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Review Article

A review of the microbial quality of potable water sources in Nigeria

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Abstract

Microbes are ubiquitous and are known to contaminate materials including food and water. This study reviews the microbial quality of potable water sources in Nigeria. The study found that the microbial quality often exceed World Health Organization/Food and Agricultural Organization allowable limit of 1.0 x 10^2cfu/ml for potable water and Standard Organization of Nigeria maximum permissible level of 10cfu/ml (total coliform) and 0 cfu/100ml (Thermo tolerant Coliform or *E. coli,* Faecal streptococcus and *Clostridium perfringens* spore). However, surface water has high microbial load than the ground water. In packaged water, bottled water has lower microbial diversity and density than the sachet water. The high microbial isolates and load may have contaminated the water from the environment. These microbes found in the drinking water sources are known to cause several diseases conditions. The paper suggests that drinking water sources should be properly treated prior to consumption using appropriate method; so as to reduce the occurrence of waterborne disease.

1. Introduction

Water is a vital resources needed for the sustenance of life [1-3] including aquaculture [4]. Living organisms requires water for existence, growth and proliferation [5, 6]. Furthermore, water is also essential for socioeconomic development and maintenance of the ecosystem [7, 8]. As such, water is an important component of all living things. Interestingly, nearly 70% of the earth is occupied by water [9, 10] including fresh, brackish and marine. Basically, water exist in the form of solid (ice), gaseous (vapour and liquid) [11]. According to Oparaocha *et al* [12] and Raut *et al* [13], only about 2.7 – 3.0% out of the world water resources is fresh water. Beside, the usefulness of water to living organisms, it has found applications in several areas including industries, agriculture, transportation, energy and domestic uses. Water uses are obtained by surface, ground and rain water.

On global perspctive, groundwater provide potable water to about 1.5 billion people daily and has proved to be the most reliable resources for meeting rural water demand in sub-Saharan Africa [14]. Surface water provide habitat to several aquatic organisms including planktons, fisheries, aquatic mammals and birds [3]. Surface water also harbors several aquatic plants including water hyacinth, water lily, water lettuce, salvinia and water velvet etc [15]. Rainwater is mostly used for domestic uses where surface water is unavailable espcially in the rural areas [16]. Rainwater harvesting involves collecting and storing of the water from roof and ground catchments for domestic, agricultural, industrial and environmental applications [17]. The ground water dominates the potable water supply of Nigeria. Though, some individual still prefer the surface water (Rivers, stream) espcially in the rural coastal regions. The preference of surface water to ground water could be attributed to level exposure, educational level. Galadima *et al* [18] attributed water crises in Nigeria to inefficiency in government policies, corruption, education, low budgetary funding, drought and other anthropogenic activities. Due to these obvious reasons, most Nigerians provide their potable water from boreholes i.e ground water, which quality is doubtful [9]. While several others in some state depend on well water during the rainy season and water tanker or water hawkers in dry season [19]. Though, in some states, the government still provide potable water to her inhabitants but this scheme is usually epileptic [3]. Generally, Muta'aHellandendu [7] attributed water supply challenge to include inadequate policy, legal, regulatory and institutional framework, high population growth, low investment level in operation and maintenance of water scheme, inadequate public awareness etc. Nkamare *et al* [20] stated that accessibility and availability of fresh clean water is essential to sustainable development, which is crucial for health living, food production and poverty reduction. Irrespctive of the source of potable water, monitoring and surveillance is inadequate in Nigeria.

For humans and livestocks, quality water is essential to maintain normal functioning of the various parts of the body. Poor quality water adversely affects humans causing disease conditions [20]. According to Garba *et al* [21, 22], potable water quality is evaluated based on the generally appearance (turbidity), taste, colour and odour, but this do not indicate that the water is free from contaminants. Hence, water quality is usually monitored with regard to the phyisco-chemical, heavy metal and microbial characteristics. The phyisco-chemical water quality parameters such as colour, pH, turbidity, total suspnded solids, total hardness, total alkalinity salinity, electrical conductivity etc play a significant role in determining the suitability of such water for consumption purposes. Additionally, parameters such as nitrate, nitrite, sulphate, calcium, sodium, magnesium, potassium, carbonates determine the nutrient level of such water and its suitability for aquatic life. While dissolved oxygen; chemical and biological oxygen demand helps in evaluating the pollution index of the water. Heavy metals have been severally reported in potable water sources in Nigeria including surface, ground water and rain water. Heavy metals are typically classified into essential (iron, manganese, zinc, copper) and non essential (cadmium, chromium, lead and mercury), with

regard to their usefulness in biological diversity. The phyisco-chemical and heavy metal parameters have permissible guideline recommended by World Health Organization (WHO) and Standard Organization of Nigeria (SON) (Nigerian Agency that regulate the quality of potable water resources). When the heavy metals exceed that maximum permissible concentration for potable water, such water is said to be contaminated by such heavy metal. Naturally, most heavy metals are found in variable concentration in the environment [3].

