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Assessment of Physicochemical Parameters of Water from Selected Boreholes Around Nnewi Industrial Area, Anambra State, Nigeria

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Abstract: The study seeks to evaluate the quality of borehole water around the Nnewi industrial area of Anambra State, Nigeria, and to determine the extent of its deterioration due to waste from nearby industries. Samples were collected from 16 different borehole sampling sites around 8 industries for twelve consecutive months (May 2019 to April 2020) and analysed for various physicochemical parameters such as pH, temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), etc., using standard methods. The results were compared with World Health Organisation (WHO) standards. In both seasons, data acquired indicate COD ranges of 4.50 – 20.50 mg/L (mean value 9.63±5.28 mg/L), temperature 27.00 – 30.00°C (mean value 28.59±0.99°C), pH 5.60–7.99 (mean value 6.97±0.47), DO 2.00 – 6.60 mg/L (mean3.99±0.76 mg/L), BOD 4.00 – 9.60 mg/L (mean 6.54±1.33mg/L). All the physicochemical parameters examined, with exception of BOD and COD, are within the WHO standard limits. Pearson's correlation showed that physicochemical parameters were strongly and moderately correlated with each other at either $p < 0.01$ or < 0.05. The BOD and COD results revealed that the borehole water was found to be contaminated, unfit for drinking, and likely health hazards to users. It is, therefore, recommended that water from these study areas will be properly treated before human consumption, to rid it of contaminants.

Keywords: Borehole, Industrial Contamination, Physicochemical Characteristics, Water Quality

1. Introduction

The discharge of industrial waste into water bodies is the major cause of environmental degradation and pollution in many developing countries [1]. Wastes are mainly obtained from industrial, domestic and agricultural activities. Many of these industries lack proper disposal facilities for toxic wastes that may be harmful to human health [2]. These effluents entering the water bodies are in liquid and solid forms.

The danger of uncontrolled waste disposal in Nigeria and Nnewi in particular will render groundwater unsafe for drinking and domestic use, which poses a threat to human life.

Most industries in Nnewi urban areas use water without proper wastewater treatment plants, and therefore, get rid of their wastes into the water bodies. Untreated effluents from industries discharged into the water bodies contain hazardous and toxic substances, which are harmful to human health [3]. Examples of contaminants in untreated effluents include viruses, bacteria, algae and their derivatives, heavy metals, non-biodegradable organic substances, and other toxicants that deteriorate the receiving water bodies and the environment [4, 5].

The dangers of this to human health and the environment are very great in magnitude. The health effects of contaminated water on humans are the out breaks of waterborne diseases such as hepatitis, typhoid, diarrhea, cholera, etc [6, 7].

Periodic monitoring of physical and chemical water quality indicators is very important for protecting and evaluating the purity of the ecosystem. The evaluation of pollution control measures, identifying changes in water quality, and early discovery of water quality problem sare some of the advantages of periodic monitoring [8].

Borehole water is the main source of water in Nnewi but due to the high rate of disposal of industrial effluents into the environment thereby water sources were contaminated. However, industrial effluents get into the borehole via leaching [9, 10]. Borehole water samples were obtained around Nnewi industrial areas of Anambra State, Nigeria, and were evaluated for their physicochemical properties such as temperature, pH, turbidity, chloride, dissolved oxygen, chemical oxygen demand, (COD), total solid, total dissolved solids, total suspended solid, acidity, alkalinity, calcium ion, magnesium ion, total hardness, sulphate, OH^-, HCO_3^-, biological oxygen demand (BOD), electrical conductivity, nitrite, phosphate and nitrate [11]. The values obtained were compared with the WHO standard limit [12]. Pearson correlation was performed to assess the relationship between the physicochemical water quality parameters.

All parameters monitored in this study were selected to account for diverse activities taking place in the borehole water investigated. However, the study was conducted in rainy and dry seasons so that the effects of urban run-off on water quality could be determined.

