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Monitoring of Selected Groundwater Sources for Fecal Contamination Using Bacterial and Viral Fecal Pollution Markers

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Abstract

The availability of good drinking water is an important ingredient for preventing epidemic waterborne disease and improving the quality of life. This study investigated the concentration of fecal pollution markers in selected groundwater sources in Akure, Nigeria. This is to gain a better understanding of the level of fecal contamination and behavioural dynamics of fecal indicator bacteria (such as *E. coli*, fecal coliforms, intestinal enterococci, *Salmonella*, *Shigella*) and somatic coliphages (i.e., indicator of human enteric viruses) in the groundwater sources, especially for human health protection. Water samples (n=96) were collected from selected wells in Akure metropolis over a 12-week period. Bacterial indicators were determined using membrane filtration techniques, while somatic coliphages were determined using a standardized double-agar layer method. Physicochemical characteristics of the water samples were determined using standard method. Results revealed that the concentrations of *E. coli* ranged from 3.66 to 29.33CFU/100ml, fecal coliforms ranged from 2.33 to 44.60 CFU/100ml and enterococci ranged from 2.33 to 21.66CFU/100ml. For the first time, this study demonstrated the occurrence of somatic coliphages ranging from 1.00 to 12.00 PFU/100ml in water samples collected from the selected groundwater sources within Akure metropolis. The mean values of physicochemical characteristics of water samples from the groundwater sources over the period of study showed that mean water temperature ranged from 23.9 to 24.9°C, turbidity ranged from 18.6 to 19.9 NTU and salinity ranged from 21.7 to 23.5%. Pearson's rank correlation analysis revealed that there was a positive relationship between water temperature and levels of *E. coli* (r=0.83), somatic coliphages (r=0.75) and intestinal enterococci (r=0.68). The results from this study suggests that the level of fecal contamination, occurrence and behavioural dynamics of the targeted faecal indicator bacteria and somatic coliphages in the water samples collected from selected groundwater sources from different geographical zones in Akure, Nigeria are to a large extent influenced by physicochemical factors, inadequate maintenance of the water sources, close proximity to septic tank and probable percolation of sewage into the groundwater sources. The findings suggest that the groundwater sources were prone to fecal contaminations and may contain pathogenic enteric bacteria and viruses that may result to onward transmission of waterborne diseases, hence microbially unsafe for human consumption except treated.

Keywords

Groundwater, Fecal Contamination, Fecal Indicator Bacteria, Somatic Coliphages, Health Risk

1. Introduction

Nigeria represent the eight most populous nation in the world with a total population of over 180 million people. Out of which less than 30% of the population have access to potable drinking water and safe sources of water supply [1].

Oftentimes, the quality of water depreciates because of pollution from various organic and inorganic matters. The availability of good drinking water is an important ingredient for preventing epidemic waterborne disease and improving the quality of life [2]. The deterioration of water quality primarily involves microbiological hazards, since the majority of evident water-related health problems are as a result of microbial contamination [3]. The World Health Organization has estimated that up to 85% of all diseases (including diarrhoea, typhoid fever, dysentery etc.) occur as a result of microbially contaminated water, improper or inadequate sanitation and hygiene [2].

The source of water contamination responsible for the spread of infectious diseases is almost invariably feces [4]. The detection of *E. coli, Salmonella, Shigella*, or *Clostridium perfringens* and *S. faecalis* from water is a sufficient evidence that the water is not safe for use (such as drinking, crop irrigation, bathing etc.) except treated [5]. Globally, these group of microorganisms are acceptable as useful indicators of microbiological water quality, since they show a high and close relationship with health hazards associated with the water use, mainly for gastrointestinal symptoms and they are always present in feces of warm-blooded animals [6, 7]. Moreover, it has been reported that microbial contaminants in groundwater such as viruses and parasitic protozoa pose a significant human health problem to consumers when drinking water supplies are untreated or inadequately treated [8].

Bacteriophages are viruses that are dependent on a bacterial host for replication, and those infecting fecal indicator bacteria (FIB) or other commensal intestinal species (e.g. *Bacteroides*) are subsequently shed by hosts and follow similar routes of diffusion into the aquatic environment to that of enteric viral pathogens. Bacteriophages have similar morphological characteristics to those of many enteric pathogenic viruses suggesting that they can better mimic their survival [9, 10]. They are considered the most abundant form of life on earth and can be found in all environments where bacteria grow, including soil, water and inside other larger organisms (e.g., humans) harbouring host bacteria (e.g., *E. coli* WG5) [11, 12, 13]. Coliphages are generally found in the gut and are excreted in the feces of humans and other warm-blooded animals. They have been investigated for years as possible viral indicators of fecal contamination [14]. Coliphages can be divided into seven major morphological groups, or families; four of which contain somatic coliphages and three of which contain F-specific coliphages [15, 16]. Somatic coliphages are abundant group of bacteriophages in feces and encompass DNA bacteriophages that infect coliform bacteria, including *E. coli*, via the outer membrane. The bacteriophage families *Myoviridae*, *Siphoviridae*, *Podoviridae* and *Microviridae* have somatic coliphage representatives [17]. The detection of coliphagesin groundwater sources is an indication of fecal pollution, potential presence of enteric viruses and possibly other pathogens [18]. They are the most extensively studied phages for considerations as possible indicators of fecal pollution and surrogates for viral fate and transport [19, 20, 21] and are a part of multiple regulatory frameworks involving monitoring of groundwater [22, 23]. The ability of bacteriophages to survive under unfavorable conditions is highly diversified. It has been demonstrated that a number of external physicochemical factors, such as temperature and pH may influence the survival of and persistence of bacteriophages in groundwater [24, 25].