Typically, surface water is contaminated mainly by the activities of man and natural effects. The natural occurrence depends mainly by the geology of the area. Sometimes, the activities of humans on the environment could also lead to pollution due to natural effects. Water pollution occur due to the municipal liquid wastes which gets in the surface water through soil and erosion and ground water through infiltration [3]. Sometimes, after rainfall the water could infiltrate into the soil, thereby causing ground water pollution espcially in area with high table water level. Artisan mining activities espcially in the Northern Nigeria could also lead to contamination of the environment [23] including potable water sources. Activities of oil and gas including oil and gas exploration, drilling and production, shipping, refining, storage, distribution and marketing and agricultural activities such as processing of oil palm and cassava, use of toxic chemicals such as pesticides could also contaminate potable water sources [3]. Spcifically, Ukpong and Okon [9] stated that ground water pollution arises when pollutant percolates through the soil down to the phreatic surface. The is so, because ground water flows, and as such factors like permeability of the cover deposits, depth of impermeable layers and hydraulic head gradient in the aquifer become important [9]. Angaye *et al* [24] reported that total heterotrophic bacteria, total fungi, total coliform and faecal coliform from leachates in the Niger Delta in the range of 8.23 – 10.79 Log cfu/ml, 6.25 – 8.64 Log cfu/ml, 2.42 – 2.66 Log MPN/100 ml and 1.97 – 2.34 Log MPN/100 ml respctively and heavy metals are in the order Fe>Pb>Zn>Mn>Cu>Cr>Hg>Cd being higher that their permissible limited as recommended by WHO and SON apart from Zinc concentration. Pollution of groundwater could also arise from poor hygienic level, closeness of borehole to the septic tank and waste pit [25, 26].

The consumption of contaminated water could lead to several disease conditions. For instance, a review on the concentration of arsenic in potable water sources in Nigeria was recently carried out by Izah and Srivastav [3] and they reported that the concentration of arsenic often exceed 0.01mg/l concentration recommended by SON and WHO espcially in Northern Nigeria and to a lesser extent southwestern part of the country. High arsenic concentration intake and or exposure is attributed to several disease condition including some type of cancer, cardiovascular, hematological, nervous/ neurological, respiratory, gastrointestinal, organ inflammation, birth disorders, dermatitis etc [3]. Other heavy metals could lead to reproductive and nervous system and brain and kidney damage [27, 28], increased blood pressure, anemia, and weakness in fingers, wrists, or ankles [23] (lead), diarrhoea [29], interfere with absorption of dietary iron which can result in iron deficiency anemia (manganese) [30]. Muhammad *et al* [23] summarized other heavy that cause diseases to include chromium and cadmium (impairment of the kidney and liver), copper (which causes anemia, allergies, hair loss, arthritis, cancer, depression, diabetes, fatigue, fears, fractures of the bones, headaches, heart attacks, hyperactivity, hypertension, infections, inflammation, kidney and liver dysfunction, tooth decay), iron (which causes diarrhea and lung disorder) etc. Ukpong and Okon [9] stated the effects of potable water polluted by chemicals to include cancer, arthritis, skin irritation and eruption, heart diseases, central nervous system problems, skin rashes, kidney problems and bronchitis. Generally, these disease conditions could occur when the concentration exposed to, exceed the maximum permissible limit over a long period of time. Apart from ingestion, other potential route through which human contracts heavy metals related illness is through parenteral, dermal and inhalation.

Apart from heavy metals another potential contaminants of potable water is microorganisms and parasites (helminthes and protozoan). Surface water aid in the transmission of parasitic disease conditions such as giardiasis, schistosomiasis, cryptosporidiosis, onchocerciasis and dracuncuculiasis. Microbes are ubiquitous and they render potable water unfit for consumption, where they cause several diseases condition [5]. These microbes include bacteria, fungi and viruses. Viral diseases that can be transmitted through water include hepatitis A (which causes inflammation and necrosis of liver) and Norwalk-type virus (which causes acute gastroenteritis). Nearly 2.3 billion people globally have mortality and morbidity associated with water related diseases [19]. And about 2 million people die on annual basis due to diarrhoea related illness, which occurs mostly in children <5 years of age [31]. Again, Sunday *et al* [32] stated that water borne diseases such as cholera, typhoid fever, bacillary and amoebic dysentery kill at least 3.4 million people annually. The health problem associated with consumption of unhygienic water is large [12]. Hence this study focus on the microbial quality of potable water sources in Nigeria and their potential health implications. The paper concludes by suggesting methods of reducing microbial contamination of potable water.

