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Bacteriological and Physicochemical Quality of Mono-pumps and Boreholes used as Sources of Domestic Water Supply in Abonnema Rivers State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This study was carried out to compare the bacteriological and physicochemical qualities of boreholes and mono-pumps water samples used as sources of domestic water supply, in Abonnema Community, Akuku-Toru Local Government Area, Rivers State.

Methodology: A total of forty-eight water samples were collected twice monthly for four months and evaluated. The bacteriological parameters such as total heterotrophic bacterial, total coliform, faecal coliform, *Vibrio*, *Salmonella - Shigella* and *Pseudomonas* were analyzed using standard microbiological methods. The coliform was determined using the Most Probable number technique while, the physicochemical parameters were determined using Standard methods for the examination of water and wastewater.

Results: The total heterotrophic bacterial, *coliform*, faecal coliform, *Vibrio*, *Salmonella-Shigella* and *Pseudomonas* counts of the borehole samples ranged from 7.2×10^2 - 2.4×10^3, 2.3×10^2–4.0×10^2, 3.6×10^2-4.8×10^2, 7.3×10^2-1.4×10^3, 2.1×10^2-2.8×10^2 and 0.0×10^0Cfu/ml, respectively. The total heterotrophic bacterial counts, coliform counts, faecal coliform counts, *Vibrio* counts, *Salmonella-Shigella* counts and *Pseudomonas* counts for the mono-pump samples ranged from: 1.1×10^3-

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1.8×10^3, 2.0×10^2– 9.1×10^2, 2.4×10^2- 3.8×10^2, 4.5×10^2-8.6×10^2, 1.4×10^2 - 4.2×10^2 and 0.0×10^0Cfu/ml, respectively. The bacterial genera identified were: *Bacillus, Lynsinibacillus, Staphylococcus, Vibrio, Serratia, Enterobacter*, *Klebsiella, Shigella, Salmonella, Paenibacillus, Aeromonas* and *Geobacillus*. The means of physicochemical parameters for borehole and mono-pump, respectively were: alkalinity: 41.72±0.01-60.85±0.20 and 29.14±0.01-214.87±1.36mg/l; BOD: 8.26±0.01-10.44±0.0 and 5.12±0.01-5.79±0.01; COD: 126.52±0.01-172.41±0.04 and 83.20±0.44-218.00±0.57; DO: 6.31±0.01 and 3.05±0.07-8.29±0.01; calcium: 5.10±0.28-; 4.83±0.00-10.15±0.00 and 2.71±0.00-14.04±0.00; iron: 2.01±0.00-3.37±0.00 and 1.90±0.00-4.73±0.00; lead: 0.38±0.00-1.07±0.00 and 1.24±0.00-1.63±0.00; nitrate: 0.42±0.00-1.08±0.00 and 1.14±0.00-1.75±0.00; zinc:1.10±0.00-3.18±0.00 and 0.39±0.00-1.82±0.00; phosphate: 0.03±0.00-0.13±0.00 and 0.15±0.00-0.87±0.00; pH: 6.54±0.00-7.05±0.07 and 6.29±0.00-6.93±0.01; salinity: 4.02±0.00-5.14±0.00 and 2.83±0.00-5.88±0.00; total organic carbon: 1.39±0.01-2.81±0.010 and 1.64±0.00-3.42±0.01; polycyclic aromatic hydrocarbon: 32.69±0.00-55.73±0.00 and 45.10±0.00-61.49±0.00mg/l; total petroleum hydrocarbon:58.90±0.00-66.15±0.00 and 60.31±0.00-92.11±0.00 mg/l.

Conclusion: The high counts of bacterial groups of public health importance identified from this study, including the presence of: COD, DO, Fe, Pb, Phosphate, Zinc, TPH and PAH in high concentrations reveals contamination of the water sources. Thus, treatment before drinking is recommended.

Keywords: Bacteriological; coliforms; boreholes; mono-pumps; physicochemical quality.

1. INTRODUCTION

The importance of water to the existence of life is continually endangered due to the increase in anthropogenic activities and the call for good water quality [1]. According to previous studies, natural activities including anthropogenic activities determines the water quality whether it is surface or ground water [2]. These man-made activities such as pit-latrine, soak away pits, indiscriminate disposal of refuse, underground storage tanks for chemicals and petroleum products, the use of fertilizers, pesticides and herbicides can directly or indirectly introduce these substances into groundwater that could impact on its quality [1,2]. Water is used for various activities such as agriculture, domestic activities, recreation, transportation and other activities. Despite the fact that about seventy percent of the earth is occupied by water, only about 0.3 % of it is available for human use [3]. Water pollution is the introduction of substances into the water body which generally renders or makes the water not suitable for a particular purpose. According to Obire and Alali [4], contamination of water could also be possible when wells are dug very close to septic tanks and that floods which carries different contaminants from different regions could contaminate drinking water.