This study was aimed at determining the concentration of bacterial and viral fecal pollution markers in selected groundwater sources in Akure, Nigeria. This is to gain a better understanding of the level of fecal contamination and behavioural dynamics of fecal indicator bacteria (such as *E. coli*, fecal coliforms, intestinal enterococci, *Salmonella*, *Shigella*) and somatic coliphages (i.e., indicator of human enteric viruses) in the groundwater sources. The influence of physicochemical parameters (such as temperature, pH, salinity, turbidity etc.) on the bacterial and viral indicators were also examined. This is important since temporal variability in environmental conditions may affect the sanitary quality of water by influencing the survival and possible proliferation of microbial pathogens that may consequently be responsible for an infectious disease outbreak.

2. Materials and Methods

2.1. Description and Selection of the Study Area

Akure is a city in southwestern Nigeria and is the capital of Ondo State. The city has a human population of over eight hundred thousand (800,000). Akure is situated at 7°18'29.8"N and 7°12'46.5" N latitude, 5°07'34.6E and 5°15'38.5E longitude and 396 m elevation above the sea level (Figure 1).

2.2. Collection of Water Samples

Water samples were collected weekly over a period of twelve (12) weeks in the months of February, March and April, 2017. On each sampling occasion, water samples were collected in accordance with standard protocol [26] from two groundwater sources in each selected geographical location (i.e., north, south, east and west) within Akure metropolis and a total of 96 grab water samples were collected over the study period. The water samples were collected aseptically with sterile 800 ml screw-capped bottles labelled appropriately and transported in a cool box with ice packs to the laboratory within one hour for analysis.

2.3. Enumeration of Fecal Indicator Bacteria in Water Samples from the Groundwater Sources

The concentrations of *E. coli*, fecal coliforms and intestinal enterococci in the water samples were determined using the membrane filtration method (ISO 9308-1, ISO 7899-2) [27, 28]. The membrane filter was placed on membrane setup and about 100ml of water sample were filtered through. The membrane filters (model P1938) were placed on freshly prepared membrane laurylsulphate agar (MLSA), membrane fecalcoliform agar (m-FC) and membrane enterococci agar (m-Ent) and the plates were incubated at 37°C for 24 h (MLSA), 44°C for 24 h (m-FC) and 37°C for 48 h (m-Ent) and colonies were counted, calculated and expressed as colony-forming units (CFU) 100ml^{-1} of water. The concentrations of *Salmonella* and *Shigella*in the water samples were determined using pour plate techniques [29]. A tenfold serial dilution was made using sterile distilled water. One millilitre of the water sample was pipetted from dilution factor 1:100 using a sterile pipette and introduced into sterile disposable petri dishes. Thereafter, 20ml freshly prepared selective media; *Salmonella-Shigella* agar (SSA) was poured onto the petri dishes containing the samples. Agar plates were incubated at 37°C for 24-48h and colonies were counted, calculated and expressed as colony-forming units (CFU) 100 ml^{-1} of water.

2.4. Enumeration of Somatic Coliphages in Water Samples from the Groundwater Sources

The concentrations of somatic coliphages in the water samples were determined by direct plaque assay using a standardized double-agar method (ISO 10705) [30]. Approximately 50 ml of the water samples were filtered through a 0.22µm Millex-GP syringe filter (model Z359904). The required media – Modified Scholten's Agar (MSA), semi-solid Modified Scholten's Agar (ssMSA) and Modified Scholten's Broth (MSB) were prepared according to manufacturer's specification. Bacterial host strain (*E. coli* WG5) were grown to ensure confluent lawns for phage detection. One millilitre of sample (filtered water) was added to 1 ml of bacterial host strain and 2.5 ml of semi-solid agar in a 5ml vial. The mixture was vortexed and poured onto a solid agar plate, swirled gently for even distribution and allowed to solidify. All inoculated plates were incubated appropriately and plaques (clear zones of lysis) were counted and expressed as plaque-forming units (PFU) 100 ml^{-1} of water.