2. Microbial density and diversity of potable water sources in Nigeria

Quality water supply is one of the requirements for human existence. The quality of water is examined to assess its hygienic level as well as its suitability for general use [33]. Due to environmental conditions and activities of human, clean, pure and safe water which exist in nature gets contaminated [34]. The microbial populations and isolates of potable water sources in Nigeria are presented in Table 2 and 3 respctively. The high microbial population from surface water could have stemmed from soil pollution which is leached into the surface water via runoff. The microbial load could increase in potable water, if the containers used in gathering, collection and storage are contaminated. This could manifest in the water quality. Ideally, microbes ought not to be found in potable water, hence it depict that such water is microbially contaminated [6]. Contaminated water have been linked to infectious and parasitic diseases [35].

The microbial populations are typically highest in surface water and rain water, followed by ground water and least in sachet and bottled water. Aji *et al* [37] surveyed the sachet water in Jere and Maiduguri, Borno state, Nigeria and reported that over 80% of the sachet water used for drinking purposes contains coliforms, hence making such water unfit for human consumption. Also, Akpoborie and Ehwarimo [38] reported absence of coliform in bottled and sachet water sold in Warri, Delta state, Nigeria. The microbial density i.e total heterotrophic bacteria count; total coliform, fecal coliform often exceeds the recommended limits. The World Health Organization/Food and Agricultural Organization stated 1.0 x 10^2cfu/ml as allowable limit for potable water [32, 34, 39]. In Nigeria, SON [40] stated maximum permissible level of total coliform as 10cfu/ml, Thermo tolerant Coliform or *E.coli,* Faecal streptococcus and *Clostridium perfringens* spore as 0 cfu/100ml. The storage duration could influence the microbial counts of potable water [41], materials used in covering water during storage [42], season [43-45]. Microbes such as *Staphylococcus aureus*, *Escherichia* coli, *Proteus, Pseudomonas, Enterobacter, Salmonella, Klebsiella, Bacillus* spcies etc were the dominant microbial diversity found in the different

potable water sources in Nigeria. To a lesser extent, *Alcaligenes faecalis, Aeromonas, Micrococcus, Citrobacter, Streptococcus, Vibrio, Shigella, Enterococcus, Flavobacterium, and Chromobacterium* spcies etc. Information of fungal diversity in potable water sources is few in literature. This could be associated to their non-use as indicator organisms in water quality. As such authors focus more on total heterotophic bacteria counts and total enteric counts such as coliforms, salmonella-shilgella counts and Vibro counts. Also, uncommon bacteria such as *Clostridium perfringens, Phaerotilus, Erwinia* and *Yersinia* spcies were only reported in Foma River, Ita-Nmo, Ilorin, Nigeria [10]. According to Adewoye and Adewoye [46], bacteriological quality of potable water is vital and as such monitoring and surveillance must be given utmost consideration due to the fact that disease outbreak have be associated poorly treated or contaminated water. However, Agbabiaka and Oyeyiola [10] reported the fungal diversity of Foma River, Ita-Nmo, Ilorin, Nigeria to include *Curvularia, Penicillium, Rhizopus, Fusarium, Mucor, Cladosporium, Saccharomyces, Mortierella* and *Asprgillus* Spcies.

The microbial diversity and density in the potable water sources is a reflection of the contamination level. For the packaged water, the high microbial load could be due to the method and hygienic conditions of the producer and their environment. In rain water, Egbe *et al* [47] stated that contamination occurs due lack of a protective covering thus, enhancing external source. Bello *et al* [48] noted that poor sanitary and protected water collection and storage containers/tanks, unhygienic techniques in dispnse water from household storage containers (including faecally contaminated hands and dippers, lack of protection against contamination introduced by vectors and insufficient cleaning of vessels to prevent biofilm formation and accumulation of sediments and pathogens could enhance microbial contamination of potable water. Hence, the presence of these bacteria's is an indication that the water sources are not potable for human consumption [11]. The occurrence of pathogens in water resources is a sign that such waters may result in the transmission of waterborne diseases [35, 47, 49].