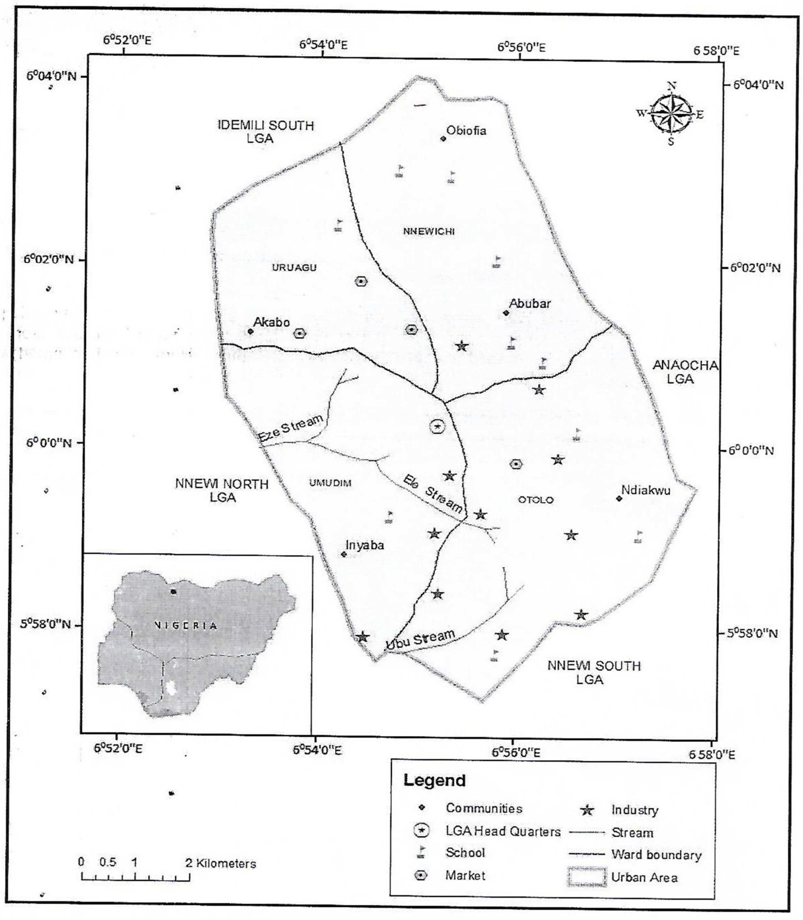
It is therefore, in the best interest of society to examine the borehole water quality to probe the likelihood of the health hazards outlined above and to ascertain the suitability of such waters for domestic uses and drinking. It is in this regard that borehole water around Nnewi industrial area is being evaluated for its water quality.

2. Materials and Methods

2.1. Study Area

The study was carried out in Nnewi urban area. The city is one of the fastest-growing urban areas in Anambra State, Nigeria. It is comprised of 4 communities whichare NnewiIchi, Umudim, Otolo and Uruagu. It has a population of about 391,227, based on the 2006 national census [13]. Nnewi has an area of 1741.53 km^2, located in between (latitudes 6° 01' and 6° 57' North) and (longitudes 6° 45' and 6° 55' East). The annual rainfall ranges from 1500 to 2000 mm [14].

The manufacturing industries in Nnewi urban area are RIMCO industries Ltd (Vegetable oil), Cutix industries PLC (Electrical cables), Ibeto industries Ltd (automobile batteries), A- Z Industries Ltd (Lubricating oil), Jimex industries Ltd (aluminium products), etc. The wastewater from these industries is channelled into Streams through a drainage system.



Source: Ministry of Commerce and Industry, Anambra State (2013).

Figure 1. *Map of Nnewi North LGA Showing Location of Industries.*

2.2. Samples Collection

The various industries were located on the map of Nnewi North L. G. A (Figure 1). Water samples were collected from 16 different borehole water sourceswithin eight industriesin the study area (two borehole water samples around each industry). The sampling descriptions adopt a code for each borehole waters sampling location (Table 1). Sampling was done between 8–10am each day at one-month intervals for twelve consecutive months during the rainy season (May – October 2019) and dry season (November 2019 – April 2020). Samples were collected using a two-litreplastic container (screw-capped) that have been thoroughly washed withdetergent, then rinsed with 10% HNO_3 to avoid contamination and thereafter rinsed three times with distilled water. At the site of sample collection, the tap was allowed to run for at least 1 minute without collection so that the sample collection would be a true representative of the water. The containers were rinsed several times with the target water samples before filling them with water samples. Thereafter, the containers were properly labelled. They were placed in an ice chest and then transported to the laboratory for analysis. All the samples were stabilized with 1ml concentrated HCl in each container to avoid micro-organisms affecting their concentrations and then stored in the laboratory. All the samples were analysed for different physicochemical properties.

Borehole sampling sites were selected based on their closeness to the industries.

Table 1. *Descriptions of sampling locations.*

Sample Codes	Identification	Sampling locations
Sample 1	Borehole	A – Z petroleum product limited Umudim Nnewi
Sample 2	Borehole	A – Z petroleum product limited Umudim Nnewi
Sample 3	Borehole	RIMCO Nigeria limited Umudim Nnewi
Sample 4	Borehole	RIMCO Nigeria limited Umudim Nnewi
Sample 5	Borehole	Tummy-Tummy foods Ind. Ltd Umudim Nnewi
Sample 6	Borehole	Tummy-Tummy foods Ind. Ltd Umudim Nnewi
Sample 7	Borehole	C. O. Prince AluminumNnewi-Ichi
Sample 8	Borehole	C. O. Prince AluminumNnewi-Ichi
Sample 9	Borehole	Innoson Vehicle Manufacturing Co. Ltd Umudim Nnewi
Sample 10	Borehole	Innoson Vehicle Manufacturing Co. Ltd Umudim Nnewi
Sample 11	Borehole	Ibeto Petrochemical Industries Ltd Otolo Nnewi
Sample 12	Borehole	Ibeto Petrochemical Industries Ltd Otolo Nnewi
Sample 13	Borehole	Jimex Industries Nigeria Ltd Otolo
Sample 14	Borehole	Jimex Industries Nigeria Ltd Otolo
Sample 15	Borehole	Cutix Company Otolo Nnewi
Sample 16	Borehole	Cutix Company Otolo Nnewi

