevalence when applied to Nigeria because the country has a warm climate all year round. However, good manufacturing practices irrespective of the climate appear to be the key factor in producing packaged

water free of coliforms. It has been shown that levels of coliform bacteria and *E. coli* detected in sachet water samples in Ghana, a country with similar climate to Nigeria, were statistically and significantly lower than levels detected from several water sources including public taps [91].

4.4.5 Enterobacter

The genus *Enterobacter* consists of coliforms that are known to be of non-fecal origin. It is believed [92] that many *Enterobacter* species, which could act as pathogens, are widely encountered in nature but are most frequently isolated in human clinical specimens possibly because phenotypic identification of all species belonging to this taxon is usually difficult and not always reliable. Therefore, the identification of this genus in borehole and sachet water may need a revisit since molecular methods were not used. The organism is known as a ubiquitous and persistent Gram-negative bacterium in drinking water [17], but there are few studies of its occurrence or prevalence in borehole and sachet water or other water sources in Nigeria.

To understand the carbapenemase-producing *Enterobacter* spp. and the development of molecular diagnostics, Chavda et al. [93] used genomic analysis of 447 sequenced strains to establish diverse mechanisms underlying the molecular evolutionary trajectory of drug-resistant *Enterobacter* spp. Their findings showed the acquisition of an antibiotic resistance plasmid, followed by clonal spread and horizontal transfer of *blaKPC*-harboring plasmids between different phylogenomic groups. The report also showed repeated transposition of the *blaKPC* gene among different plasmid backbones.

4.4.6 Proteus

Proteus species are Gram-negative opportunistic rod-shaped bacteria known for its swarming motility and contamination of agar plates. Furthermore, on agar plates, the bacteria undergoes a morphological conversion to a filamentous swarmer cell expressing hundreds of flagella, and during infection, histological damage is caused by cytotoxins including hemolysin and a variety of proteases [94]. The organism is reported to have negative and positive advantages. According to Drzewiecka [95], *Proteus* species may be indicators of fecal pollution, which may cause food poisoning when the contaminated water or seafood is consumed, and it could be used for bioremediation activity due to its tolerance and ability to utilize polluting compounds as sources of energy.

Virulence factors may include fimbriae, flagella, outer membrane proteins, lipopolysaccharide, capsule antigen, urease, immunoglobulin A, proteases, hemolysins, and amino acid deaminases [96]. The ability to swarm and survive is facilitated by the upregulation of FlhD(2)C(2) transcription activator, which activates the flagellar regulon [97]. The prevalence of *Proteus* spp. in borehole or sachet water may be aided by its ability to swarm and colonize the production environment.

4.4.7 Vibrio

In Nigeria, the most reported species among the *Vibrio* species that cause water-related infection is *Vibrio cholerae*. The organism causes cholera, which is an infection that is characterized by watery stooling. The disease has killed hundreds of people in Nigeria in the last decade. According to Faruque et al. [98], a lysogenic bacteriophage designated CTXΦ encodes the Cholera toxin (CT), which is strongly influenced by environmental conditions [99]. The organism is responsible for the

profuse diarrhea, and molecular epidemiological surveillance has revealed clonal diversity among toxigenic *V. cholerae* strains with continuous emergence of new epidemic clones. It has not been established if the strains found in boreholes and sachet water are the *V. cholerae* O1 or O139 strains that cause cholera [100]. There is a possibility that they could be non-O1 or non-O139 strains that are common in the environment.

In 2017, the WHO launched a global strategy on cholera control with a target to reduce cholera deaths worldwide by 90% [101]. The strategy is to use safe oral cholera vaccines in conjunction with improvements in water and sanitation to control cholera outbreaks and for prevention in areas known to be high risk for cholera. Nigeria can be classified as a high-risk area, and the occurrence of *Vibrio* species in borehole or sachet water suggests that they could transmit cholera. Outbreaks occur regularly in Nigeria, and it is always difficult to bring it under control. An outbreak in 2018 was characterized by four epidemiological waves and led to 836 deaths out of 43,996 cases [102], whereas that of 2010 killed a total of 1716 out of 41, 787 cases [103]. In both cases, the case fatality rate was over 1% recommended by WHO.

4.4.8 Bacillus

Bacillus cereus is a food safety concern among several species of *Bacillus*. It is naturally widely distributed in nature, and it is known as a Gram-positive rod bacterium that is responsible for food poisoning [104]. It can proliferate because of unhygienic practices [105] and can attach to drinking water infrastructure [106]. This suggests that the ubiquity of the organism, poor hygiene, and attachment to equipment may be why *Bacillus* has been repeatedly isolated from boreholes and sachet water by previous investigators.

Bacillus growth is sometimes considered an insignificant contaminant. Some strains like *B. subtilis* is used for probiotics [107], whereas a strain like *B. cereus* which secrets toxins like hemolysins, phospholipases, an emesis-inducing toxin, and proteases [108] is not used due to obvious reasons. Toxin production in *B. cereus* requires the transcription factor *PlcR*, which controls expression of virulence factors [109]. Virulence-associated gene profiles have been used to evaluate the genetic backgrounds and relationships of food poisoning cases among other isolates from the environment, and it was concluded that both molecular and epidemiological surveillance studies could be used effectively to estimate virulence [110].

4.4.9 Salmonella

The species *Salmonella typhi* and *Salmonella paratyphi* cause typhoid fever and remain a major public health concern in Asia and Africa [111] due to antimicrobial resistance. For developed countries, it is believed that some non-typhoidal strains are zoonotic in origin and acquire their resistance in the food animal host before onward transmission to humans through the food chain [112]. It has been reported that the overall global burden of *Salmonella* infections is high and this may be the reason why in 2017, the WHO listed fluoroquinolone-resistant *Salmonella* spp. as priority pathogens for which new antibiotics were urgently needed [113].

The bacterium can survive in aquatic environments by a number of mechanisms, including entry into the viable but non-culturable state or residence within free-living protozoa [114]. Survival in water may have contributed to the isolation from borehole and sachet water in studies by others. It is not certain if the isolates encountered in this study cause typhoid fever or are the non-typhoid causing strains. Hence, additional studies are required to establish the prevalent type of *Salmonella* in water-producing facilities in Nigeria. A recent report found

that typhoid fever still poses a serious health challenge in Nigeria and is a major health security issue [115]. It was recommended that a combined approach that includes the use of typhoid vaccines, improvements in sanitation, and safe water supply is essential.

5. Conclusions

The overall bacteria quality of the borehole and sachet water in the community studied needs improvement. An improvement can be achieved by focusing on areas with coliform contamination. Boreholes should be sited where pollutants will not easily contaminate them. Regular water testing should be carried out to ensure the attainment of WHO guidelines always. Where deviations are found, corrective actions should be undertaken. The literature on bacteria from boreholes and sachet water in Nigeria shows that not much molecular characterization has been carried out; hence an opportunity exists for more investigations. Regulatory oversight for sachet water production and the use of boreholes by large community populations requires improvement. It is recommended that universities should carry out periodic surveillance of boreholes and sachet water sold near them to support the SDG targets of the WHO.

Conflict of interest

The authors declare no conflict of interest.

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