The occurrence of coliform in the potable water sources could be due to the presence of human and animals excreta in such water [47, 50]. The excreta could provide appropriate nutrients require for growth and proliferation. Generally, *E. coli* and *Enterobacter aerogenes* in potable water indicates presence of recent faecal matters [8,51]. Isikwue and Chikezie [36] stated that feacal coliform in water is influenced by presence of wastewater and septic system effluent, animal waste, sediment load, temperature and nutrients levels. International standards for water quality aimed at preventing pathogenic microbes in potable water, which is due to the fact that pathogen that contaminates water could transmit infectious diseases [52].

Table 1: Microbial population found in different potable water sources in Nigeria

THB, cfu/ml	Total Coliform, MPN/100ml	Fecal *coliform*, MPN/100ml	*Salmonella-Shigella*, cfu/ml	*Vibrio*, cfu/ml	TF, cfu/ml	Sources of water	Location	Ref.
4.26 -4.78 $\log_{10}$	9-240	-	0	0	0-2.9 log10	Tap water	Elele, Rivers state	[41]
0- 4.53	0-28	-	0	0	0 – 4.53 log10	Sachet water		
0.32 – 1.38x10^2	<3 – 11	0-3	-	-	-	Borehole	Umuahia North; Abia State	[25]
-	6 - 145 x 103 MPN/ml	-	-	-	-	Borehole	Maiduguri metropolis, Borno state	[53]
2.5 – 8.1 x10^2	11 – 26	2 - 11	-	-	-	Borehole	Ikwuano-Umuahia, Abia state	[54]
1.637 – 9.3 x10^5	163 – 243	60 - 85	-	-	41- 85 x10^2	Borehole	Yenagoa metropolis, Bayelsa state	[55]
1.45×10^3- 1.5×10^6	14 – 198	5-56	-	-	-	Tap, stream and well	Opuraja, Okpe LGA, Delta state	[56]
1.1 – 4.5 x10^3	250 – 560	-	-	-	-	Borehole	Amike – Aba, Ebonyi state	[57]
5.2 – 15 x10^4	2 – 51 cfu/100ml	-	-	-	-	Borehole	Eastern, Obolo, LGA, Akwa Ibom state	[58]
-	27 – 1600	-	-	-	-	Well	Kaduna North LGA, Kaduana state	[59]
0.021 -1.6 x10^3	0 – 210	0 – 6cfu/ml	-	-	-	Different sources of water in storage tank	Ilorin Metropolis, Kwara state	[60]
4.43 – 4.85$\log_{10}$	4.23 – 4.68 $\log_{10}$ cfu/ml	-	-	-	-	Bottled water	Ado-Ekiti metropolis, Ekiti state	[2]
4.10– 6.00 $\log_{10}$	5.00 – 5.48 $\log_{10}$ cfu/ml	-	-	-	-	Sachet water		
0 - 2.7 x 104	7 – 398	-	-	-	-	Sachet packaged water	Minna metropolis, Niger state	[61]
3.5 x 10^3	3.0 x 10 10^3	-	0	0	-	Borehole	Villages in Ohafia LGA Abia State	[62]
1.3 x 10^5	6.3 x 10 10^4	-	0	0	-	Well		
9.6 x 10^4	3.9 x 10 10^4	-	0	0	-	Spring		
2.5 x 10^6	1.9 x 10 10^6	-	0	9.2 x 10^5	-	Stream		
2.86 - 3.45 log	1.62 log cfu/ml	-	-	-	-	Sachet packaged water	Western Nigeria	[63]
1.6 – 5.5 ×10^3	0 – 34	-	-	-	-	Private Borehole	Uruan LGA Akwa Ibom State	[9]
0 – 9.0n ×10^1	0	-	-	-	-	Public borehole		
-	<21 – <31	9 - 12	-	-	-	Reservoirs	Ero and Ele, Ekiti state	[8]
0.27 - 1.23 x 104 cfu/ml	-	-	-	-	-	River	Foma River, Ita-Nmo, Ilorin, Nigeria	[10]
0.15-5.4×10^6	1.5-3×10^5 cfu/ml	6×10^4 CFU/100ml	-	-	0.70 - 8.0 x 103 cfu/ml	ground water and packaged water supply	Federal University of Technology, Owerri, Nigeria	[12]
4.5 – 5.4 x 10^4	23 -26	4-6	0 – 2.0 x 10^2	1.3 – 1.8 x 10^2	-	Well	Calabar Metropolis Cross River state	[11]
2.0- 5.8 x 10^4	12-25	12 – 25	0 – 2.8 x 10^2	0 – 2.6 x 10^2		Stream		
1.4 – 2.0 x 10^3	8 -9	8-9	0	0	-	Borehole		
3.8 x 10^4	20	20	1.6 x 10^2	1.3 x 10^2		River		
1.0 – 2.01 x 10^6	1600 - >1800	-	0 – 2.4 x 10^4	0 – 2.8 x 10^4	-	Borehole	Eyaen Community Area of Edo State	[19]
1.90 - 2.38 × 10^5	3 – 20	-	-	-	-	Sachet water	-	[46]
1.40 – 1.96 x 10^4	0 – 2	0	-	-	-	Sachet water	Maiduguri Metropolis	[52]
	7.3 x 10^6	3.9 x 10^6	-	-	-	Well water	Sabon Gari Osogbo Osun state	[64]
10 - 82	0 – 9	-	-	-	-	Sachet water	Markets and Motor parks in Aba town, south east of Nigeria	[65]
1.0 -980 x 10^6	0 – 1800 (1.5 – 3800 x 10^2)	-	-	-	-	Borehole, well water, storage tank, stream	Akungba-Akoko, Nigeria	[66]
3.93 – 6.8 x 10^4	-	-	-	-	-	Stream, borehole and spring	Uturu, Abia State	[34]
1.0 – 9.0 x 10^2	0.8 – 9.0 x 10^2	-	-	-	-	Borehole	Aba South Metropolis, Abia State	[26]
0.1 – 9.9 x 10^4	0.06 – 1.95 x 10^4	-	-	-	-	Stream	Oluji/Oke Igbo, Odigbo and Ondo East, Ondo state	[67]
0 - 2.5 x 10^2	0 – 16	-	-	-	-	Borehole	Ijebu-Ode, Southwestern Nigeria	[48]
0 - 8.1 x 10^2	16 – 1100	-	-	-	-	Well		
-	2 – 1600	0 - 2.5×10^4	-	-	-	-	Ota, Ogun state	[1]
I.6x10^5	3 – I0	-	-	-	-	Borehole	Akungba - Akoko, Ondo State	[68]
0.851-1.63x10^3	1-7 cfu/ml	-	-	-	-	Borehole	Ijebu Land, Ogun state	[39
0.3 – 56 x 10^6	0.5 – 14 x 10^6 cfu/100ml	-	-	-	-	Sachet packaged water	Oluyole, Ibadan South West and Ibadan South East LGA, Oyo State	[51]