Tube well water also known as mono-pump is a drinking water source that is made with a hand suction pump which is of cast iron and has a small diameter [5]. The tube well is constructed with a long iron handle which is used in forcing water out of the ground by the lifting of the handle up and bringing it down. While borehole is a hydraulic structure which when correctly built allows the flow of water from the underground [6]. These boreholes are dependent on electricity to aid in pumping water out of the aquifer. According to WHO [7], microbial pollution or the presence of microorganisms in drinking water pose greater risk to the persons who consume the water. This implies that pathogenic microorganisms in the effluents or feacal materials could cause serious illness to consumers of such water bodies. According to Obire and Osigwe [8], the most serious hazard to the general wellbeing from microorganisms in water is related with utilization of drinking-water that is sullied with human and animal excreta.Water supply in Abonnema is of groundwater source (hand-dug well, mono- pump and borehole). Rain falls and hand-dug wells and have been the major sources of domestic water supply in this zone before the advent of borehole and mono-pump. These groundwater sources have been installed in Abonnema at various depths depending on the availability and level of groundwater table with or without tight casing, cover or elevation from ground level [9]. In many cases, immediate environmental conditions are unfavourable; for instance, proximity of wells from latrines, the effects of oil, defecating in the nearby bushes, exploitation and exploration in the area coupled with the direct sewage – contamination of natural water bodies due to the cultural habit of defecating inside rivers, practiced in Niger Delta Regions of Nigeria have contributed greatly to water pollution [9]. This study was carried out to evaluate the bacteriological and physicochemical qualities of these water sources.

2. MATERIALS AND METHODS

2.1 Study Area

The area under study is Abonnema, a community situated in Akuku - Toru Local Government Area of Rivers State in the Niger Delta region of Nigeria. The coordinates are situated between latitude 40^{o} 43′ and 40^{o} 45′ North of Equator and between longitude 7^{o} 7′ and 7^{o} 12′ East of the Greenwich Meridian in DMS (Degrees Minutes Seconds). The most predominant activity of people from this region is fishing since the area has a large area of land covered with water. The men are mostly fishermen while their women and others who do not fish, partake in buying and selling activities of fishes, fishing net, hooks, nylons and other trading activities [10].

2.2 Collection of Water Samples

Forty-eight water samples (24 each of boreholes and mono-pumps) were collected randomly in sterile bottles from Abonnema community in Akuku-Toru Local Government Area of Rivers State. The boreholes were designated boreholes 1, 2 and 3 while mono-pumps were designated: mono-pumps 1, 2 and 3 respectively. The water samples were collected twice from the three different mono-pumps and boreholes monthly for four months (May to August, 2019). Table 1 show the coordinates of the locations where the water samples were collected. Both boreholes and mono-pumps were allowed to run for three minutes before sterile bottles were placed under the flowing (running) water [11]. Prior to the collection of samples, the mouth of both boreholes and mono-pumps were disinfected with Sodium Hypochlorite (NaOCl) and neutralized with Sodium Thiosulphate ($Na_2S_2O_3$) so as to get rid of any possible contaminants. Samples were collected at the areas were the local inhabitants usually fetched their water. Samples were properly labeled and transported in an ice packed box and immediately carried to the Microbiology Laboratory of Rivers State University for investigation.

2.3 Bacteriological Quality Determination

This was done using a tenfold serial dilution as described by Prescott et al. [12].Using sterile physiological saline, 1ml of each sample was dispersed into 9ml, shaken to mix properly, which gave the initial 10^{-1} dilution. This was then diluted to 10^{-4}, then 0.1ml aliquot from 10^{-2} to 10^{-4} were inoculated and spread of on the various agar using spread plate method. The plates were incubated in an inverted position at $37^{o}C$ for 24hours. Colonies that emerged were counted and colony forming unit per ml calculated. Colonies were sub-cultured to obtain pure cultures which were stored for further test. Nutrient agar medium was used for the enumeration of total heterotrophic bacteria. Total Coliform was determined using the Most Probable number technique, MacConkey broth was used and positive results were indicated by acid and gas production on incubation at $37^{o}C$ for 48 hours, *Vibrio* was determined using Thiosulfate-citrate-bile salts sucrose agar, faecal coliform was determined using Eosin Methylene Blue medium, *Salmonella* and *Shigella* were determined using *Salmonella*-*Shigella* agar, *Pseudomonas* were determined using Cetrimide agar.

2.4 Identification and Characterization of the Isolates

This was done based on the cultural, morphological and biochemical characteristics of the various isolates obtained. The biochemical tests carried out for the identification and characterization of the isolates include: Gram staining, sugar fermentation tests, oxidase, indole, methyl red, Voges Proskauer, citrate utilization, motility, catalase, starch hydrolysis, and coagulase test [13].