2.3. Physicochemical Analyses of Borehole Water Samples

22 parameters were evaluated in the sampled borehole waters. The parameters analysed include temperature and pH which were determined insitu at the sampling site using a calibrated mercury thermometer and pH meter (Hanna microprocessor pH meter, Model: HI991300)) respectively according to the American Public Health Association method (APHA) [15]. Electrical conductivity was measuredusing a conductivity meter (Yantai Stark instrument, Model: DDS-307A). Turbidity was measured using a turbidity meter (Thermo Fisher Scientific, Model: AQ4500). TSS, TDS, and TS were determined using a gravimetric method of analysis (APHA 2005). Nitrates, sulphate, nitrite and phosphates were determined by UV-visible spectrophotometer (Bioevo peak, Model: 721G-100). Chloride ion content was determined by the Argentometric method. Alkalinity, acidity and total hardness (TH) were determined by the titrimetric method. DO, BOD and COD were determined using the Winkler method [15]. High pure analytical reagent grade chemicals and distilled water were used to prepare solutions for the physicochemical analysis. All the reagents and chemicals used for the analysis were of certified analytical grade and procured from Sigma-Aldrich U.S.A.

The analyses of physicochemical parameters of the sampled borehole water were done in triplicate using standard methods and mean values were recorded [15]. The blank samples were analysed to make sure the accuracy, reproducibility and reliabilityof the laboratory measurement processes. Most of the parameters were measured in mg/L. The pH has no unit. Turbidity was measured in NTU and electrical conductivity was measured in µS/cm. The analytical results were also compared with local and International standards where applicable.

2.4. Pollution Index (PI)

PI was determined as a function of the concentration of each parameter against the baseline standard given by the WHO [16]. It gives information on the relative pollution contributed by each parameter. PI values < 1.0 indicate no pollution while values >1.0 indicate a significant degree of pollution [16]. The PI was evaluated using equation (1);

$$PI = \frac{\text{Concentration}}{\text{Standard}} \tag{1}$$

2.5. Statistical Analyses

The data obtained from the sampled borehole water were analyzed by using the software Microsoft Office Excel 2007.

Correlations analyses were determined using Pearson's correlation to evaluate the interaction between the parameters. Statistical Package for Social Sciences (SPSS) software (SPSS 20.0 version at 95 % level of confidence) was used for the analysis [17].

3. Results and Discussion

3.1. Physicochemical Parameters of Sampled Borehole Waters

Each sample collected was analysed for 22 physicochemical parameters. These include temperature, DO, pH, turbidity, chloride, COD, acidity, alkalinity, Ca^{2+}, Mg^{2+}, TH, TDS, TSS, TS, sulphate, nitrate, OH^-, HCO_3^-, BOD, EC, nitrite and phosphate. The sampled borehole water showed various concentrations of physicochemical properties in rainy and dry seasons. The mean values of physicochemical parameters were compared with WHO standard limits for drinking water quality [12].

The monthly mean distributions of physicochemical parameters of sampled borehole water during the rainy season are shown in Figures 2 and 3.

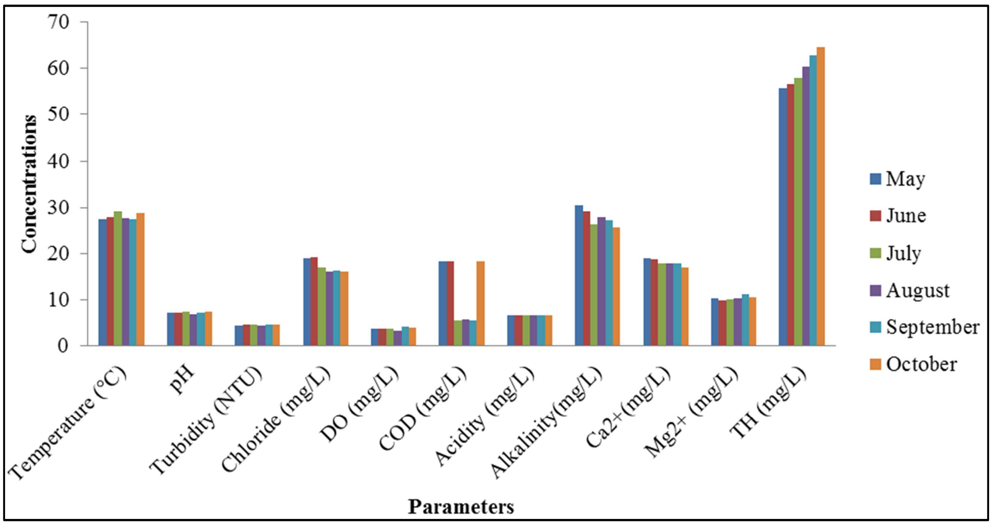


Figure 2. *Monthly mean distributions of physicochemical analyses of sampled borehole water of the rainy season.*

3.1.1. Temperature

From Figure 2, temperature measures the degree of hotness or coldness of a substance [2]. The temperature had the least concentration of 27.438°C in May and September while the highest concentration of 29.119°C was observed in July. The concentrations of temperature were within the WHO recommended limit of 0 – 30°C [12]. The values obtained for temperature might be due to the time difference in the sample collection [18]. The values obtained were similar to those reported by Chukwu; Eboagu *et al.* [19, 20]. Temperature is an important parameter used to measure water quality.