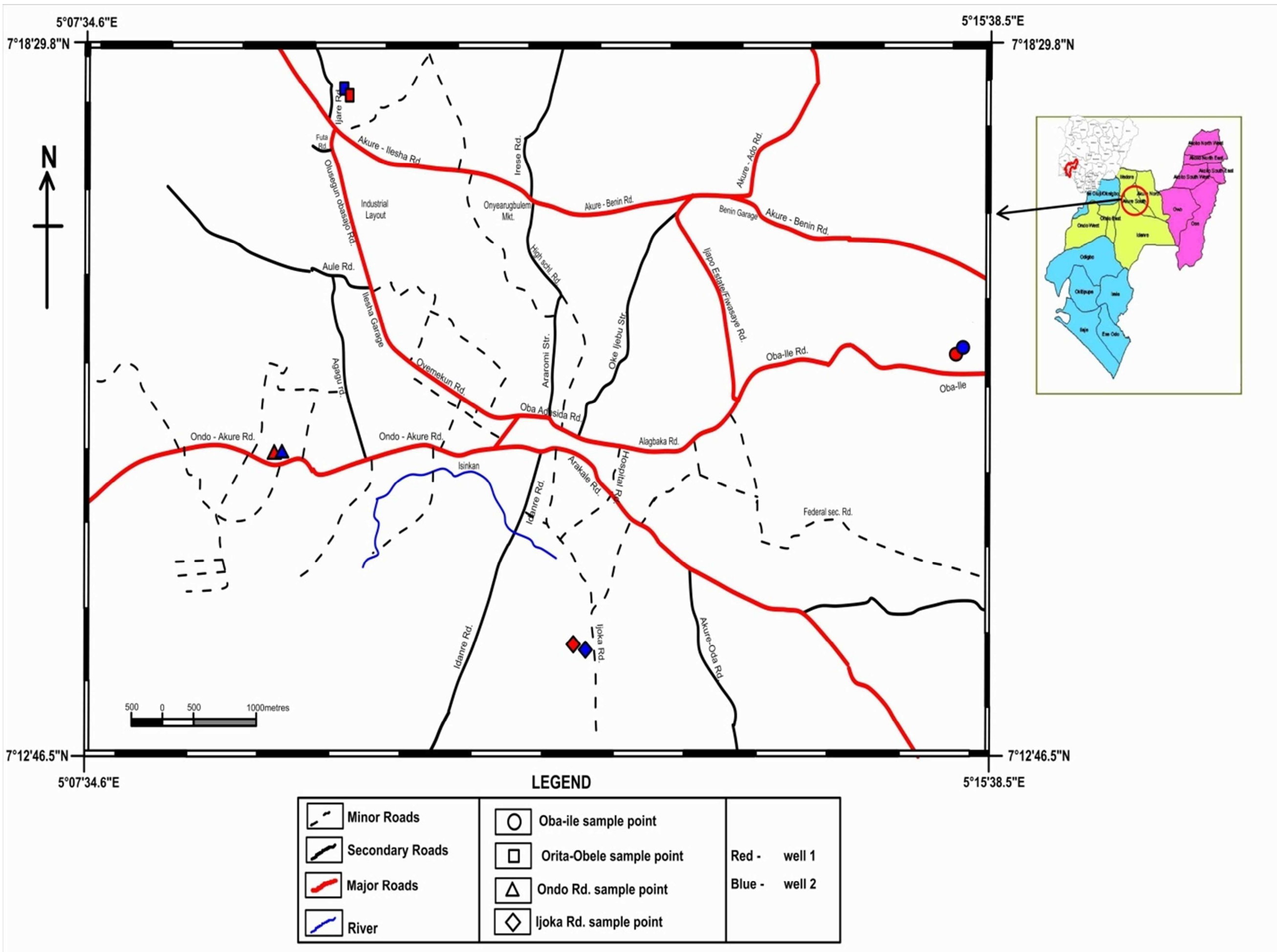

Figure 1. Map of Akure metropolis showing the study area.

2.5. Determination of Physicochemical Properties of Groundwater Samples

The physicochemical properties of the water samples were measured using standard methods [Anon. 2012]. Temperature (Celsius) and pH were determined on-site with the use of Hanna multimeter instrument (HI 98107). The salinity (percentage) of the water samples was determined using Hanna multimeter instrument (HI98203). The turbidity (nephelometric turbidity units) of the water samples was determined using Hanna multimeter instrument microprocessor with cuvette (HI93703). Total dissolved oxygen (milligrams per litre) and electrical conductivity (micro Siemens per centimetre) of the water samples were determined using Probe (Oakton instrument – CON510 series). Dissolved oxygen (milligrams per litre) of the water samples was determined using Hanna multimeter instrument (HI96732).

2.6. Statistical Analysis

The data obtained from this study were subjected to general descriptive statistics and presented as mean ±standard deviation (minimum-maximum). Analysis of variance and test of significance using Duncan's new multiple range test were undertaken using Statistical Package for Social Sciences (SPSS) Version 20.0, and all data were subjected to two – tailed Pearson's rank correlation analysis at two levels of significance ($P<0.01$ and $P<0.05$) representing 99% and 95% confidence interval respectively, to determine whether there were positive correlations between the concentration of the fecal pollution markers and physicochemical properties of the waters from the groundwater sources.

