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Spatial and Seasonal Distribution of Microorganisms in Water Bodies, Port Harcourt, Nigeria

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Abstract

Microorganisms are ubiquitous in nature and play significant roles in human culture and health. They are often distributed in water bodies. Thus, the spatial and seasonal distribution of microorganisms in water bodies (ground, surface and well water) in Port Harcourt, South-south Nigeria was investigated during the rainy and dry season of 2022. Three (3) sample locations were identified (Abuloma, Borikiri and Eagle Island) and different sources *vis-à-vis* ground (borehole), surface water (river) and hand dug well-water were collected from the locations. Samples were collected in 10mL sterile container, placed in an ice-packed cooler and were transported to the laboratory for microbial analysis. Morphologically isolated colonies obtained from different plates marked on nutrient agar, MacConkey agar, m-HPC agar plate, Thiosulphate Citrate Bile Salts Agar (TCBS), and Erosin Methyl Blue (EMB) agar to purify was effectively carried out. Result among others revealed increase in total heterotrophic bacteria (THB) in ground water exercised an explicit relationship with the increase in surface water except that of the hand-dug wells across sample locations during the dry and wet seasons. These increases could possibly give rise to more harmful organisms in the water bodies. More so, there could be possible Salmonellosis infection among vulnerable children who are unavoidably disposed to consuming such salmonella-contaminated water resources accidentally due to its increased concentration. Dysentery, diarrhea, nausea, abdominal cramp among others may be common among water utilizers from the study area because of the presence of shigella that causes shigellosis. The bioavailability of various microorganisms like vibrio, shigella and salmonella and their increases in concentration could possibly be linked with poor water sanitation, sewage and solid waste management. This may becatalyzed by derelict regulation enforcement agency or dearth of officers to put to practice the needed regulation, and in addition the paucity of education and awareness campaign on the citizenry as it relates to their actions and inactions (activities) on water bodies. Thus, all consumable water should be treated before ingestion is facilitated and relevant agencies should step up action plan to ameliorate these deficiencies within the study zone in a bid to ensure and maintain water safety and therefore, good health.

Keyword: water bodies, spatial, seasonal, distribution, microorganisms.

INTRODUCTION

Microorganisms are organisms of microscopic sizes that could exist as single cell forms or as a colony of cells. They could be bacteria, fungi, archaea or protists (Singh, 2008; Kelly, 2017) However, prions (abnormal pathogenic agents that are transmissible) (Belay & Schonberger, 2005) and viruses do not belong to this group of organisms (Kelly, 2017; William et al, 2017). In human culture and health, microorganisms play significant roles which are not limited to sewage treatment phenomena, food fermentation, fuel production, enzymatic activities, production of bioactive compounds, among others. Nevertheless, in modern society, varied forms of microorganisms have been used for biological warfare and bioterrorism. More so, they are key components of productive soil and they make up the human microbiota including the indispensable gut flora and the epidemiologically known infectious diseases. Also, they produce oxygen, decompose organic material, provide nutrients for plants and at these processes, greenhouse gases are released to the atmosphere at the same time. They therefore play a crucial role in relation to climate and climate change (Jacobsen & Johansen, 2023), and maintaining human health, albeit some can be morbific in plants and humans (American Society for Microbiology, 2022; Libre Texts Library, 2023). They are easily adapted to different habitats (such as extreme cold or very hot conditions, high pressure or high radiation environment like Deinococcusradiodurans (Kelly, 2017, William et al, 2017). Microorganisms sum up a larger part of the planet's living material and thus play a major role in maintaining the earth's ecosystem. They can be divided into seven major typologies according to (Libre Texts Library, 2023) to include fungi, bacteria, viruses, algae, protozoa, archaea and multicellular animal parasite (helminths). Each typology has a distinctive means of location, production, cellular composition and morphology.

Water is one of the free gifts of nature. It is a compound that has an element of hydrogen and oxygen in the ration of 2:1 (Bibiye et al, 2022). Water comes from diverse sources such as streams, hand dug wells, lakes, sea, ocean, spring, lagoon. It is an indispensable nutrient at every age, consequently optimal hydration is a crucial component for good health. Water accounts for about 60% of an adult's body weight (Hooper et al, 2016; Chan, 2023). In human health, water helps to restore fluids lost through metabolism, breathing, sweating, and the removal of waste. It helps to keep one from overheating, lubricates the joints and tissues, maintains healthy skin, and is necessary for proper digestion according to (Chan, 2023). It's the perfect zero-calorie beverage for quenching thirst and rehydrating your body (Millard-Stafford, 2012; The National Academy of Sciences, 2019). The National Academy of Medicine (Millard-Stafford, 2012) and (The National Academy of Sciences, 2019) suggest an adequate intake of daily fluids of about 13 cups and 9 cups for healthy men and women, respectively, with 1 cup equaling 8 ounces. The National Academy of Medicine maintained that water is highly needed by all ages (Table 1) aside water-rich foods.