Table 1. Coordinates of the sampling locations

Water Sources	Compounds	Coordinates
M1	Membere's	4.747^{0} N, 6.767^{0} E
M2	Jack's	4.728^{0} N, 6.773^{0} E
M3	Granville's	4.731^{0} N, 6.776^{0} E
B1	Membere's	4.747^{0} N, 6.767^{0} E
B2	Jack's	4.728^{0} N, 6.773^{0} E
B3	Granville's	4.736^{0} N, 6.775^{0} E

2.5 Physicochemical Parameters

The temperature readings of the water samples were determined in the field using mercury in glass thermometer graduated in centigrade (^oC) and this was recorded at the point of sample collection. The other physicochemical parameters were analyzed in the laboratory using the methods described by APHA [14], and they include: Alkalinity, Biological Oxygen Demand (BOD), Calcium Carbonate ($CaCO_3$), Chemical Oxygen Demand (COD), Dissolve Oxygen (DO), Iron, Nitrate concentration (NO_3-N), Lead, pH, Phosphate, Salinity, pH, Total Organic Carbon (TOC), Turbidity, Zinc, Polycyclic Aromatic Hydrocarbon (PAHs) and Total Petroleum Hydrocarbon (TPH).

3. RESULTS

Results of the Total Heterotrophic bacterial counts for boreholes and mono-pumps ranged from 7.2×10^2±0.40 to 2.4×10^3±0.33 and 1.1×10^3±0.33 to 1.8×10^3±0.31Cfu/ml, respectively. Total coliforms ranged from 2.3×10^2±1.08 to 4.0×10^2±1.20 Cfu/ml in Boreholes and ranged from 2.0 $\times10^2$ ±1.23 to 9.1 × 10^2 ±1.41 Cfu/ml in Mono- pumps, *Vibrio* counts ranged from 3.6 $\times10^2$ ±1.23 to 4.8 × 10^2 ±1.02 Cfu/ml in boreholes and ranged from 2.4 $\times10^2$ ±1.08 to 3.8 × 10^2 ±1.22 Cfu/ml in Mono – pumps. Faecal coliform counts ranged from 7.3 $\times10^2$ ±1.38 to 1.4 × 10^3±0.48 Cfu/ml in boreholes and ranged from 4.5 $\times10^2$ ±0.39 to 8.3 × 10^2 ±0.42 Cfu/ml in Mono- pumps. *Salmonella/Shigella* counts ranged from 2.1×10^2 ±1.27 to 2.8×10^2 ±1.29 Cfu/ml in boreholes and ranged from 1.4×10^2±1.15 to 4.2×10^2±1.51 Cfu/ml in Mono- pumps while *Pseudomonas* had no counts.

Table 2 has the results of the most probable number of mono-pumps which ranged from 6 to 350 cfu/100ml in boreholes and 6 to 1600 cfu/100ml in mono- pumps.

The results of the Physicochemical Parameters are presented in Table 3.

Table 3 shows that results of Alkalinity ranged from 41.72±0.01 to 60.85±0.20mg/l for boreholes and 29.14±0.01 to 214.87±1.36mg/l for mono-pumps. BOD ranges were from 8.26±0.01 to 10.44±0.01mg/l for boreholes and 5.12±0.01 to 5.79±0.01mg/l in mono-pumps. Chemical oxygen demand ranges from 126.52±0.01 to 172.41±0.04mg/l in boreholes and 83.20±0.44 to 218.00±0.57mg/l in mono-pumps. Dissolved oxygen ranges from 5.10±0.28 to 6.31±0.01mg/l in boreholes and 3.05±0.07 to 8.29±0.01mg/l in mono-pumps. Calcium ranged from 4.83±0.00 to 10.15±0.00mg/l in boreholes and 2.71±0.00 to 14.04±0.00 mg/l in mono-pumps, Iron ranged from 2.01±0.00 to 3.37±0.00 mg/l in boreholes and 1.90±0.00 to 4.73±0.00mg/l in mono-pumps, Lead ranged from 0.38±0.00 to 1.07±0.00mg/l in boreholes and 1.24±0.00 to1.63±0.00mg/l in mono-pumps, Nitrate ranged from 0.42±0.00 to 1.08±0.00mg/l in boreholes and 1.14±0.00 to 1.75±0.00mg/l in mono-pumps, Zinc ranged from1.10±0.00 to 3.18±0.00mg/l in boreholes and 0.39±0.00 to 1.82±0.00mg/l in mono-pumps, Phosphate ranged from 0.03±0.00 to 0.13±0.00mg/l in boreholes and 0.15±0.00 to 0.87±0.00 mg/l in mono-pumps. pH ranged from 6.54±0.00 to 7.05±0.07mg/l in boreholes and 6.29±0.00 to 6.93±0.01 mg/l in mono-pumps, Salinity ranged from 4.02±0.00 to 5.14±0.00mg/l in boreholes and 2.83±0.00 to 5.88±0.00 mg/l in mono-pumps, Temperature ranged from 26.20±0.00 to 29.35±0.07mg/l in boreholes and 27.50±0.00mg/l to 29.35±0.07 mg/l in mono-pumps, turbidity ranged from 0.03±0.00mg/l to 0.08±0.00mg/l in boreholes and 0.03±0.00 to 0.12±0.00 mg/l in mono-pumps. TOC ranged from 1.39±0.01 to 2.81±0.0.10mg/l in boreholes and 1.64±0.00 to 3.42±0.01 mg/l in mono-pumps, polycyclic aromatic hydrocarbons ranged from 32.69±0.00 to 55.73±0.00mg/l in boreholes and 45.10±0.00 to 61.49±0.00 mg/l in mono-pumps while total petroleum hydrocarbon ranged from 58.90±0.00 to 66.15±0.00mg/l in boreholes and 60.31±0.00 to 92.11±0.00 mg/l in mono-pumps.