3.1.2. pH

The pH had the least concentration of 6.75 in August and the highest concentration of 7.41 in July. The values of pH were within the WHO recommended limit of 6.5 – 8.5 for safe drinking water [12]. The results obtained for pH were similar to those reported byEdori and Nna; Edwin *et al.* [18, 21]. All the borehole water samples obtained during the rainy season were alkaline in nature except for the month of August which is slightly acidic. The alkalinity of borehole water samples in the rainy season may be due to the presence of bicarbonates (part of essential raw materials for production) lost into the soil and percolated into the underground soil through rainwater [22, 23].

3.1.3. Turbidity

Turbidity is the unclear condition of water caused by particles of organic matter, sand, clay and silt being held in suspension [24]. Turbidity had the least concentration of 4.379 NTU in May and the highest concentration of 4.615 NTU in October. The concentrations of turbidity were within the WHO standard limit of 0 – 5 NTU [12].

3.1.4. Chloride

Chloride ion is known for the maintenance of acid-base balance [25]. Chloride had a minimum concentration of 15.988 mg/L in August and a maximum concentration of 19.102mg/L in June. The concentrations of Cl^- were within the WHO permissible limit of 0 – 250mg/L [12]. The Cl^- concentrations obtained were similar to those reported by Ezeribe et al. [26]. Chloride ions in small concentrations are not harmful to humans drinking the water, but high chloride content in water may promote pipe corrosion [27].

3.1.5. DO, COD and BOD

DO is an important parameter for drinking water quality. DO have a minimum concentration of 3.334mg/Lin August and a maximum concentration of 4.032mg/L in September. The concentrations of DO were within the WHO permissible limit of 0 – 7.5mg/L [12]. Relatively lower values of DO were recorded in the rainy season which might be a result of the effect of low water temperature [28, 29].

COD had a minimum value of 5.356mg/Lin July and a maximum value of 18.30mg/L in June. The COD values were above the WHO standard limit of 10mg/L except for the month of July, August and September which are below the WHO standard limit [30]. The COD values obtained were similar to those reported by Eid [31]. COD is a parameter used to determine the suitability of water for drinking [32].

BOD had a minimum concentration of 6.10mg/L in August and a maximum concentration of 6.601mg/L in May. The concentrations of BOD were above the WHO recommended limit of 6mg/L. The concentrations of BOD obtained were similar to those reported by Obi and Okocha [33]. The high BOD values obtained might be due to industrial effluents from the study area, that moved into the underground through leaching, thereby constituting water contamination by increasing the amount of organic mattercontent [10].

3.1.6. Acidity and Alkalinity

Acidity had a minimum concentration of 6.509mg/L in July and a maximum concentration of 6.651mg/L in October. Acidic water contributes mainly to the corrosion of metals [34].

Alkalinity had a minimum concentration of 25.603mg/L in October and a maximum concentration of 30.491mg/L in May. The alkalinity values were within the WHO standard limit of 0 – 100mg/L [12].

3.1.7. Total Hardness (TH)

The hardness of water is caused by the presence of dissolved polyvalent metallic ions, predominantly calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}). The TH had a minimum concentration of 55.78mg/L in May and a maximum concentration of 64.476mg/L in October. TH concentration was within the WHO recommended limit of 0 – 200mg/L $CaCO_3$ [12]. TH values were recorded for the sampled boreholes which fall within moderately soft water classifications [35] and are good for domestic use. The mean values of TH were increased due to an increase in the seepage of ions in the rainy season [19].

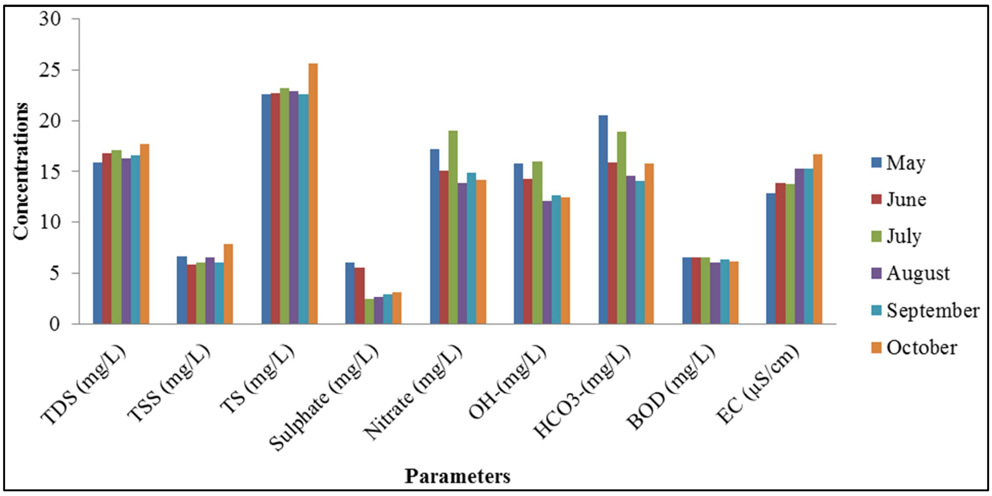


Figure 3. Monthly mean distributions of physicochemical analyses of sampled borehole water during the rainy season.