Table 1: Daily water intake based on age

Age	Daily Adequate Intake
1-3 years	4 cups, or 32 ounces
4-8 years	5 cups, or 40 ounces
9-13 years	7-8 cups, or 56-64 ounces
14-18 years	8-11 cups, or 64-88 ounces
men, 19 and older	13 cups, or 104 ounces
women, 19 and older	9 cups, or 72 ounces
pregnant women	10 cups, or 80 ounces
breastfeeding women	13 cups, or 104 ounces

Source: https://www.hsph.harvard.edu/nutritionsource/water/

Furthermore, the need to have quality water for human consumption at all levels of life has become a teething problem in most developing countries due to poverty, poor technological know-how and paucity of political will. This could promote microbial contamination since most of the inhabitants lack water hygiene, sanitation and safety, and such could accentuate the public health status of the citizen in a general sense noting that water is a vehicle for the transportation of diseases to man. Diseases such as cholera, typhoid, dracontiasis, diarrhea, dysentery, among others are water-based or water-related diseases that affect human health due to microbial interaction with water bodies (Achalu, 2008; Bibiye, 2023). A good example is the presence of *Escherichia coli,* as a water-based indicator of microbial contaminants, which simply defines the presence of water-borne pathogens (Okafor, 1985; Okpokwasili & Akojubi, 1996; Chukwura, 2001; Venter, 2001). Also, Feachem (2001) observed that the major health threat posed by drinking unsafe water is infectious diseases. Lack of municipal water supply has led to great water and sanitation crises in most developing countries. Many people fall back to different water sources and many of these contain dangerous and harmful contaminants (Onyenekenwa, 2011). Therefore, this study is aimed at assessing the occurrence and seasonal distribution of microorganism in well, surface and groundwater bodies in Port Harcourt as there is paucity of data.

METHODOLOGY

Study Area

Port Harcourt is a cosmopolitan city with a geographical coordinate that lies between latitude 4º49′27.0012″N and longitude 7º2′0.9996″E respectively. It is 9 meters above sea level and has a tropical climate with significant rainfall pattern in most months of the year. The average annual temperature is 26.4ºC or 79.5ºF. It has precipitation of about 2708 mm or 106.6 inches per annum. Most precipitation occurs in September with an average of 141 mm or 16.3 inches. The driest month is January with 36 mm or 1.4inch rainfall. Temperature varies by 2.4 ºC or 36.3 ºF throughout the year. More so, the warmest month of the year occurs in February with an average temperature of 26.70 ºC or 81.7′F while August serves as the coldest month, with an average temperature of 25.2ºC or 77.4ºF.

Collection of Water Samples

Groundwater (Boreholes), surface water (River) and well water (Hand dug wells) samples were collected from Abuloma, Borikiri and Eagle Island respectively. Samples were collected for microorganism analyses in clean containers after rinsing the containers with the sample to be collected. Water samples for microbial analyses were collected separately in one (1 Ltre) sterile container. The sampling containers were filled to the brim to expel oxygen which could trigger reactions and falsify results. Water samples were preserved in ice chests to inhibit the activity of microbes.

Microbiological Analysis

This method enhances the analyses of water by way of estimating the number of bacteria present and to allow the recovery of microorganisms in order to identify them. Different water sources were processed for the isolation of bacteria as described elsewhere (Ruangpan &Tendencia, 2004; Malisha et al., 2011; Sandle, 2016). The plate count examination was employed and it relies on bacteria growing a colony on a nutrient medium, so that the colony becomes visible to the naked eye, and the number of colonies on a plate were counted. A nonselective medium is used to obtain a total enumeration of the sample (i.e., a heterotrophic plate count). When it is required to obtain a specific bacterial species, a selective medium was used. Membrane filtration was used for the detection of E. coli and total coliform counts). For the detection of total coliform, the membrane filter was placed on M-Endo agar LES (Hi-Media) and the bacterial colonies developed were counted by a colony counter (Cole-Parmer, India). For the detection of E. coli, membrane filters were cultured on Rapid Hi-chrome Agar (Hi-media, M1465). All plates were incubated at 35 ± 2◦C for 24 hours (APHA, 2017). However, the bacteria isolates were identified on the basis of standard culture, morphological and biochemical characteristics (Malisha et al, 2011; Ogbonna et al., 2019; Cheesebrough, 2006; Reyes, 2018; Holt et al., 1994). Microbiological quality control and assurance were considered using WHO standard guidelines from 2008 and APHA 1999 (Standard method for examination of water and waste water) in a bid to ensure the reliability of laboratory results.