4. DISCUSSION

The results of the microbiological analysis revealed that the mono-pump water sources had higher heterotrophic bacterial counts than the borehole samples. Despite this observed difference, the THB of both sources are grossly above the NSDWQ [15] stipulated limit of 1.0 x 10^2 Cfu/ml. The high total heterotrophic bacterial counts are an indication of high organic and dissolved salts in water [16]. The primary sources of these bacteria are animal and human wastes. Water with low microbial population is as a result of purification of the soil as dissolved organic matter and pathogenic microorganisms are removed from water during subsurface passage through adsorption and trapping by fine sandy materials, organic matter and clay [17]. Okoro et al. [18] recorded high heterotrophic bacterial counts of 1.7×10^2 to 3.0×10^4 Cfu/ml in Borehole Water Sources in Nsukka Urban Area, Enugu State, Nigeria. Uzoigwe and Agwa [19] also recorded a high heterotrophic bacterial count of 3.1×10^5 to 6.6×10^5 Cfu/ml in Borehole Water Sources in Port Harcourt. Douglas and Isor [20] also recorded high total heterotrophic bacterial counts which had a range of 1.7×10^5 to 6.5×10^7 Cfu/ml in pond water located in Ogoni land, Nigeria. The total heterotrophic bacterial counts in boreholes were significantly different from that of mono-pumps at ($P \geq 0.05$) and this has also been reported by Wokem and Lawson-Jack [9]. Microorganisms are ubiquitous in nature and so having this handful population of heterotrophic organisms in water was not strange at all [12].

Similarly, the ranges of total coliform counts in the mono-pump water sources were higher than those obtained from the borehole water sources. Also, both water sources do not comply with the WHO standard of total coliform of 10Cfu/ml for potable water. The *Vibrio* counts of the boreholes were higher than the counts obtained from the mono-pump water sources and both sources exceeded the WHO standard of 0Cfu/100ml for potable water. Uzoigwe and Agwa [19] also recorded a high *Vibrio* count of 2.5×10^2 to 3.5×10^2 Cfu/ml in Borehole Water Sources in Port Harcourt. The faecal coliforms counts of the boreholes were higher than those obtained from Mono-pumps and both sources do not comply with the WHO standard of 0Cfu/100ml faecal coliform in drinking water. Uzoigwe and Agwa [19] also recorded high faecal counts of 2.1×10^2 to 4.5×10^2 Cfu/ml in Borehole Water Sources in Port Harcourt. High coliform counts indicate the occurrence of faecal contamination.

The *Salmonella/Shigella* counts were higher in the mono-pump water sources than in the borehole water sources. The MPN values of mono-pumps had a range from 6 to 350 MPN Index/100ml in boreholes and 6 to 1600 Cfu/100ml in mono- pumps. Similar results were obtained by Okafor et al. [21] that recorded MPN values ranging from 140 to 1600 MPN Index/100ml while Ayandele et al. [22] recorded MPN results of 49 to1600 MPN Index/100ml. Increase in bacteria is as a result of high organic matter in the water. The presence, type and volume of microbial populations in water often times serves as indicators for pollution. Microbial contaminants make water unhealthy for several purposes [23]. There is generally an acceptable limit for microbial population that can be tolerated. Basically, the maximum permitted levels for microbiological requirements are total coliform count of ten (10), thermo tolerant coliform or *E. coli*, faecal *streptococcus* and *Aeromonas* zero [15]. Following closely, other microbial population as reported in the Table 1, the population of total coliform, *Vibrio* counts, total faecal coliform, and *Salmonella/Shigella* were statistically correlating as these microbes were counted in all the water samples.