3.1.8. Total Dissolved Solid (TDS) and Total Suspended Solid (TSS)

From Figure 3, TDS had the least concentration of 15.909mg/L in May and the highest concentration of 17.731mg/L in October. The values of TDS were within the WHO recommended limit of 0 – 500mg/L [12]. The TDS values obtained were similar to those reported by Edori *et al.* [36].

TSS had a minimum concentration of 5.883mg/L in June and a maximum concentration of 7.888mg/L in October. The values of TSS were within the WHO permissible limit of 0 – 30mg/L [12].

3.1.9. Electrical Conductivity (EC), Sulphate and Nitrate

EC measures the ionic content of sampled water and also determines its ability to conduct an electric current [9]. EC had a minimum concentration of 12.90mg/Lin May and a maximum concentration of 16.706mg/L in October. The values of EC were within the WHO permissible limit of 0 – 500mg/L [12].

The minimum and maximum concentrations of sulphate were 2.433 mg/L and 6.023mg/L which are observed in the month of July and May respectively. The values of sulphate were within the WHO-recommended limit of 0 – 100 mg/L [12]. The values of sulphate obtained were similar to those reported byEzeribe et al. [26]. No other side effects and health implications of excess sulphate in water have been recorded so far [37].

The minimum and maximum concentrations of nitrate were 13.939 mg/L and 19.018 mg/L which are observed in August and July respectively. All the values of nitrate were within the WHOrecommended limit of 0 – 50 mg/L [12]. The concentrations of nitrate obtained in this study were similar to those reported by Ezeribe et al. [26].

The monthly mean distributions of physicochemical parameters of sampled borehole water of the dry season are presented in Figures 4 and 5.

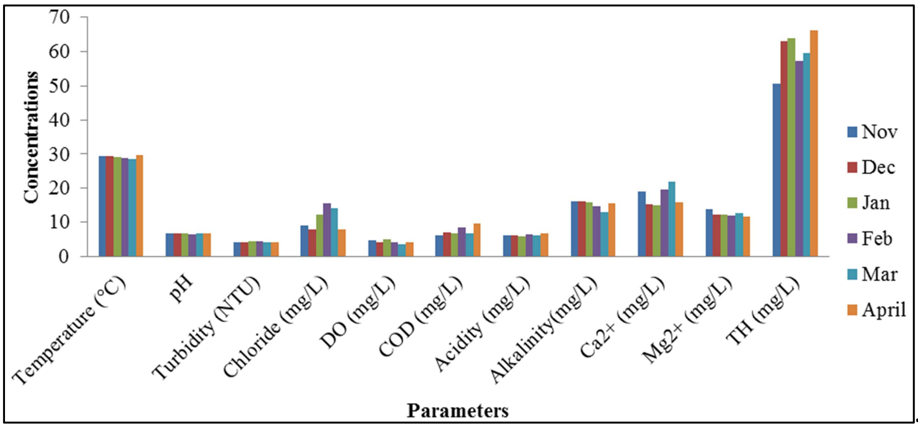


Figure 4. *Monthly mean distributions of physicochemical parameters of the sampled borehole water of the dry season.*

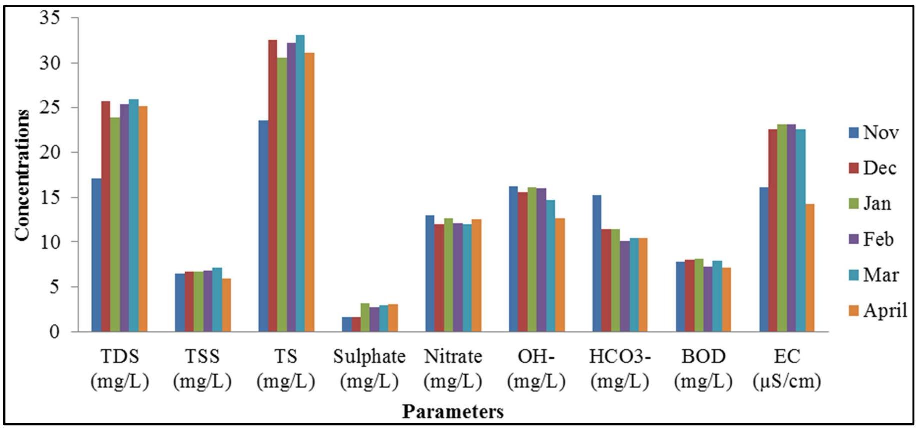


Figure 5. *Monthly mean distributions of physicochemical parameters of the sampled borehole water of the dry season.*

From Figures 4 and 5, the result showed that all the physicochemical parameters of the sampled borehole water of dry season were within their various WHO [12] recommended limits except for BOD. The monthly mean results of sampled borehole water indicated that in the dry season, the water samples were contaminated which may be due to the heavy discharge of effluents from the industries which moved into the underground through leaching, thereby causing water pollution by increasing the amount of organic matter content [10, 22].