RESULT

Microbial counts during the dry season

Total Heterotrophic Bacteria (THB) for groundwater varied slightly across sample locations. In Abuloma, THB recorded $0.65x10^6$cfu/ml while Borikiri recorded $0.60x10^6$cfu/ml and Eagle Island recorded $10.00x10^6$cfu/ml respectively. In the surface water, highest THB of $2.9x10^6$ cfu/ml was recorded in Abuloma while the least $4.20x10^6$cfu/ml was recorded in Borikiri. At the well water, highest THB of $9.40x10^6$cfu/ml was recorded in Eagle Island and the least 1.15x106 cfu/ml was recorded in Borikiri (Table 2). Total Coliform Count (TCC) for groundwater revealed high variation across sampling locations. Highest TCC $8.25x10^6$cfu/ml was recorded in Eagle Island while the least $0.00x10^6$ cfu/ml was recorded in Borikiri. Highest TCC $4.10x10^6$cfu/ml for surface water was recorded in Borikiri while the least 0.20x106 cfu/ml was recorded in Eagle Island. However, TCC for well water recorded $0.00x10^6$ cfu/ml across sampling locations (Table 2). The highest Faecal Coliform Count (FCC) for groundwater $3.40x10^6$cfu/ml occurred in Eagle Island whereas the least $0.00x10^6$cfu/ml occurred in Borikiri. Surface water had highest value of $3.20x10^6$ cfu/ml and was recorded in Borikiri while the least $2.50x10^6$cfu/ml was recorded Abuloma. There was $0.00x10^6$ cfu/ml for well water across sampling locations (Table 2).

Table 2: Microbial Counts of Water Samples across Sampling Stations

Sampling Stations	Seasons	Water sources	THB ($x10^6$)	TCC ($x10^6$)	FCC ($x10^6$)
Abuloma	Dry Season	GW	$0.65x10^6$	$5.35x10^6$	$1.55x10^6$
		SW	$21.95x10^6$	$4.10x10^6$	$2.50x10^6$
		WW	$4.65x10^6$	$0.00x10^6$	$0.00x10^6$
Borikiri	Dry season	GW	$0.60x10^6$	$0.00x10^6$	$0.00x10^6$
		SW	$4.20x10^6$	$3.60x10^6$	$3.20x10^6$
		WW	$1.15x10^6$	$0.00x10^6$	$0.00x10^6$
Eagle Island	Dry season	GW	$10.00x10^6$	$8.25x10^6$	3.40x106
		SW	$7.20x10^6$	$0.20x10^6$	Nil
		WW	$9.40x10^6$	$0.00x10^6$	$0.00x10^6$

THB=Total Heterotrophic Bacteria, TCC=Total Coliform Count, Faecal Coliform Count.

Microbial counts during the wet season

During the wet season, there was significant variation of microbial load for groundwater across sampling locations. The THB value for groundwater varied from $1.80x10^6$ cfu/ml Abuloma to $1.55x10^6$cfu/ml Borikiri and $11.00x10^6$cfu/ml Eagle Island respectively. Surface water for THB varied significantly from $23.95x10^6$cfu/ml in Abuloma, $5.70x10^6$cfu/ml in Borikiri and $8.20x10^6$cfu/ml for Eagle Island congruently while well water also varied meaningfully from $4.65x10^6$cfu/ml in Borikiri, $1.65x10^6$cfu/ml and $10.25x10^6$cfu/ml in Eagle Island (Table 3). Abuloma, Borikiri and Eagle Island TCC for groundwater had a corresponding value of 7.25x 10^6cfu/ml, $0.30x10^6$cfu/ml and $0.49x10^6$ cfu/ml respectively whereas surface water had 4.40x106 cfu/ml (Abuloma), 5.10x106 cfu/ml (Borikiri) and 0.40x106 cfu/ml (Eagle Island).Well-water had $2.27x10^6$cfu/ml in Abuloma, $0.00x10^6$cfu/mlinBorikiri and $4.70x10^6$cfu/ml in Eagle Island (Table 3). The Faecal Coliform Count (FCC) for groundwater revealed that Abuloma, Borikiri and Eagle Island had a corresponding microbial load of $2.25x10^6$cfu/ml, $0.00x10^6$cfu/ml and $3.20x10^6$cfu/ml while in surface water, Abuloma had $2.80x10^6$cfu/ml, Borikiri ($3.30x10^6$cfu/ml) and Eagle Island had $0.00x10^6$ cfu/ml respectively, and in well water, Abuloma, Borikiri and Eagle Island had 0.70 $x10^6$ cfu/ml, $0.00x10^6$cfu/ml and $0.90x10^6$cfu/ml respectively (Table 3).