Table 2: Microbial diversity found in different potable water sources in Nigeria

Klebsiella sp.	-	-	-	-	*P. aeruginosa*	*Proteus* sp.	-	-	-	-	*Chromobacterium* sp.	Sachet water	Owerri metropolis, Imo state	[69]
Klebsiella sp.	-	*Salmonella* sp.	-	-	*P. aeruginosa*	*Proteus* sp.	*Shigella* sp.	*Serratia maecscns*	*E. coli*	*Bacillus* sp.	*S. aureus*	Stored domestic tank	Ile-Ife, Osun state	[70]
Klebsiella sp.	-	*S. typhii*	*S. feacalis*	-	*P. aeruginosa*	-	-	-	*E. coli*	*Bacillus subtilis*	*Staphylococcus* sp.	Sachet packaged water	Minna metropolis, Niger state	[61]
Klebsiella sp.	*Citrobacter* sp.	*Micrococcus* sp.	*Streptococcus* sp.	*Salmonella* sp.	*Pseudomonas* sp.	*Proteus* sp.	*Serratia* sp.	*Enterococcus* sp.	*E. coli*	*Bacillus* sp.	*S. aureus*	Sachet and bottled water	Ado-Ekiti metropolis, Ekiti state	[2]
Klebsiella sp.	-	-	-	*E. aerogenes*	*P. aeruginosa*	*Proteus* sp.	-	*Vibrio cholerae*	*E. coli*	-	*Staphylococcus sp.*	*Aeromonas sp.*	Villages in Ohafia Local Government Area, Abia State	[62]
M. luteus	-	-	--	***E. aerogenes***	***P. aeruginosa***	-	-	-	***E. Coli***	-	-	Sachet packaged water	Oluyol, Ibadan South West and Ibadan, South East L. GA, Oyo State	[51]
-	-	*Salmonella sp.*	-	-	*P. aerugionosa*	-	-	*Flavobacteriu m* sp.	*E. coli*	*Bacillus sp.*	*S. aureus*	Spring, borehole and tap water	Okada, Edo state	[32]
K. pneumoniae	-	*S. paratyphi*	-	-	*P. aeruginosa*	*Proteus vulgaris*	-	-	-	*B. scereus, B. subtilis,*	*S. aureus*	Borehole	Akungba - Akoko, Ondo State	[68]
-	-	*Salmonella* sp.	*Streptococcus* sp.	*Enterobacter* sp.	*Pseudomonas* sp.	*Proteus* sp.	*Shigella* sp.	*Vibrio* sp.	*E. coli*	*Bacillus sp.*	*S. aureus*	River, well and borehole	Calabar Metropolis Cross River state	[11]
Klebsiella sp.	*Citrobacter* sp.	*Salmonella* sp.	-	*Enterobacter* sp.	-	*Proteus* sp.	*Shigella* sp.	*Vibrio* sp.	*E. coli*	*Bacillus sp.*	-	Tap water	Opuraja community of Delta State	[56]
K. aerogenes	-	*Mi. varians*	*S. faecalis*	-	-	*Proteus vulgaris*	-	-	*E. coli*	*B. subtilis*	*S. aureus*	Borehole	Uruan Local Government Area of Akwa Ibom State.	[9]
Klebsiella sp.	*Serratia* sp.	*Salmonella* sp.	*Sphaerotilus* sp.	*Enterobacter* sp.	*Erwinia* sp.	*Proteus* sp.	*Shigella* sp.	*Yersinia* sp.	*E. coli*	*Bacillus sp.*	*Staphylococcus sp.*	River	Foma River, Ita-Nmo, Ilorin, Nigeria	[10]
Klebsiella sp.	-	-	-	*Enterobacter* sp.	*Pseudomonas* sp.	*Proteus* sp.	-	*Clostridium perfringens*	-	-	*Staphylococcus sp.*	Sachet water	Aba, Abia state	[65]
Klebsiella sp.	-	-	-	*Enterobacter* sp.	-	*Pseudomonas* sp.	-	-	*E. coli*	-	*Staphylococcus sp.*	Sachet water	Maiduguri Metropolis	[52]