Table 2. *Descriptive statistics of the physicochemical parameters of borehole water samples of the rainy season.*

Parameters	Mean	Standard Deviation	Variance	Coefficient Variation (%)	Range	WHO Standard [12]
Temperature (°C)	28.030	0.907	0.823	3.240	27.00 – 30.00	30
pH	7.249	0.467	0.218	6.440	5.60 –7.99	6.50- 8.50
Turbidity (NTU)	4.522	0.238	0.057	5.260	4.00 – 4.98	5
Chloride (mg/L)	17.234	2.353	5.538	13.660	14.15 – 24.32	250
DO (mg/L)	3.714	0.619	0.384	16.690	2.00 – 4.88	7.5
COD (mg/L)	11.869	6.512	42.404	54.860	4.00 – 20.50	10
Acidity (mg/L)	6.571	0.285	0.081	4.330	6.10 – 7.30	–
Alkalinity (mg/L)	27.776	2.760	7.617	9.940	20.30 – 31.90	100
Ca^{2+} (mg/L)	18.041	1.584	2.508	8.780	14.10 – 21.00	75
Mg^{2+}(mg/L)	10.452	1.018	1.036	9.740	9.00 – 14.40	50
T H (mg/L)	59.690	7.439	55.341	12.460	45.10 – 79.25	200
TDS (mg/L)	16.753	1.653	2.732	9.870	11.22 – 19.50	500
TSS (mg/L)	6.536	1.438	2.067	22.000	3.62 – 10.00	30
TS (mg/L)	23.289	1.885	3.554	8.090	20.10 – 28.00	500
SO_4^{2-}(mg/L)	3.812	1.564	2.445	41.020	1.20 –7.00	100
NO_3^-(mg/L)	15.738	2.172	4.716	13.800	12.10 – 21.10	50
OH^- (mg/L)	13.881	2.361	5.572	17.000	9.40 – 21.30	30
HCO_3^-(mg/L)	16.635	2.946	8.676	17.710	10.00 – 24.00	30
BOD (mg/L)	6.393	0.554	0.307	10.280	6.00 –7.32	6
EC (µS/cm)	14.655	2.746	7.542	18.740	10.10 – 21.40	500

Parameters	Mean	Standard Deviation	Variance	Coefficient Variation (%)	Range	WHO Standard [12]
Nitrite (mg/L)	0.0382	0.014	0.002	37.380	0.01 –0.08	3
Phosphate (mg/L)	0.589	0.167	0.028	28.390	0.30 –0.99	5

From Table 2, BOD values of sampled borehole water during the rainy season varied from 6.00 – 7.32 mg/L with the mean value and coefficient variation of 6.393mg/L and 10.28% respectively. These values were above the WHO [12] permissible limits. BOD values recorded in sampled borehole water were slightly high. This implied that the water bodies are slightly loaded with biodegradable matter which is influenced by both anthropogenic and natural activities [38]. This could be critical during the rainy season when these organic materials are eroded into the water bodies through storm water from the industrial effluents. Unpolluted natural water bodies should have a BOD of 6.0mg/L or less [12, 30, 39]. BOD is an important parameter of water quality [40]. A high level of BOD shows that water is polluted thereby, causing dissolved oxygen depletion which could be harmful to life [41].

COD values of sampled borehole water in the rainy season ranged from 4.00 – 20.50 mg/L with the mean value and coefficient variation of 11.869±6.51 mg/L and 54.86% respectively. Most of the COD values recorded in sampled borehole water during the rainy season were above the WHO [12] recommended limit of 10 mg/L. The concentration of sampled borehole water during the rainy season shows that all the parameters with exception of BOD and a few COD were within their various WHO [12] recommended value for safe drinking water. The mean concentration of the parameters monitored in the rainy season followed the descending order: TH > T > alkalinity > TS > Ca^{2+} > Cl^- > TDS > HCO_3^- > NO_3^- > EC > OH^- > COD > Mg^{2+} > pH > $acidity$ > TSS > turbidity > SO_4^{2-} > DO > PO_4^{3-} > NO^{2-}. The mean and coefficient variation value of borehole water samples during the rainy season is a result of various factors like depth, age and physiological factors [10]. The mean values of pH, turbidity, Cl^-, COD, acidity, alkalinity, Ca^{2+}, SO_4^{2-}, NO_3^- HCO_3^-, NO_2^- and PO_4^{3-} were higher in the rainy season when compared with the dry season counterpart.