Table 3: Microbial Counts of Water Samples across Sampling Stations

Sampling Stations	Seasons	Water sources	THB ($x10^6$)	TCC ($x10^6$)	FCC ($x10^6$)
Abuloma	Wet Season	GW	$1.80x10^6$	$7.25x10^6$	$2.55x10^6$
		SW	$23.95x10^6$	$4.40x10^6$	$2.80x10^6$
		WW	$4.65x10^6$	$2.70x10^6$	$0.70x10^6$
Borikiri	Wet season	GW	$1.55x10^6$	$0.30x10^6$	$0.00x10^6$
		SW	$5.70x10^6$	$5.10x10^6$	$3.30x10^6$
		WW	$1.65x10^6$	$0.00x10^6$	$0.00x10^6$
Eagle Island	Wet season	GW	$11.00x10^6$	$0.49x10^6$	$3.20x10^6$
		SW	$8.20x10^6$	$0.40x10^6$	$0.00x10^6$
		WW	$10.25x10^6$	$4.70x10^6$	$0.90x10^6$

THB=Total Heterotrophic Bacteria, TCC=Total Coliform Count, Fecal Coliform Count.

Trends of Microorganism Presence During the Dry and Wet Season

During the dry season, the highest Vibrio occurrence for groundwater was located in Eagle Island ($6.00x10^6$cfu/ml) while the least was recorded in Borikiri ($0.00x10^6$cfu/ml). In the surface water, highest occurrence of $9.60x10^6$ cfu/ml was recorded in Abuloma while the least $1.30x10^6$ cfu/ml was recorded in Eagle Island and there were $0.00x10^6$cfu/ml occurrences of Vibrio for well water across Abuloma, Borikiri and Eagle Island respectively (Table 4). For the Staphylococcus in groundwater, highest value of $6.25x10^6$cfu/ml was recorded in Eagle Island while the least $0.00x10^6$ cfu/ml was recorded in Borikiri. More so, surface water had $6.10x10^6$cfu/ml as the highest value recorded in Abuloma with least value of $2.50x10^6$cfu/ml recorded in Borikiri whereas the well water in Abuloma and Borikiri had $0.00x10^6$cfu/ml, and Eagle Island had $7.25x10^6$cfu/ml for Staphylococcus respectively (Table 4). Borikiri and Eagle Island had $0.00x10^6$cfu/ml of Salmonella for groundwater with Abuloma recording $0.70x10^6$cfu/ml while in surface water, AbulomaBorikiri and Eagle Island recorded $1.10x10^6$ cfu/ml, $0.80x10^6$ cfu/ml and $5.00x10^6$cfu/ml correspondingly. For well water, Borikiri and Eagle Island recorded $0.00x10^6$cfu/ml of Salmonella while Abuloma recorded $0.60x10^6$cfu/ml (Table 4). Shigella in Abuloma had $1.00x10^6$cfu/ml while Borikiri and Eagle Island had a corresponding value of $0.00x10^6$cfu/ml for groundwater. Surface water in Abuloma and Eagle Island for Shigella had $1.10x10^6$cfu/ml respectively whereas Borikiri had $2.10x10^6$ cfu/ml. The well water for Shigella revealed that Abuloma recorded $1.40x10^6$cfu/ml while Borikiri and Eagle Island recorded $0.00x10^6$cfu/ml (Table 4).

Table 4: Bacteria Counts of Water Samples across Sampling Stations during the Dry Season

Sampling Stations	Seasons	Water sources	***Vibro* (DS) ($x10^6$)**	***Staph.* (DS) ($x10^6$)**	**Salmo. (DS) ($x10^6$)**	***shigella* (DS)**
Abuloma	Dry Season	GW	$0.85x10^4$	$5.50x10^4$	$0.70x10^4$	$1.00x10^2$
		SW	$9.60x10^4$	$6.10x10^4$	$1.10x10^4$	$1.00x10^2$
		WW	$0.00x10^6$	$0.00x10^4$	$0.60x10^4$	$1.40x10^2$
Borikiri	Dry season	GW	$0.00x10^6$	$0.00x10^6$	$0.00x10^6$	$0.00x10^4$
		SW	$2.20x10^4$	$2.50x10^6$	$0.80x10^6$	$2.10x10^4$
		WW	$0.00x10^6$	$0.00x10^6$	$0.00x10^6$	$0.00x10^4$
Eagle Island	Dry season	GW	$6.00x10^4$	$6.25x10^6$	$0.00x10^6$	$0.00x10^4$
		SW	$1.30x10^4$	$3.25x10^6$	$5.00x10^6$	$1.10x10^4$
		WW	$0.00x10^4$	$7.25x10^6$	$0.00x10^6$	$0.00x10^4$

DS=Dry season, Staph. = Staphylococcus, Salmo. = Salmonella.