3. Results and Discussion

3.1. Detection of Fecal Indicator Bacteria in Water Samples from the Groundwater Sources

The potential presence of fecal pollution is typically assessed using fecal indicator bacteria (FIB) (e.g., fecal coliforms, *Escherichia coli* and enterococci) as a result of the difficulties associated with direct detection of pathogens in water [31, 32, 33]. The satisfaction of culture-based assessments of FIB for use in protecting public health, however, has limitation because they display different fate and transport characteristics within natural aquatic environments when compared to that of viral and protozoan pathogens [31, 34]. The mean concentration of *E. coli* in the water samples from the groundwater sources ranged from 3.66 ±1.52 CFU/100 ml (Orita Obele; sampling week 9) to 29.33 ± 14.3 CFU/100 ml (Oba Ile; sampling week 2). In general, the total concentration of *E. coli* in the water samples from the groundwater sources appeared to be highest (191.29 CFU/100 ml) in samples collected from Oba Ile and least (144.29 CFU/100 ml) in samples collected from Orita Obele over the period of study (Figure 2). The high concentration of *E. coli* in the water samples may be as a result of inadequate maintenance of the wells, close proximity to septic tank and probable percolation of sewage into the groundwater sources. It was observed that *E. coli* were predominant in all water samples from the groundwater sources indicating that human consumption of such fecally contaminated water without treatment may result to gastroenteritis. The result is in line with those obtained on studies of the bacteriological properties of water samples from groundwater sources in a selected market location in Ibadan, Nigeria, where the authors observed that *E. coli* was the major indicator bacteria isolated from the water samples [35]. The levels of *E. coli* in the water samples from the groundwater sources in this study do not conform with the guideline on the microbial quality of drinking water that stated that water meant for dinking must contain less than one *E. coli* CFU/100 ml [2].

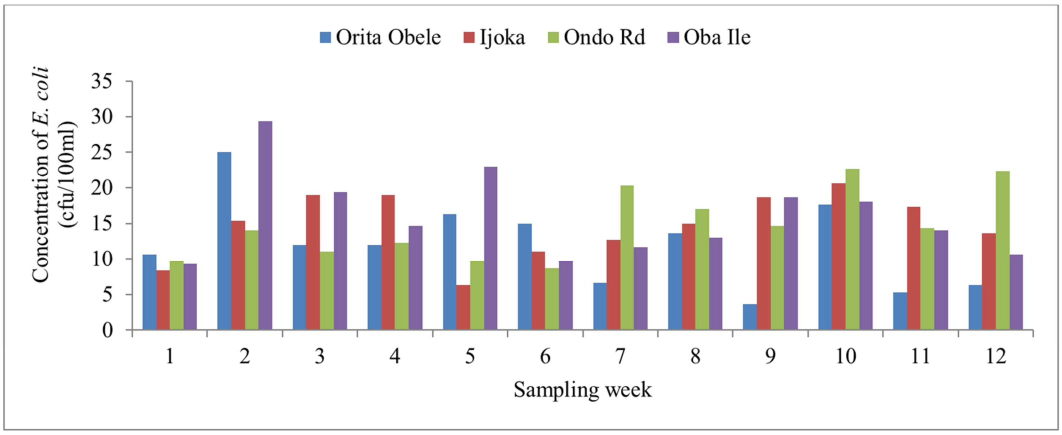

Figure 2. *Concentration of E. coli (CFU/100ml) in the groundwater samples.*

The levels of fecal coliforms in the water samples from the groundwater sources ranged from 2.23 ± 0.57 CFU/100 ml (Oba Ile; sampling week 12) to 44.60 ± 8.73 CFU/100 ml (Oba Ile; sampling week 1). The total concentration of fecal coliforms in the water samples from the groundwater sources appeared to be highest (192.23CFU/100 ml) in samples collected from Oba Ile and least (181.28 CFU/100 ml) in samples collected from Ondo Road over the period of study (Figure 3). Studies have shown that many groundwater sources in Nigeria are commonly contaminated with fecal coliforms [36, 37]. The high occurrence of fecal coliforms in the water samples from groundwater sources may be as a result of the construction of the wells near septic tank. This observation agrees with those obtained on studies on groundwater quality in Ogbomoso, Nigeria, where the authors stated that locating shallow wells at closed proximity to septic tanks, refuse dumps and the defecation of domestic animals around the vicinity of such wells may lead to fecal pollution of water from such sources and consumption of such water may lead to outbreak of waterborne diseases [37].

The levels of fecal coliforms in the water samples from the groundwater sources in this study were higher than the guideline on the microbial quality of drinking water that stated that water meant for dinking must contain less than one fecal coliforms CFU/100 ml [2].

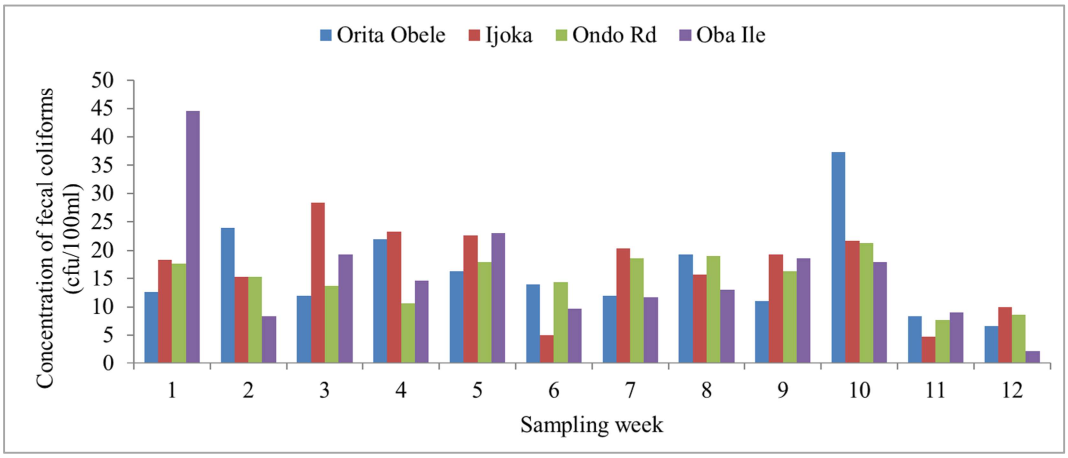

Figure 3. *Concentration of fecal coliforms (CFU/100ml) in the groundwater samples.*