K. pneumonae	-	-	*Streptococcus* sp.	*Enterobacter aerogenes*	*P. aeruginosa*	-	*Shigella* sp.	-	*E. coli*	*Bacillus sp.*	*S. aureus*	Borehole	Aba South Metropolis, Abia State	[26]
Micrococcus acidophilus	-	-	*St. lactis*	*E. r aerogenes*	*P. putida, P. fluorescens, P. aeruginosa*	*Proteus mirabilis*	-	-	-	*B. subtilis, B. alvei, B. cereus*	*S. aureus*	Sachet water	-	[46]
-	*Serratia* sp.	*Salmonella* sp.	-	-	-	-	-	-	*E. coli*	*B. subtilis*	*S. aureus*	Stream	Oluji/Oke Igbo, Odigbo and Ondo East	[67]
Klebsiella sp.	-	*Salmonella* sp.	-	-	*P. aeruginosa*	*Proteus* sp.	*Shigella* sp.	*Enterococcus* sp.	*E. coli*	-	*S. aureus*	Borehole	Ijebu-Ode, Ogun state, Nigeria	[48]
Micrococcus luteum	-	-	*St. lactis*	*E. aerogenes*	*P. aeruginosa*	*Proteus vulgaris*	*Alcaligenes faecalis*	*Aeromonas* sp.	*E. coli*	*B. cereus*	*S. aureus*	sachet-packaged drinking water	Western Nigeria	[63]
-	-	-	*S. faecalis*	-	-	-	-	-	*E. coli*	*Bacillus sp.*	-	Packaged water supply	Federal University of Technology, Owerri, South Eastern Nigeria	[12]
K. pneumoniae	*freundii, C. Citrobacter*	*Salmonella*	-	-	-	*Proteus vulgaris*	-	-	-	*Serratia marcescens*	-	River	Fulani Settlements in GidanKwano, Minna, Niger State	[47]
-	-	*Salmonella* sp.	-	-	*Pseudomonas* sp.	-	-	-	*E. coli*	-	-	River	River Nun at Amassoma axis, Bayelsa state	[71]
Klebsiella sp.	-	*Salmonella typhi*	-	*E. aerogenes*	*Pseudomonas* sp.	*Proteus* sp.	*Shigella* sp.	*V. cholera*	*E. coli*	-	*S. aureus*	Borehole	Eyaen Community Area of Edo State	[19]
Klebsiella sp.	-	-	-	*Enterobacter* sp.	*Pseudomonas* sp.	-	-	-	*E. coli*	*Bacillus* sp.	*S. aureus*	Tap and sachet water	Elele, Rivers state	[41]
Micrococcus varians	*Corynebacteri um kutscheri*	-	*Streptococcus* sp.	-	*P. aeruginosa*	-	-	*L. brevis*	*E. coli*	*B. licheniformis, B. circulans*	*S. aureus*	Different sources of water in storage tank	Ilorin Metropolis, Kwara state	[60]
Micrococcus varians	-	-	-	*E. faecalis*	*P. aeruginosa*	-	-	*C. perfringens*	*E. coli*	*B. subtilis*	*S. aureus*	Borehole	Eatern Obolo LGA, Akwa Ibom state	[58]
-	-	-	*S. faecalis*	*E. aerogenes*	*P. aeuginosa*	*Proteus* sp.	-	-	*Bacillus* sp.	*S. aureus*	-	Borhole	Amike – Aba, Ebonyi state	[57]
Klebsiella sp.	*Citrobacter* sp.	*Salmonella* sp.	-	*Enterobacter* sp.	*Enterobacter* sp.	*Proteus* sp.	*Shigella* sp.	*V. cholera*	*Bacillus* sp.	*Bacillus* sp.	-	Tap, well and stream	Opuraja, Okpe LGA, Delta state	[56]
K. pneumoniae	-	*Salmonella typhi*	-	-	-	*Shigella dysenteriae*	*Shigella dysenteriae*	-	*E. coli*	-	*Staphylococcus sp.*	Well water	Sabon Gari Osogbo Osun state	[64]
Klebsiella sp.	*Diptheriods* sp.	*Salmonella* sp.	*Streptococcus* sp.	*E. aerogenes*	*P. aeuginosa*	*Proteus* sp.	*Shigella* sp.	*C. perfringens*	*E. coli*	-	*S. aureus*	Surface water	Guma LGA, Benue state	[45]