During the wet season, Vibrio recorded $0.00x10^6$cfu/ml in Borikiri and Eagle Island respectively while Abuloma recorded $1.25x10^4$ cfu/ml for groundwater. Abuloma, Borikiri and Eagle Island had values of $9.80x10^4$ cfu/ml, $3.20x10^4$cfu/ml and $2.30x10^6$ cfu/ml for surface water with a corresponding well water value of $1.70x10^6$ cfu/ml, $0.00x10^6$cfu/ml and $2.70x10^6$ cfu/ml (Table 5). Staphylococcus for groundwater recorded 7.00x104 in Abuloma, 0.05x106 cfu/ml (Borikiri) and 5.70x106 cfcu/ml (Eagle Island) while surface water recorded 7.10x104 cfu/ml (Abuloma), 3.70x106 cfu/ml (Borikiri) and 4.25x106 cfu/ml (Eagle Island) and well water recorded 2.70x104 cfu/ml (Abuloma), 0.00x106 cfu/ml Borikiri and 7.25x106 cfu/ml Eagle Island respectively (Table 5). Salmonella varied from location to location. Abuloma recorded $0.80x10^4$cfu/ml while Borikiri and Eagle Island recorded $0.00x10^6$ respectively for groundwater. The surface water bacteria analysis revealed that Abuloma recorded $1.30x10^4$ cfu/ml, Borikiri ($0.90x10^6$cfu/ml) and Eagle Island had $7.00x10^6$cfu/ml while in the well water, Abuloma, Borikiri and Eagle Island recorded $0.60x10^4$cfu/ml, $0.00x10^6$cfu/ml and $0.80x10^6$ respectively (Table 5). In the same vein, Shigella in Abuloma recorded $1.00x10^2$cfu/ml, Borikiri and Eagle Island recorded $0.00x10^4$ cfu/ml congruently for groundwater while surface water recorded $1.70x10^4$cfu/ml (Abuloma), $2.50x10^4$cfu/ml (Borikiri) and $1.70x10^4$cfu/ml (Eagle Island). Well water showed $1.40x10^2$cfu/ml in Abuloma, $0.00x10^4$ cfu/ml in Borikiri and $1.80x10^4$ cfu/ml in Eagle Island correspondingly (Table 5).

Table 5: Bacteria Counts of Water Samples across Sampling Stations during the Wet season

Sampling Stations	Seasons	Water sources	***Vibro* (WS) ($x10^6$)**	***Staph.* (WS) ($x10^6$)**	**Salmo. (WS) ($x10^6$)**	***Shigella* (WS)**
Abuloma	Wet Season	GW	$1.25x10^4$	$7.00x10^4$	$0.80x10^4$	$1.00x10^2$
		SW	$9.80x10^4$	$7.10x10^4$	$1.30x10^4$	$1.70x10^2$
		WW	$1.70x10^4$	$2.70x10^4$	$0.60x10^4$	$1.40x10^2$
Borikiri	Wet season	GW	$0.00x10^6$	$0.05x10^6$	$0.00x10^6$	$0.00x10^4$
		SW	$3.20x10^6$	$3.70x10^6$	$0.90x10^6$	$2.50x10^4$
		WW	$0.00x10^6$	$0.00x10^6$	$0.00x10^6$	$0.00x10^4$
Eagle Island	Wet season	GW	$0.00x10^6$	$5.70x10^6$	$0.00x10^6$	$0.00x10^4$
		SW	$2.30x10^6$	$4.25x10^6$	$7.00x10^6$	$1.70x10^4$
		WW	$2.70x10^6$	$7.25x10^6$	$0.80x10^6$	$1.80x10^4$

WS=Wet season, Staph. = Staphylococcus, Salmo. = Salmonella.