The isolates from the water samples identified include the following genera: *Bacillus, Lynsinibacillus, Staphylococcus, Vibrio, Serratia, Enterobacter*, *Klebsiella*, *Shigella, Salmonella, Paenibacillus, Aeromonas* and *Geobacillus.* Onuorah et al. [24] isolated *Klebsiella, Vibrio, Enterobacter, Staphylococcus* and *Salmonella* spp from the borehole water they examined in Ogbaru Community, Anambra State, Nigeria while Abdullahi et al. [25] isolated *Klebsiella and Salmonella* spp from the Staff school, Science Department and female hostel boreholes in Niger State Polytechnic, Zungeru campus.

The implications of these results are that, mono-pumps and boreholes samples contain high degree of microbial populations and since individuals in the community solely depended on these water sources for drinking and other functions, there could be possible disease outbreak sooner or later as long as these water sources are not treated. *Vibrio* spp is implicated in cholera and gastroenteritis. *Salmonella* causes typhoid fever and other salmonellosis. *Escherichia coli* cause acute diarrhea and gastroenteritis [23]. *Bacillus* spp which were also identified in both mono-pump and boreholes samples. *Bacillus* spp are still found in water that has gone through a form of treatment due to their ability to form spores. The presence of these organisms is indicative of the level of personal hygiene and sanitary conditions of the environment.

It has been reported that in most part of Benin and Port Harcourt, which are in Niger Delta Region of Nigeria that public boreholes and mono-pumps are sited without proper geological surveys [1]. Where waste disposal pits as well as septic tanks, soak away pits and pit latrines and flowing streams of water laden with faeces were located which is also typical of the sampling area. This practice is highly condemnable and must be discouraged. This must have been the reason for the record of faecal contamination of the ground waters as evidenced in this research. Moreover, the cultural habit of using open water latrines in the riverine communities of Rivers State may also have a significant role to play as long as oral-faecal route of transmission of pathogens and water borne diseases are concerned.

The results of Alkalinity revealed that B1, B2, M2, B3 and M3 were all within the WHO limit of 200mg/l except for M1 which has a value above the WHO limit. Wokem and Lawson-Jack [9] recorded alkalinity values of 65.20±30.2mg/l to 74.10±28.30mg/l in borehole water which was also within the WHO limit. Alkaline water has been proven to have some health benefits as it aids calcium retention thereby improving bone health [26]. Alkalinity in water is due to the presence of bicarbonates, carbonates and hydroxides of calcium, sodium and potassium. Alkaline plays an important role in neutralizing the acidity of water which increases with dissolved carbon dioxide [27]. Alkalinity measures the capacity of water to resist a change in pH that would tend to make the water more acidic.

Results of pH revealed that all the water samples were within the WHO [7] and SON [28] acceptable limit of 6.5 to 8.5mg/l. Measuring alkalinity and pH values of potable water is vital so as to determine the corrosivity of the water. Water with a low pH (<6.5) as seen in mono-pump 2 could be acidic, soft and corrosive. Hence, it could leach metal ions such as iron, manganese, copper, lead, and zinc from aquifer, plumbing fixtures and piping and have associated aesthetic problems such as metallic or sour taste, staining of laundry and the characteristic "blue-green" staining of sinks and drains [7]. Water that is acidic has been identified to cause damage to cells of the mucous membrane, eye and skin irritation. Water with a pH > 8.5 could indicate that the water is hard, although hard water does not pose a great risk but can cause aesthetic problems. Wokem and Lawson- Jack [9] recorded mean values of pH ranging from 6.20±0.2 to 6.80±0.4mg/l which were within the WHO [7] guideline of 6.5 to 8.5. However, contrasting pH value lower than the 6.20±0.2 to 6.80±0.4 limit was recorded by Ogbonna et al. [29] with values ranging from 5.5 to 6.1 in Borehole water from Borikiri area of Port Harcourt. The pH of water is important because many biological activities can occur within a narrow range, thus any variations beyond an acceptable limit could be fatal to a particular organism [30].

Results for BOD revealed that all values obtained, were within the WHO limit of 14mg/l. The BOD is a pollution parameter mainly to assess the quality of effluent or wastewater. Untreated wastewater usually has a high oxygen demand. Industrial wastewater exhibits a higher COD, caused by dissolved chemicals or pollutants from washing processes. BOD directly affects the amount of DO in water bodies. The consequences of high BOD are the same with those for low DO; aquatic organisms become stressed, suffocate and die [7].

The results for COD in all samples were relatively high and above the WHO acceptable limit (40mg/l). The implication is that the chemicals could greatly affect human health and this also shows that all the water samples analyzed are heavily laden with chemical impurities. High concentrations of COD, decreases DO and lead to anaerobic an condition which is deleterious to aquatic life forms.