References

3. Potential health implications

Humans needs regular and accessible quality water supply, which constitute a significant part of the protoplasm and provides vital necessity for physiological and biochemical processes [9]. But the use of poisonous chemicals could percolate in the earth layers and contaminate ground waters thereby constituting public health [9]. On global perspctive, World Health Organization estimated that about 4 billion cases of diarrhea related illness and 2.2 million deaths occurs annually [72]. In Nigeria, Federal Ministry of Health and various State Ministries of Health have reported an increased rate of poor potable water related diseases.

Potable water is meant for human consumption, hence should be free of pathogens and other objectionable materials including colour, tastes etc. The microbial quality of potable water is a concern to consumers, water suppliers, regulators and public health authorities. This is because water is a vehicle through which waterborne pathogens that could cause diseases are transmitted [64]. The presences of coliforms i.e a water quality indicator suggest the occurrence of entero pathogens in such water [68]. *E. coli* is the best organism for assessing potable water quality [73]. The bacterial diversity found in potable water sources are associated with infectious diseases including gastroenteritis, typhoid and paratyphoid fevers, bacillary dysentery dysentery, cholera [9,35,74], and urinary tract infections etc. Spcifically, fecal coliform could cause typhoid fever, hepatitis, gastroenteritis, dysentery, cholera, hepatitis A and poliomyelitis [9, 32]. Salmonella spcies is the causative agent of typhoid fever. Typhoid fever is one of the enteric diseases that is transmitted through water [9]. Other diseases caused by bacteria diversity found in potable water sources in Nigeria include urinary tract infection (*Proteus* spcies), ellulitis, wound infections, septicemia, urinary tract infections, hepatobiliary, gastrointestinal and ear infections (*Aeromonas* spcies) [75,76], meningitis and brain abscess (*Citrobacter* spcies) [77], pneumonia, neonatal sepsis and urinary tract infections [78], bacteremia/septicemia, endocarditis (*Bacillus* spcies), sinusitis, sore throat (*Streptococcus* spcies), gastroenteritis (*Yersinia* spcies), Necrotic enteritis and poisoning characterized by abdominal cramps and diarrhea (*Clostridium perfringens),* skin lesions, sepsis etc. (*Chromobacterium violaceum*), bacteremia, urinary tract infections and meningitis (*Enterococcus* spcies).