DISCUSSION

A heterotroph is an organism that cannot produce its own food, but takes nutrient from other sources or organic carbon, principally from animal or plant material. In the food chain, heterotrophs are not producers rather they are consumers (primary, secondary and tertiary consumers) (Hogg, 2013; Biology Dictionary, 2016; Amanvdaz et al., 2015). Thus, heterotrophic bacteria are those bacteria that need organic substrates to get their chemical energy for growth and development, and they are groups of microorganisms that utilizes carbon as food. They are the most ubiquitous bacteria in nature and are found in every type of water (Amanvdaz et al., 2015; Bibiye et al, 2022a; CT, 2023). Heterotrophic bacteria naturally are residents of the human body and animal. Various typologies such as Gram-negatives (Proteus, Enterobacter, Aeromonas, Citrobacter, Pseudomonas, Klebsiella, Flavo bacterium, Sratya, Moraxella, Alcaligenese and Acinetobacter), and gram-positives: (Bacillus and Micrococcus) exists according to Bartram et al. (2003). The National Primary Drinking Water Regulations (NPDWR) established by the U.S. EPA states that lower concentrations of heterotrophic bacteria in the drinking water is linked to a better maintenance of the treatment and distribution systems. The total heterotrophic bacteria (THB) highest concentration ($21.95x10^6$cfu/ml) dry season and $23.95x10^6$cfu/ml wet season across different water bodies in this study was found in surface water at Abuloma sampling location whereas the least concentration of $0.65x10^6$cfu/ml groundwater during the dry season and $1.55x10^6$ cfu/ml groundwater during the wet season occurred in Borikiri. This indicates high concentration of THB across water bodies. Heterotrophic bacteria present in water poses no health risks to humans but a high heterotrophic plate count (HPC) is an indicator for ideal conditions for the growth of bacteria. This can enhance breeding ground for more dangerous bacteria like Legionella or Escherichia Coli, and could cause foul-tasting water, lead to corrosion or slime growth in pipes (CT, 2023). Water bodies that exceed THB count of >500 cfu/ml i.e., $5.00x10^2$cfu/ml are considered very high and are not ideal for consumption (Centers for Disease Control and Prevention, 2015; Dobaradaran, 2006). The high concentration of THB in groundwater, surface water and the well water in this study possibly could be due to seepages, run-off, and poor environmental sanitation.

Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. However, the most basic test for bacterial contamination of a water supply is the test for total coliform bacteria. Total coliform counts (TCC) give a wide-ranging indication of the sanitary condition of a water supply (New York State Department of Health, 2023). TCC in water body is an indicator bacterium (i.e., it signals contamination in drinking water during testing) (FAQs, 2022, PSE, 2022). The health effects of drinking water that contains indicator bacteria can range from no physical impact to severe illness; e.g., gastrointestinal illness (GI), with symptoms starting within a few hours, days or weeks after consuming the water. GI symptoms can include some or all of the following: nausea, vomiting, cramps, diarrhea, muscle aches, headache and low-grade fever (FAQs, 2022). In the current study, during the dry season, groundwater for Eagle Island had the highest concentration of 8.60x10^6cfu/ml followed by groundwater (5.35x10^6cfu/ml) and surface water (4.10x10^6cfu/ml) in Abuloma, 3.6x106 cfcu/ml for surface water in Borikiri respectively. These values and that obtained during the wet season for all dissimilar water bodies are higher when compared with that obtained by (PSE, 2022, Rygala et al, 2020). Total coliform bacteria are target bacteria in drinking water quality analyses. Their presence in ground, surface and well water in this study could be due to waste management deficiency. Total Coliforms are not likely to cause illness, but their presence specifies that water supply may have been contaminated by more harmful microorganisms or may be a sign of bacterial regrowth. This is in line with (U.S. Environmental Protection Agency, 2008). who also maintained the presence of Total coliform bacteria in water body could trigger the growth of harmful bacteria, a condition inimical to public health.

Furthermore, faecal coliforms are facultatively anaerobic, rod-shaped, gram-negative, non-sporulating bacteria. They belong to the group of total coliforms that are considered to be present in such specific areas in the gut and faeces of warm-blooded animals, and are considered more accurate indication of human and animal waste (Doyle & Erickson, 2008, Water Quality Monitoring, 1996). The presence of fecal coliform in a drinking water sample often indicates recent fecal contamination, meaning that there is a greater risk that pathogens are present than if only total coliform bacteria is detected (Washington State Department of Health, n.d.). During the dry season, Eagle Island recorded 3.4x10^6cfu/ml for groundwater while Borikiri recorded 3.2x10^6cfu/ml for surface water respectively. The high concentration of FCC as indicated in this study could be as a result of leakages of septic tank interaction with groundwater aquifer super imposed by soil voidance capacity while at Borikiri, it could be due to discharges of waste of human and animal nature into the surface water body. More so, at the wet season, the high values of 2.55x10^6cfu groundwater and 2.80x10^6 for surface water in Abuloma including that of surface at Borikiri (3.30x10^6 cfu/ml) could be due to run-off and seepages. Poor waste management and environmental sanitation could enhance the possible cause and spread of fecal coliform in water bodies. This corroborate with the views of (FCDPH, 2009) that poor hygiene status, environmental sanitation, sewage management among others are responsible for the increases and spread of fecal coliform in water bodies.