The DO revealed that values of B1, B2, M2, B3, and M3 were above the WHO limit of 4.0 to 5.0mg/l while M1 was below the WHO limit. DO analysis measures the amount of gaseous oxygen dissolved in an aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement) and as a waste product of photosynthesis [14]. Environmental impact of total dissolved oxygen gas concentration in water should not exceed 13-14 mg/l. Concentrations above this level could be harmful to aquatic life [14]. The presence of dissolved oxygen in water most often determines the type of microorganisms present in such water. Water with high volume of dissolved oxygen is said to be of good quality. As DO levels of water drop below 5.0mg/l, aquatic life is put under stress. The lower the concentrations of DO, the greater the stress on the organisms [14].

Results of Iron concentrations revealed that values of all water sources were high and above the WHO [7] and NSDWQ [15] limit of 0.3mg/l. Extensive consumption of drinking water containing high Fe concentration level causes haemosiderosis (liver damage), diabetes mellitus, arteriosclerosis and many other neurodegenerative diseases [31]. Iron in water supply stains plumbing fixtures, stains clothes during laundry, incrusts well screens and clogs pipes [32]. Iron corrosion products have been reported to promote bacterial activities in water systems thereby favouring the increase of both suspended microorganism and biofilms – associated bacteria as well as coliforms [33]. The presence of ferric oxide as a result of rusting can increase bacterial cultivability, especially in anaerobic conditions [34]. Previous study has reported high concentrations of iron ranging from 0.15 to 3.26mg/l and from 0.045 to 1294mg/l in groundwater [35].

Lead (Pb) concentrations in the samples revealed that values of boreholes and mono-pump were slightly above the WHO, SON, and NSDWQ limits of 0.01mg/l. High levels of exposure to lead is associated with hemolytic anemia, paralysis and severe abdominal cramps while low levels of exposure is associated with irritability, abdominal discomfort and mild fatigue [36]. Lead is a cumulative general poison and associated with several health hazards like anemia, seizures, coma and death [7], reproductive effects. According to Troesken [36], lead has been widely used as a plumbing material up until the early 1980s despite its toxic effect, owing to its resistance to aggressive ground conditions and malleable characteristics, but also most likely in a mistaken belief that the internal corrosion films arising from lead oxidation and their subsequent stabilization would form a protective layer that will prevent further metal releases into water, and owing to ignorance of health effects. PVC pipes also contain lead compounds that can be leached from them and result in high lead concentrations in drinking water.

Phosphate concentrations in the samples revealed that values of B1, B2, and M3 were within the WHO limit of 0.05 to 0.37mg/l, B3 was below the WHO limit while M1 and M2 had values above the WHO limit of 0.05 to 0.37mg/l. Phosphates are not toxic to people or animals unless they are present in very high concentrations. High levels of phosphate can cause increased growth of algae and large aquatic plant, which can result in decreased level of DO; a process called eutrophication. This can lead to fish kills and the degradation of habitat with loss of species.

The results of Temperature revealed that values of B1, M1, B2, M2, B3 and M3 were all within the WHO and NSDWQ acceptable limit for drinking water, this is not unconnected to the ambient environment of the Boreholes and Mono- pumps. Aladejana and Talabi [37] also reported temperature ranging from 27.5 to 33.1^{O}C which were within the WHO and NSDWQ. Optimal ambient temperature is required for the sustainability of biodiversity, as extreme temperature might obligue the proliferation of exotic/alien species.

Results of Turbidity revealed that all water samples were clear and within the WHO and NSDWQ limit of 5NTU. Okoro *et al*. [18] recorded the concentration of 0.2±0.06 to 0.5±0.12NTU which was within the 5NTU limit. The consumption of high turbid water may cause a health risk, as excess turbidity can protect pathogenic microorganisms from the effects of disinfectants [38].

Results of Zinc revealed that values of M1, B2, M2, B3 and M3 were within the WHO and NSDWQ limit (3mg/l) while B1 was slightly above the limit. Excess amount of zinc leads to abdominal pain, vomiting, headache and tiredness [7]. The results of Calcium revealed that values of M1, B2, M2, B3, B3 and M3 are within the WHO and NSDWQ acceptable limit of 75mg/l. Wokem and Lawson-Jack [9] also recorded concentrations of Ca ranging from 52.6±3.23 to 58.50±26.0mg/l which were within the WHO limit too.