The levels of intestinal enterococciin the water samples from the groundwater sources ranged from 2.33±2.30 CFU/100 ml (Orita Obele; sampling week 1 and 5) to 21.66 ± 4.04 CFU/100 ml (Ijoka; sampling week 10). The concentration of intestinal enterococci in the water samples from the groundwater sources appeared to be highest (172.96CFU/100ml) in samples collected from Ijoka and least (87.62 CFU/100ml) in samples collected from Orita Obele over the period of the study (Figure 4). Interestingly, studies have demonstrated that *Enterococcus* species such as *E. faecalis* and *E. faecium* are frequently found in human intestines, while certain species in the genus such as *E. mundtii* and *E. gallinarum* typically reside in non-human hosts [38, 39, 40, 41]. In this study, all the drinking water samples collected from the four geographical locations tested positive for intestinal enterococci. This result is in agreement with those obtained in microbial groundwater sampling protocol for fecal-rich environments, where the authors observed that the levels of enterococci in the monitoredwater samples were initially very highand later stabilized. The authors suggested that the high concentrations of enterococci may be as a result of the formation of biofilms, fecal contamination in the immediate surroundings, sewage leakage and contamination introduced while lowering the pump inside the groundwater [42]. The levels of enterococci in the water samples from groundwater sources in this study were higher than the guideline on the microbial quality of drinking water that stated that water meant for dinking must contain less than one enterococci CFU/100 ml [2].

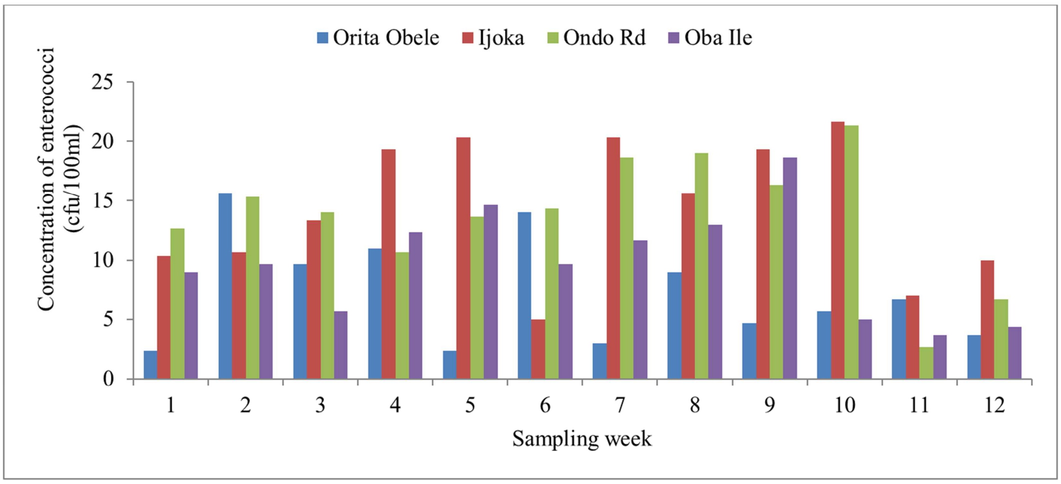

Figure 4. *Concentration of intestinal enterococci (CFU/100ml) in the groundwater samples.*

The concentration of *Salmonella*in the water samples from the groundwater sources ranged from 0.33 ± 0.57 CFU/100 ml (Orita Obele; sampling week 12) to 20.00 ± 12.01 CFU/100 ml (Ijoka; sampling week 5). The concentration of

Salmonella in the water samples from the groundwater sources appeared to be highest (131.64 CFU/100ml) in samples collected from Ijoka and least (63.28 CFU/100ml) in samples collected from Orita Obele over the period of the study (Figure 5). *Salmonella paratyphi* has been demonstrated to be the causative agent of paratyphoid fever, a mild form of enteric fever [43]. The main habitat of *Salmonella* is the intestinal and are excreted by humans, pets, farm animal and wild life. This pathogen has been reportedly detected in water as well as in contaminated groundwater and do not seem to multiply but they can survive several months in water if the conditions such as temperature and pH are favourable [44]. It was observed that some of the selected groundwater sources were uncovered and sited close to septic tank. Their shallowness may have contributed to the high concentration of *Salmonella* detected in the water samples. This result is in agreement with those obtained in groundwater samples in Sagamu, Nigeria, where the authors reported high levels of *Salmonella typhi* in the water samples [44]. The direct sources of this pathogen in water are fecal matter from infected people, sewage or agriculture pollution. Generally, groundwater used as drinking water sources in rural communities in Nigeria have been demonstrated to be reservoirs of *Salmonella*. Although, some authors suggested that the consumption of groundwater was an independent risk factor for a number of confirmed cases of *Salmonella* in Taiwan [45]. In Ibadan, Nigeria *Salmonella typhi* and *paratyphi* were detected in groundwater and the microbial water quality was observed to correlate positively with the pattern of waterborne disease in the selected areas [46].