Table 3. *Descriptive statistics of the physicochemical parameters of borehole water samples of the dry season.*

Parameters	Mean	Standard Deviation	Variance	Coefficient Variation (%)	Range	WHO Standard [12]
Temperature (°C)	29.151	0.711	0.506	2.440	28.00 – 30.00	30
pH	6.685	0.239	0.057	3.590	6.00 – 7.30	6.50- 8.50
Turbidity (NTU)	4.244	0.256	0.065	6.030	3.24 – 5.40	5
Chloride (mg/L)	11.182	3.363	11.308	30.070	7.00 – 19.10	250
DO (mg/L)	4.267	0.781	0.609	18.300	2.50 – 6.60	7.5
COD (mg/L)	7.397	1.867	3.486	25.240	4.50– 12.83	10
Acidity (mg/L)	6.315	0.493	0.243	7.810	4.36 – 7.20	
Alkalinity (mg/L)	15.305	2.574	6.625	16.820	10.00 – 19.70	100
Ca^{2+} (mg/L)	17.873	3.851	14.827	21.540	10.10 – 27.00	75
Mg^{2+}(mg/L)	12.436	1.851	3.427	14.890	10.15 – 19.13	50
T H (mg/L)	60.025	7.504	56.307	12.500	40.30 – 79.25	200
TDS (mg/L)	23.874	3.869	14.968	16.210	13.50 – 30.30	500
TSS (mg/L)	6.641	1.088	1.184	16.380	4.50–8.76	30
TS (mg/L)	30.515	3.973	15.788	13.020	20.10 – 37.56	500
SO_4^{2-}(mg/L)	2.559	0.909	0.826	35.530	1.10 – 5.60	100
NO_3^-(mg/L)	12.322	1.130	1.276	9.170	10.00 – 15.20	50
OH^- (mg/L)	15.202	2.004	4.014	13.180	10.30 – 19.40	30
HCO_3^-(mg/L)	11.500	2.496	6.232	21.710	7.00 – 19.00	30
BOD (mg/L)	7.689	0.769	0.591	10.000	6.10 –9.60	6
EC (µS/cm)	20.303	4.332	18.765	21.340	10.20 – 27.20	500
NO^{2-} (mg/L)	0.023	0.008	0.000	36.580	0.01 – 0.04	3
PO_4^{3-}(mg/L)	0.097	0.178	0.032	184.530	0.03 – 1.11	5

From Table 3, BOD values of sampled borehole water of dry season ranged from 6.10 – 9.60 mg/L with a mean value of 7.689±0.769 mg/L. BOD values were above the WHO [12] standard limit. The high BOD value was a result of oxygen depletion which confirms the presence of pollutants in water [1]. The pollution might be a result of the industrial discharge of effluent into the environment and indiscriminate dumping of refuse [22]. All the parameters examined in the dry season were within their various WHO [12] standards except BOD values. Total hardness and nitrite had mean values of 60.025 ± 1.851 mg/L and 0.023 ± 0.008 mg/L with a coefficient variation of 12.50% and 36.58% respectively. The mean values for temperature, DO, Mg^{2+}, TH, TDS, TSS, TS, OH^-, BOD, and EC were slightly higher in the dry season when compared with their rainy season counter-part.

3.2. Pollution Index

Table 4. *Shows pollution index (PI) values of sampled borehole water for rainy and dry seasons.*

Parameters	PI (Rainy Season)	PI (Dry Season)
Temperature	0.934	0.972
pH	0.967	0.891
Turbidity	0.904	0.849
Chloride	0.069	0.045
DO	0.495	0.568
COD	1.187	0.740
Acidity	–	–

Parameters	PI (Rainy Season)	PI (Dry Season)
Alkalinity	0.278	0.153
Ca^{2+}	0.241	0.238
Mg^{2+}	0.209	0.249
T H	0.298	0.300
TDS	0.034	0.048
TSS	0.218	0.221
TS	0.047	0.061
SO_4^{2-}	0.038	0.026
NO_3^-	0.315	0.246
OH^-	0.463	0.507
HCO_3^-	0.555	0.383
BOD	1.066	1.282
EC	0.029	0.041
NO^{2-}	0.013	0.008
PO_4^{3-}	0.118	0.019
∑PI	8.478	7.847

Table 4 shows the PI results of sampled borehole water for rainy and dry seasons. COD and BOD had high PI of 1.187 and 1.066 in the rainy season while BOD had a high PI of 1.282 in the dry season respectively. The PI values were greater than 1.00 which indicated that there was a significant degree of pollution while the other parameters had a pollution index less than 1.00 (PI < 1.00) which shows no danger of pollution in sampled borehole waters. Since the PI values of COD and BOD were above 1.00 (PI> 1.00), it suggested that drinking and use of these borehole waters was likely to cause obvious health hazards because the higher the PI value, the higher the probability of the hazard risk on humans body [42].