Micrococcus spcies are non-pathogenic but could cause disease in immunocompromized patients [79]. However, in rare cases endocarditis can be caused by *Micrococcus luteus. Staphylococcus aureus* and *Staphylococcus saprophyticus* is found in the nasal passage, hands and skin of humans as normal flora, but could cause genitourinary disease. Different spcies of *Pseudomonas* are pathogenic. For instance, *Pseudomonas aeruginosa* can cause perirectal infections, pediatric diarrhea, gastroenteritis and enterocolitis and giving port of entry for septicemia and bacteremia; skin and soft tissue, urinary tract, bone and joint, respiratory infections, Bacteremia and septicemia [80,81]. Vibrio spcies are known to cause cholera, gastroenteritis and sepsis. *Alcaligenes faecalis* is an harmless, opportunistic bacterium, but when it invade the inside the body it can cause disease such as peritonitis in peritoneal dialysis patients, urinary tract infections, and postoperative endophthalmitis, sepsis, meningitis, endocartitis enteric fever, appendicitis, cystitis, chronic suppurative otitis media and pneumonitis [82].

The fungi reported in potable water source (river) by an author could have been introduced into the river resulting from contamination from soil contaminated either through soil erosion or man activities. Typically, some of the fungal diversity such as *Penicillium, Fusarium* and *Asprgillus* spcies is known to produce mycotoxins. Mycotoxins are toxic secondary metabolites produced by molds. For instance; *Asprgillus* spcies (which produces aflatoxins and ochratoxins), *Fusarium* spcies (which produces Moniliformin and Fumornisins) and *Penicillium* spcies (which produces citrinin and cyclopiazonic acid) are known to causes disease conditions in immunocompromized patients [83]. Gomes *et al*[84] classified immunocompromized patients as individuals with underlying conditions such as hematological malignancies, solid tumors, transplantation, diabetes mellitus, AIDS, chronic alcoholism, cirrhosis, renal failure, burns, pregnancy, intravenous drug abuse and those under treatment including radiation, cytotoxic chemotherapy, antirejection medications, or corticosteroids that causes immune depression. Ribes *et al* [85] also stated that host risk factors to several human diseases include diabetes mellitus, neutropenia, sustained immunosuppressive therapy, chronic prednisone use, iron chelation therapy, broad-spctrum antibiotic use, severe malnutrition and breakdown in the cutaneous barrier such as trauma and surgical wounds.

The potential diseases caused by this fungus include Asprgillosis (*Asprgillus* spcies), mucormycosis (*Mucor* spcies) and hyalohyphamycosis (*Penicillium* and *Fusarium* spcies). These fungal infections are mostly opportunistic systemic mycoses. Mycotoxins produced by these fungal spcies have low virulence i.e not aggressive [86]. Similarly, subcutaneous mycoses such as *Curvularia* spcies mostly found in soil and vegetation in temperate country are known to cause phaeohyphomycosis [87]. The incidence rate of disease caused by *Curvularia* spcies is rare. Mortierella spcies were reported in surface water and this fungal pathogen can cause disease in animals, but no sufficient evidence to suggest that they are true human pathogens [85]. Hence their occurrence could mainly be from contamination from the environment.

4. Conclusion

Water sources for human consumption is suppose to be free from objectionable (colour, taste, turbidity) and microbial contaminants. In Nigeria, potable water sources are met by surface (River, stream, spring), ground water (borehole, well) and to lesser extent rainwater. Borehole water is usually packaged into bottle and sachet for sales. Sometimes water vendor buy ground water with 20 liter jerry cans and sell to people residing in such area. Sachet water popularly known as “Pure water” are patronized by Nigerian probable due to their convenience to quench taste. This packaged water are vended in several locations including several public places including motor parks, garage, markets, streets, along express way, outskirt of schools and hospitals. The microbial density of various potable water sources often exceed the World Health Organization/Food and Agricultural Organization allowable limit of 1.0 x 10^2cfu/ml for potable water and Standard Organization of Nigeria maximum permissible level of 10cfu/ml (total coliform) and 0 cfu/100ml (Thermo tolerant Coliform or *E. coli,* Faecal streptococcus and *Clostridium perfringens* spore). Typically, microbial load of the different potable water sources in the order surface water (River, stream)> ground water (well and borehole). However, microbial density were least in packaged water bottled water<sachet water. Several dominant microbial diversity found in the potable water sources including *Staphylococcus aureus*, *Escherichia* coli, *Proteus, Pseudomonas, Enterobacter, Salmonella, Klebsiella, Bacillus* spcies etc are known to cause diseases conditions. Other deadly pathogenic microbes reported in surface water include *Vibrio* spcies and *Clostridium perfringens.* To reduce the incident of microbial water borne diseases in Nigeria we suggest that drinking water should be adequately treated before consumption. Also strategic monitoring and surveillance approach should be encouraged to ensure compliance by water vendors.

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