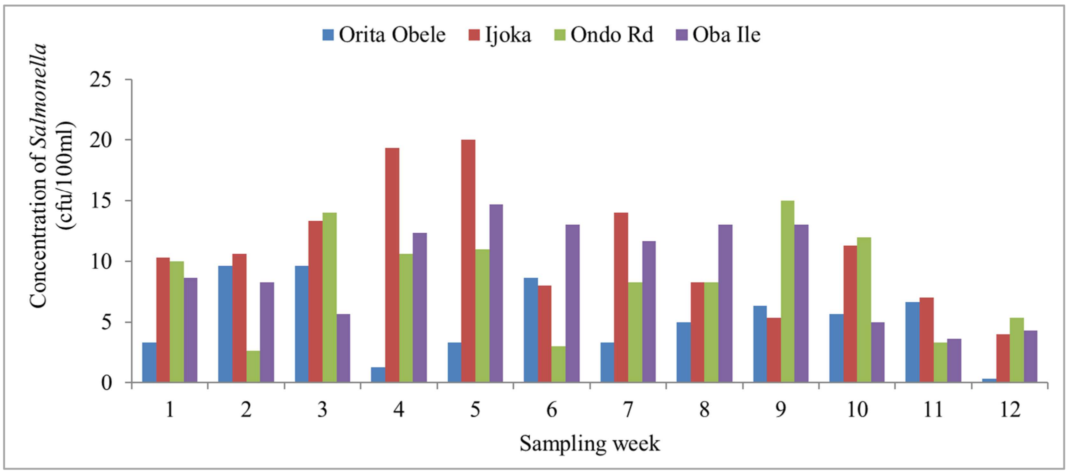

Figure 5. *Concentration of Salmonella (CFU/100ml) in the groundwater samples.*

The concentration of *Shigella* in the water samples from the groundwater sources ranged from 1.33 ± 1.52 CFU/100 ml (OritaObele; sampling week 4) to 15.00 ± 5.29 CFU/100 ml (Ondo Road; sampling week 9). The concentration of *Shigella*in the water samples from the groundwater sources appeared to be highest (118.3 CFU/100ml) in samples collected from Oba Ile and least (76.31 CFU/100ml) in samples collected from Ijoka (Figure 6). *Shigella* is another pathogen widely found in drinking water and incidences of shigellosis outbreak as a result of poor water quality have been reported throughout the world [2]. Results from this study revealed high levels of *Shigella* and this is in agreement with those obtained in studies onmicrobialquality of some selected shallow wells in Ogbomoso, South Western Nigeria, where the reported high levels of *Shigella* in the water samples [47]. The recovery of *Shigella* spp in groundwater samples from KanakkaryPanchayath, Kottayam District, Kerala State, Indiaalso demonstrated that groundwater sources prone to fecal pollution may contain high levels of *Shigella* [48].