Vibrios are microbiologically characterized as gram-negative. They are highly capable of moving spontaneously and are facultative anaerobes (not requiring oxygen), with one to three whiplike flagella at one end (Britannica, n.d.). Vibrio Infections are gastrointestinal illnesses which are caused by an ingestion of Vibrio bacteria, that are found in contaminated water and food (Weekes &Kotra, 2007). Three species of vibrio are of significance to humans: V. cholerae is the cause of cholera, and V. parahaemolyticus and V. vulnificus both act as agents of acute enteritis, or bacterial diarrhea (Britannica, n.d., Eyisi et al, 2013). High Levels of Vibrio (6.00x10^4) in surface water in Abuloma and that of groundwater in Eagle Island (6.00x10^4) during the dry season were recorded when compared with the works of Eyisi et al., (2013) at Akwa Ibom, South-south Nigeria. During the wet season at Abuloma, surface (9.80x10^4cfu/ml), well (1.70x106 cfu/ml) and groundwater (1.25x10^4cfu/ml) vibrio count was high. At Borikiri, surface (3.20x10^6cfu/ml) for vibrio count was also high including surface (2.3x10^6cfu/ml) and well water (2.70x10^6cfu/ml) in Eagle Island. This high level of vibrio could possibly enhance the spread of cholera among end-users of these water sources within the study period. Furthermore, open defecation and sewage disposal at sea may have contributed to the increases in surface and groundwater Vibrio concentration in this study.

Staphylococcus is a Gram-positive bacterium that appear spherical (cocci) and form a grape-like cluster when viewed under a microscope. Staphylococcus species are facultative organisms that have the propensity to grow in both aerobic and anaerobic environments. Staphylococcus is capable of causing several diseases to man and animal (Lidell et al, 1940; Medical Consumer's Advocate, 2001; Stevens et al, 2014; Online Etymology Dictionary, 2018). Due to their ability to penetrate or produce toxin, they can cause a variety of diseases in humans and animals. They cause food-poisoning, break down leucine into isovaleric acid which is the main cause of food odour (Stevens et al, 2014). Staphylococcus appeared to be high in groundwater (5.50x10^6cfu/ml) and surface water 6.10x10^6cfu/ml in Abuloma, 6.25x106 cfu/ml for groundwater, 3.25x106 cfu/ml for surface water and 7.250x106 cfu/ml for well water in Eagle Island respectively during the dry season. The high concentration of Staphylococcus species in the well water at Eagle Island could be due to poor environmental and water sanitation condition. However, during the wet season, Abuloma (ground, surface and well water) recorded a corresponding value of $7.00x10^4$cfu/ml, $7.10x10^4$cfu/ml and $2.70x10^4$ cfu/ml/ml. These values are high and indicate contamination of water bodies. More so, at Eagle Island, the values for ground, surface and well water values (5.70x106 cfu/ml, 4.25x106 and 7.25x106 cfu/ml) respectively presents the heavy contamination of water sources with staphylococcus. This portends a public health issue that demands attention by all and sundry in a bid to control its perceived impact on consumers of these sources of water.

Salmonella is a genus of rod-shaped gram-negative bacteria of the family Enterobacteriaceae. It lives in the intestinal tracts of animals and birds and is transmitted to man via the eating of food contaminated with animal faeces. Contaminated foods are frequently animal in origin. They include beef, poultry, seafood, milk, or eggs. Salmonella infection is caused by a group of bacteria called Salmonella. The bacteria are passed from faeces of people or animals to other people or animals. However, all foods, including some unwashed fruits and vegetables can become contaminated (JHM, 2023). In humans, Salmonella typhi occur due to contamination of food or water, and can precipitate to a life-threatening infection called typhoid fever. During the dry season, high presence of Salmonella in Abuloma ($1.10x10^4$cfu/ml) and Eagle Island ($5.00x10^6$cfu/ml) for surface water was recorded. Indiscriminate disposal of commingled waste body catalyzed by poor environmental sanitation may have been responsible for these high values of salmonella in the surface water body. Values were also high ($1.30x10^4$cfu/ml in Abuloma and $7.00x10^6$cfu/ml in Eagle Island) during the wet season for surface water. Surface run-off, water sanitation deficiency and poor waste management could be responsible among others for these high values.