Nitrate concentrations revealed that values of B1, M1, B2, M2, B3 and M3 were all within the WHO and NSDWQ limit of 10mg/l. Excess Nitrate in drinking water can cause a number of disorders including methemoglobinemia in infants, gastric cancer, goiter, birth malformations and hypertension [38]. Also, excess nitrate can cause hypoxia (low levels of DO) and can become toxic to warm blooded animals at high concentrations or under certain conditions [14]. Nitrate and nitrite are naturally occurring ions that are part of nitrogen cycle. There are many sources of groundwater nitrate concentrations, such as improper disposal of waste, waste from animal farms, use of nitrogenous fertilizers [2]. Nitrates concentrations within the WHO [7] limit ranging from 0.11 to 3.57mg/l was recorded by Okpokwasili et al. [2] in ground water supply. Nitrates commonly occur naturally in groundwater but high concentrations may be associated with animal and human waste, open septic or sewage systems and fertilizers from farm.

Table 2. Bacterial Counts of Mono-pumps and Borehole Water Samples (Cfu/ml)

LOCATION	THB	TCC	TVC	FCC	TSSC	TPC
Borehole1	$2.19\times10^{3}\pm0.39^{b}$	$4\times10^{2}\pm1.20^{a}$	$4.81\times10^{2}\pm1.02^{a}$	$1.35\times10^{3}\pm0.48^{a}$	$2.06\times10^{2}\pm1.27^{a}$	$0.00\times10^{0}\pm0.00^{a}$
Borehole2	$7.18\times10^{2}\pm0.40^{a}$	$3.5\times10^{2}\pm0.34^{a}$	$4.69\times10^{2}\pm0.4\ 9^{a}$	$7.88\times10^{2}\pm0.41^{a}$	$2.56\times10^{2}\pm1.29^{a}$	$0.00\times10^{0}\pm0.00^{a}$
Borehole3	$2.36\times10^{3}\pm0.33^{b}$	$2.25\times10^{2}\pm1.08^{a}$	$3.62\times10^{2}\pm1.23^{a}$	$7.31\times10^{2}\pm1.38^{a}$	$2.81\times10^{2}\pm1.29^{a}$	$0.00\times10^{0}\pm0.00^{a}$
mono1A	$1.05\times10^{3}\pm0.33^{b}$	$2.0\times10^{2}\pm1.23^{a}$	$2.38\times10^{2}\pm1.08^{a}$	$4.50\times10^{2}\pm0.39^{a}$	$1.43\times10^{2}\pm1.15^{a}$	$0.00\times10^{0}\pm0.00^{a}$
MonoB	$1.11\times10^{3}\pm0.44^{a}$	$4.81\times10^{2}\pm1.\ 25^{a}$	$3.75\times10^{2}\pm1.22^{a}$	$7.75\times10^{2}\pm1.56^{a}$	$4.19\times10^{2}\pm1.51^{a}$	$0.00\times10^{0}\pm0.00^{a}$
MonoC	$1.78\times10^{3}\pm0.31^{b}$	$9.12\times10^{2}\pm1.\ 41^{a}$	$2.81\times10^{2}\pm1.2\ 4^{a}$	$8.62\times10^{2}\pm0.42^{a}$	$1.43\times10^{2}\pm1.27^{a}$	$0.00\times10^{0}\pm0.00^{a}$
WHO Standards	500Cfu/ml	10Cfu/ml	0Cfu/ml	0Cfu/ml	0Cfu/ml	-----

**Means with the same alphabets show no significant difference (P ≤ 0.05)*

Key:*THB – Total heterotrophic bacteria, TCC – Total coliform count, TVC – Total Vibrio count, FCC –Faecal coliform count, TSSC – Total Salmonella- Shigella count, TPC – Total Pseudomonas count*

Table 3. Results of the most probable number (MPN Index/100ml) of Water Sources

Water Samples	1st	2nd	3rd	4th	5th	6th	7th	8th	WHO Standard
B1	26	170	60	33	26	21	17	170	0
B2	9	350	22	9	9	70	26	350	0
B3	90	6	9	90	90	90	6	6	0
M1	14	90	17	>1600	>1600	34	14	90	0
M2	9	12	9	50	50	7	17	12	0
M3	14	14	6	17	17	34	>1600	14	0