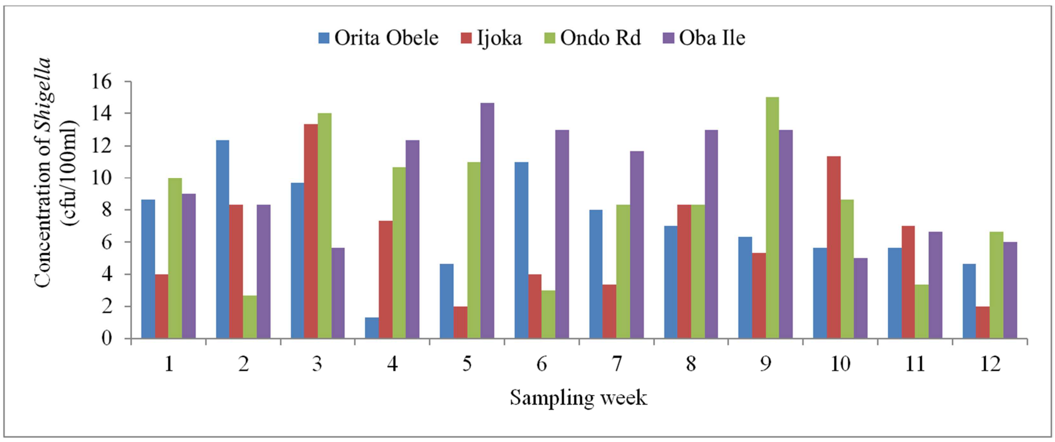

Figure 6. *Concentration of Shigella (CFU/100ml) in thegroundwater samples.*

3.2. Detection of Somatic Coliphages in Water Samples from the Groundwater Sources

The levels of somatic coliphagesin the water samples from the groundwater sources ranged from 1.00 ± 1.00 PFU/100 ml (Ondo Road; sampling week 2 and Oba Ile; sampling week 3 and 10) to 12.00±3.00 PFU/100 ml (Ondo Road; sampling week 4 and 5). However, not all thewater samples from the groundwater sources tested positive for somatic coliphages i.e., non-detect values were recorded on five sampling occasions in OritaObele, two sampling occasions in Ijoka, four sampling occasions in Ondo Road and eight sampling occasions in Oba Ile. In general, the concentration of somatic coliphagesin the water samples from the groundwater sources appeared to be highest (47 PFU/100ml) in samples collected from Ondo Road and least (4 PFU/100ml) in samples collected from Oba Ile (Figure 7). Studies have demonstrated that bacteriophages may be used as surrogates of enteric viruses because they demonstrate many characteristics that are similar to those of mammalian viral pathogens and cannot replicate without a metabolizing host bacteria [8, 49]. They are easier and cheaper to detect and enumerate than actual viral pathogens. They have been used as potential tools in microbial source tracking to distinguish sources of fecal pollution in water sources [38, 50, 51]. Somatic coliphages are the most abundant group of phages and they are shed in enormous quantities in the feces of humans and non-humans and have been shown to be potentially useful indicators of the presence of enteric viruses in aquatic environments [52, 53]. For instance, a study demonstrated that somatic coliphages provided a better indication of the risk of adenovirus contamination in overlying watersobtained from River Ouse, England than existing bacterial indicators [20]. Interestingly, there are limited information on the use of somatic coliphages to monitor the microbial quality of drinking water sources in Nigeria. For the first time, this study demonstrated the occurrence of somatic coliphages in water samples collected from selected groundwater sources in four geographical locations (i.e., north, south, east and west) within Akure metropolis. The detection of somatic coliphages in the water samples suggests the potential presence of enteric viruses in the groundwater sources.

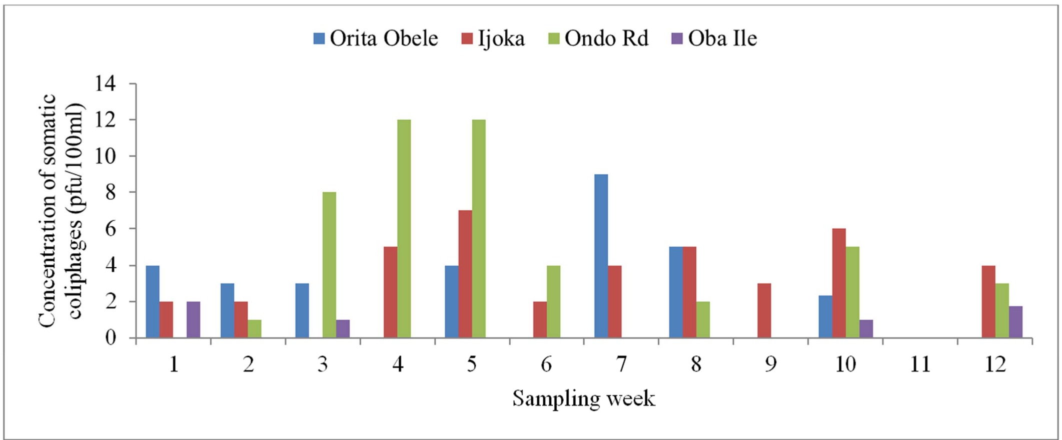

Figure 7. *Concentration of somatic coliphages (PFU/100ml) in thegroundwater samples.*

3.3. Relationship Between Observed Physicochemical Characteristics, Fecal Indicator Bacteria and somatic Coliphages in Water Samples from Selected Groundwater Sources

The mean values of physicochemical characteristics of water samples from the groundwater sources over the period of study showed that mean water temperature ranged from 23.9 to 24.9°C, pH ranged from 6.6 to 6.8, electrical conductivity ranged from 122.9 to 123.9 μm/cm, turbidity ranged from 18.6 to 19.9 NTU, salinity ranged from 21.7 to 23.5%, total dissolved oxygen ranged from 25.8 to 31.0 mg/l and dissolved oxygen ranged from 6.8 to 7.0 mg/l (Table 1).