Shigella is a group of bacteria that causes an acute intestinal illness called Shigellosis. It has four species namely Shigella sonnei (S. sonnei or "Type D"), S. flexneri (or "Type B"), S. boydii and S. dysenteriae (Safe Drinking Water Foundation, 2023). There are 40 different serotypes within the four Shigella species. One type of S. dysenteriae, called S. dysenteriae type 1, is responsible for many of the severe or fatal cases of shigellosis. Throughout the world, S. flexneri is the most common species of Shigella (Safe Drinking Water Foundation, 2023). According to the (New York State Department of Health, 2023) report, Shigellosis occurrence is common among people due to ingestion of contaminated food or water with the bacteria. There was presence of Shigella species in ground ($1.00x10^2$cfu/ml), surface water ($1.00x10^2$cfu/ml) and well $1.4x10^2$ for Abuloma, $2.1x10^4$cfu/ml surface water in Borikiri and surface water $1.1x10^4$cfu/ml for Eagle Island during the dry season. Albeit, $1.00x10^2$, $1.70x10^2$ and $1040x10^2$cfu/ml was found in ground, surface and well water in Abuloma, $2.50x10^4$cfu/ml in surface water in Borikiri; $1.70x10^4$ and $1.8x10^4$ cfu/ml in Eagle Island also indicated the high presence of shigella during the wet season. This signifies that users of ground and well water for human consumption within the study zone could possibly suffer from Shigellosis whenever there is paucity of water sanitation and treatment.

SUMARRY OF FINDINGS

1. The high concentration of total heterotrophic bacteria count (THB) in the various water bodies during the dry and wet season within the study period is likely to precipitate to the growth of harmful microorganisms that could affect the health of humans directly or indirectly.
2. Total heterotrophic bacteria concentration differs significantly with that of Fecal coliform bacteria mostly in the well water across season.
3. Heterotrophic bacteria count greater than five hundred (>500) in consumable water body is regarded as high concentration.
4. In the instance of increased staphylococcus species as observed in this study, there could be possible impact of staphylococcus infection on the health of the inhabitants who often utilized these water bodies inadvertently.
5. There could be possible Salmonellosis infection among vulnerable children who are unavoidably disposed to consuming such salmonella-contaminated water resources accidentally due to its increased concentration.
6. Dysentery, diarrhea, nausea, abdominal cramp among others may be common among water utilizers from the study area because of the presence of shigella that causes shigellosis.

IMPLICATIONS OF THE STUDY

1. Lack of effective water and environmental sanitation activities may have possibly enhanced and promoted the increase of fecal coliform (FCC) in various water bodies as revealed in this study.
2. The presence of various microorganisms like vibrio, staphylococcus, shigella and salmonella in this study could be as a result of poor sewage and solid waste management catalyzed by derelict regulation enforcement agency or officers within the study zone.
3. There is paucity of water (groundwater- borehole and well water) resource treatment before consumption was enhanced.
4. Most of the end-users of the water are unaware of the public heath implication of the presence of these microorganisms in the water bodies hence do not reason water treatment as a significant curbing measure.

CONTRIBUTION TO KNOWLEDGE

The study found out that there was a momentous correlation between water sources and micro-organisms distribution as there were higher concentration of THB, TCC and FCC respectively across seasons. The findings also revealed the presence of vibrio, salmonella, shigella and staphylococcus in water bodies seasonally, and thus could accentuate the health of end-users. These findings are original and contribute to the literature on the spatial and seasonal distribution of microorganisms in water bodies providing insights that can inform policies and practice for the improvement of water quality for human consumption and recreational activities Port Harcourt, Rivers State.

CONCLUSION

Water pollution due to the contamination from total heterotrophic and coliform bacteria has become a thoughtful problem because of their potentials for contracting diseases from pathogens. However, coliform bacteria are often denoted as "indicator organisms" for the reason that they point to the potential presence of disease-causing bacteria in water. The existence of coliform bacteria in water does not give the assurance that drinking the water will cause an illness but their presence indicates that a contamination alleyway exists between a source of bacteria conceivably surface water, septic system, animal waste, among others and the water supply. Users of these water resources could suffer from diarrhea, stomach cramp, nausea among others due to the presence of organisms such as shigella, salmonella and vibrio. Therefore, effective and efficient water purification phenomenon should be carried out before such water bodies are utilized for public or private consumption or recreational activities in a bid to reduce the associated health risk.

RECOMMENDATIONS

1. Water from the various resources should undergo treatment either by boiling or mechanical wise before consumption is enhanced by the public.
2. End-users of water resources should be sensitized and possibly educated on the implication of the presence of microorganisms in water bodies.
3. Agencies in-charge of enforcing water sanitation and waste management should be encouraged to be dutiful at all levels of their operation and where there is paucity, government should do the needful to employ fresh agencies to cushion the impact.
4. All boreholes should be treated periodically before dispensing for use.
5. All hand dug wells should be guided with parapet walls, precast concrete and must have a lid to prevent run-off, undue encroachment by animals and other vectors.
6. All consumable water should be treated before ingestion is facilitated and relevant agencies should step up action plan to ameliorate these deficiencies.

COMPETING INTEREST

Authors have declared that no competing interests exist

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