Table 4. Results of the physicochemical analyses

	WATER SOURCES						
PARAMETER	**B1**	**M1**	**B2**	**M2**	**B3**	**M3**	**WHO STANDARDS**
Alkalinity(mg/l)	60.85±0.20	214.87±1.36	48.34±0.50	36.82±0.01	41.72±0.01	29.14±0.01	200MG/L
BOD (mg/l)	8.26±0.01	5.79±0.01	9.14±0.01	5.97±0.01	10.44±0.01	5.12±0.01	14mg/l
Calcium (mg/l)	4.83±0.00	2.71±0.00	7.56±0.00	14.04±0.00	10.15±0.00	12.00±0.00	75mg/l
COD (mg/l)	126.52±0.01	218.00±0.57	172.41±0.04	96.17±0.01	128.91±0.02	83.20±0.44	40mg/l
DO (mg/l)	5.10±0.28	3.050±0.07	6.31±0.01	8.290±0.01	5.11±0.01	5.86±0.07	4.0-5.0mg/l
Iron (mg/l)	2.01±0.00	4.73±0.00	3.02±0.00	1.90±0.00	3.37±0.00	2.4±0.00	0.3mg/l
Nitrate (mg/l)	1.08±0.00	1.75±0.00	0.72±0.00	1.14±0.00	0.42±0.00	1.41±0.00	10mg/l
Lead (mg/l)	1.07±0.00	1.63±0.00	0.38±0.00	1.53±0.00	0.83±0.00	1.24±0.00	0.01ml
pH	7.05±0.07	6.93±0.01	6.54±0.00	6.29±0.00	6.55±0.01	6.57±0.00	6.5- 8.5
Phosphate (mg/l)	0.13±0.00	0.87±0.00	0.08±0.00	0.38±0.00	0.03±0.00	0.15±0.00	0.05-0.37
Salinity (mg/l)	5.14±0.00	5.88±0.00	4.99±0.00	3.78±0.00	4.02±0.00	2.83±0.00	200mg/l
Temperature (^oC)	29.35±0.07	29.35±0.07	28.75±0.07	27.50±0.00	26.20±0.00	27.85±0.07	Ambient
TOC (%)	2.81±0.01	3.42±0.01	1.72±0.01	2.18±0.01	1.39±0.01	1.64±0.00	No std
Turbidity (NTU)	0.03±0.00	0.12±0.00	0.05±0.00	0.03±0.00	0.08±0.00	0.05±0.00	5NTU
Zinc (mg/l)	3.18±0.00	1.82±0.00	1.52±0.00	0.61±0.00	1.10±0.00	0.39±0.00	3mg/l
PAH	61.49±0.00	48.73±0.00	45.10±0.00	32.69±0.00	41.54±0.00	55.73±0.00	10mg/l
TPH	92.11±0.00	72.73±0.00	60.31±0.00	59.86±0.00	66.15±0.00	58.90±0.00	10mg/l

The amount of the total organic carbon (TOC) of the boreholes which ranged from 1.39 to 2.81 was less than the 1.64 to 3.42% range obtained from the mono-pump samples. Thus, the mono-pump water samples had higher TOC values.TOC which represents the amount of carbon found in an organic compound is often used as a non-specific indicator of water quality indicating the presence of decaying organic matter [39]. The high values of TOC in the mono-pump water sources could mean that the mono-pump water sources had more decaying organic matter than the borehole water sources.

The results of PAH concentrations revealed that values of B1, M1, B2, M2, B3 and M3 were all above the WHO [7] limit of 10mg/l and Environmental Guidelines and Standards in the Petroleum Industry in Nigeria (EGASPIN, 2018) target value of 0.1µg/l for groundwater. The results of Total petroleum hydrocarbons (TPH) revealed that values of B1, M1, B2, M2, B3 and M3 were all above the WHO [7] limit of 10mg/l. These values were also above the EGASPIN [40] THC target value of 50µg/l for groundwater. Okpokwasili and Douglas [2] reported a TPH concentration ranging from 0 to 445.0mg/l for ground water in the Niger Delta region. PAHs and TPHs have been shown to be identified as important pollutants as a result of their high mutagenic, carcinogenic and teratogenic nature by the United State Environmental Protection Agency, World Health Organization and European Union [41]. Okpokwasili and Douglas [2] attributed the presence of PAH and TPH in groundwater as a result of groundwater contamination from leaking underground pipelines and storage tanks. The presence of high concentrations of these substances in water can result in the development of various types of cancer in man.

5. CONCLUSION

The bacteriological analyses of the water samples have revealed that boreholes and Mono-pumps in Abonnema community are laden with faecal contaminants which may be pathogenic and could pose a great health risk to the rural populace who consumes this water daily. The detection of faecal coliform in significant numbers indicated a breach of the sanitary integrity of the water sources, which may result in the outbreak of water borne diseases. More so, while most of the physicochemical parameters complied with National and International guidelines, parameters such as: COD, DO, Fe, Pb, phosphate, Zn, PAHs and TPH do not. This signified heavy metal pollution. The differences observed in the concentrations of these water quality parameters from boreholes to mono-pumps could be attributed to climatic, geographic and geologic variations between the areas of sample source. Therefore, the presence of some hazardous biological, chemical and physical impurities in the water sources which were above the acceptable limits could pose a health risk to the inhabitants who rely heavily on the underground water sources primarily as their source of domestic water and even for livestock production. A form of pretreatment, even if it is boiling or disinfection of the water is recommended before use.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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