The relationship between observed physicochemical characteristics and fecal pollution markers in water samples from the groundwater sources were analyzed using a two – tailed Pearson's rank correlation at two levels of significance ($P<0.01$ and $P<0.05$) representing 99% and 95% confidence interval respectively. The Pearson's rank correlation revealed that water temperature correlated positively with *E. coli* (r=0.83) and somatic coliphages (r=0.75). Electrical conductivity correlated positively with *Salmonella* (r=0.71) and fecal coliforms (r=0.75). Salinity showed positive correlation with *E. coli* (r=0.87) and somatic coliphages (r=0.77). Total dissolved solids also correlated positively with *E. coli* (r=0.68) and intestinal enterococci (r=0.71). Dissolved oxygen correlated positively with somatic coliphages (r=0.82) and fecal coliforms (r=0.76). Turbidity showed positive correlation with intestinal enterococci (r=0.72) and somatic coliphages (r=0.65) (Table 2). The sanitary quality of water may be affected by temporal variability in environmental conditions thus, influencing the survival and possible proliferation of microbial pathogens that may consequently be responsible for an infectious disease outbreak. Globally, fecal indicator bacteria are widely acceptable as useful indicators of fecal pollution of water sources and somatic coliphages have also been proposed and used as surrogates of enteric viruses in water matrices [20, 21, 31, 49]. In this study, the ways in which physicochemical parameters (such as temperature, pH, salinity, turbidity etc.) influence the survival of fecal indicator bacteria and potential indicator of enteric viruses in the water samples collected from selected groundwater sources in four geographical locations within Akure metropolis were investigated. Water temperature correlated positively with the levels of *E. coli*, fecal coliforms, intestinal enterococci, *Salmonella*, *Shigella* and somatic coliphages. This observation is contrary to many studies that have demonstrated that water temperature is related to solar radiation levels and a major factor influencing the inactivation of enteric bacteria [54, 55] and enteric viruses [23, 56]. This observation may likely be due to the fact that most of the groundwater sources were covered thus, shielding the enteric bacteria and somatic coliphages from direct solar radiation. Similarly, salinity showed a positive correlation with levels of fecal indicator bacteria and somatic coliphages. Again, this observation is not in agreement with studies that have shown that salinity have a negative effect on enteric bacteria and viruses [55, 57]. The results obtained in this study showed that the degree of turbidity, total dissolved solids and electrical conductivity of the water samples from the groundwater sources influenced positively the levels of *E. coli*, intestinal enterococci and somatic coliphages in the water samples. This is in agreement with studies that have shown that the level of colloidal matter to which microbes are able to attach is directly related with the abundance of enteric bacteria and viruses in water matrices [58, 59]. The values of pH showed no relationship with the levels of fecal indicator bacteria and somatic coliphages in the water samples. As would be expected, dissolved oxygen correlated positively with levels of fecal indicator bacteria and somatic coliphages. This may likely be as a result of the oxygen requirement for growth and proliferation of the bacterial and viral indicators.

Table 1. *Physicochemical characteristics of underground water samples from four geographical locations in Akure metropolis over the period of study.*

Parameters	OritaObele	Ijoka	Ondo Road	Oba-Ile
Temp (°C)	24.3±1.7 (19.0-26.5)	24.9±2.4 (19.0-29.0)	23.9±1.0 (21.5-26.0)	24.3±1.0 (21.6-27.0)
pH	6.6±0.4 (5.9-7.7)	6.8±0.1 (6.5-7.1)	6.8±0.2 (6.0-7.1)	6.8±0.2 (6.0-7.3)
EC (µs/cm)	123.1±2.8 (118.5-129.0)	122.9±3.4 (119.0-128.0)	123.7±2.1 (120.0-128.0)	123.9±1.9 (120.0-128.5)
Turb (NTU)	18.6±3.1 (12.5-23.5)	19.9±1.9 (16.0-23.5)	19.7±0.9 (17.0-22.0)	19.9±1.1 (18.0-27.5)
Salinity (%)	23.5±3.3 (16-29.2)	23±3.3 (17.0-28.0)	22.4±2.5 (19.0-26.0)	21.7±2.0 (18.5-27.5)
TDS (mg/l)	28.0±7.3 (18-44)	31.0±8.4 (20.5-44.0)	30.1±9.0 (20.0-44.0)	25.8±5.6 (20.0-44.0)
DO (mg/l)	6.9±0.5 (5.6-8.1)	6.8±0.5 (5.5-7.8)	7.0±0.4 (6.0-7.7)	6.9±0.3 (6.5-7.7)

Keys: Values presented are expressed as mean values ± standard deviation (minimum-maximum) (n=24). Temp – Temperature; EC – Electrical conductivity; Turb – Turbidity; TDS – Total dissolved solids; DO –Dissolved oxygen. Bold signifies least and highest values for each parameter.

Table 2. *Significant Pearson's rank correlation between observed physicochemical parameters and fecal indicator bacteria in water samples from selected groundwater sources in Akure metropolis.*

Parameters	*E. coli*	*Salmonella*	*Shigella*	Enterococci	Fecal coliforms	Somatic coliphage
Temp (°C)	0.83**	0.57*	0.55*	0.68*	0.58*	0.75**
pH	0.37	0.32	0.34	0.25	0.35	0.34
EC (µs/cm)	0.91**	0.71**	0.70**	0.87**	0.75**	0.85**
Salinity (%)	0.87**	0.50*	0.47	0.80**	0.53*	0.77**
TDS (mg/l)	0.68*	0.29	0.26	0.71**	0.28	0.57**
DO (mg/l)	0.89**	0.74**	0.72**	0.78**	0.76**	0.82**
Turb (NTU)	0.75**	0.59*	0.59*	0.72**	0.60*	0.65*

Key: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed), (n=96). Temp – Temperature; EC – Electrical conductivity; Turb – Turbidity; TDS – Total dissolved solids; DO –Dissolved oxygen. Bold signifies positive correlation.

4. Conclusion

The results from this study suggests that the level of fecal contamination, occurrence and behavioural dynamics of *E. coli*, fecal coliforms, intestinal enterococci, *Salmonella, Shigella* and somatic coliphages in water samples collected from selected groundwater sources from different geographical zones in Akure, Nigeria are to a large extent influenced by physicochemical factors, inadequate maintenance of the water sources, close proximity to septic tank and probable percolation of sewage into the groundwater sources. The findings suggest that the groundwater sources were prone to fecal contaminations and may contain pathogenic enteric bacteria and viruses that may result to onward transmission of waterborne diseases, hence microbially unsafe for human consumption except treated.

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