The PI value for sampled borehole waters in rainy and dry seasons were 8.478 and 7.847 respectively. This shows that the PI of the rainy season was > the dry season. These might be a result of the leaching of groundwater by wastewater through flooding, which polluted the borehole water [43]. The results of borehole water samples showed that BOD had a PI value greater than 1 (PI> 1) which confirmed that the waters from boreholes were polluted and unfit for drinking, therefore will cause abnormal health effects.

3.3. Correlation Results

Tables 5 and 6 show the results of the correlation analysis.

Table 5. *Correlation of physicochemical analysis of sampled borehole water of the rainy season.*

	T	pH	TUR	Cl^-	DO	COD	ACID	ALKA	Ca^{2+}	Mg^{2+}	TH
T	1										
pH	.188	1									
TUR	.190	.134	1								
Cl^-	-.121	.003	-.259*	1							
DO	-.041	.115	.259*	-.156	1						
COD	-.037	.210*	-.047	.320**	.113	1					
ACID	.029	.034	.131	-.055	-.069	.061	1				
ALKA	-.411**	.022	-.152	.048	.023	.262*	-.074	1			
Ca^{2+}	-.181	.078	-.156	-.085	.094	.108	-.041	.435**	1		
Mg^{2+}	-.154	-.107	-.264**	-.100	.005	-.130	-.124	-.069	-.034	1	
TH	.084	.041	-.091	-.336**	.061	-.088	-.072	-.024	-.009	.173	1

Table 5. *Continued.*

	TDS	TSS	TS	SO_4^{2-}	NO_3^-	OH^-	HCO_3^-	BOD	EC	NO_2^-	PO_4^{2-}
TDS	1										
TSS	-.262**	1									
TS	.677**	.533**	1								
SO_4^{2-}	-.190	.035	-.140	1							
NO_3^-	-.099	-.114	-.173	.093	1						
OH^-	-.362**	.023	-.301**	.287**	.514**	1					
HCO_3^-	-.138	.033	-.095	.336**	.558**	.589**	1				
BOD	-.085	.054	-.033	.243*	.245*	.275**	.100	1			
EC	.033	.236*	.209*	-.283**	-.257*	-.210*	-.273**	-.158	1		
NO_2^-	-.235*	-.125	-.301**	.363**	.333**	.390**	.305**	.218*	-.127	1	
PO_4^{2-}	-.236*	.057	-.163	.256*	.699**	.592**	.641**	.310**	-.328**	.287**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 6. *Correlation of physicochemical analysis of sampled borehole water of the dry season.*

	T	pH	TUR	Cl^-	DO	COD	ACID	ALKA	Ca^{2+}	Mg^{2+}	TH
T	1										
pH	.015	1									
TUR	-.099	-.138	1								
Cl^-	-.404**	-.113	.141	1							
DO	.112	.053	.187	-.160	1						
COD	.110	-.067	.050	-.013	-.165	1					
ACID	.097	.001	.030	-.109	-.122	.357**	1				
ALKA	.086	-.141	.030	-.365**	.198	.076	.045	1			

	T	pH	TUR	Cl^-	DO	COD	ACID	ALKA	Ca^{2+}	Mg^{2+}	TH
Ca^{2+}	.042	-.246*	-.069	.429**	-.366**	.095	-.039	-.245*	1		
Mg^{2+}	-.063	.047	-.114	-.054	.059	-.207*	-.127	-.013	.267**	1	
TH	.123	.071	-.033	-.086	-.155	.202*	-.012	.004	-.106	-.114	1

Table 6. *Continued.*

	TDS	TSS	TS	SO_4^{2-}	NO_3^-	OH^-	HCO_3^-	BOD	EC	NO_2^-	PO_4^{2-}
TDS	1										
TSS	-.043	1	.								
TS	.962**	.232*	1								
SO_4^{2-}	.320**	-.053	.298**	1							
NO_3^-	-.151	-.097	-.173	-.053	1						
OH^-	-.238*	.130	-.197	-.058	-.136	1					
HCO_3^-	-.580**	-.075	-.586**	-.473**	.168	.111	1				
BOD	-.065	.071	-.044	-.080	.117	.153	.150	1			
EC	.324**	.280**	.392**	.047	-.179	.305**	-.224*	.217*	1		
NO_2^-	.016	.299**	.097	.003	-.078	.092	-.188	.092	.198	1	
PO_4^{2-}	.105	.067	.121	-.216*	-.076	-.032	.067	-.253*	.147	-.099	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

From Table 5, the statistical analysis done on the data generated was observed that at $p< 0.05$, parameters that correlated positively with one another include: pH correlated with COD (r = 0.210); Turbidity correlated with DO (r = 0.259); COD with alkalinity (r = 0.262); TSS with EC (r = 0.236); TS with EC (r = 0.209); SO_4^{2-} with BOD (r = 0.243); NO_3^- with BOD (r = 0.245) and BOD with NO_2^- (r = 0.218). These showed that an increase in pH leads to an increase in these other parameters and since the value is greater than 0.05, the relationship between the two is strong [17].

At $p< 0.01$, parameters that correlated positively with one another include: TDS correlated with TS (r = 0.677); TSS correlated with TS (r = 0.533); NO_3^-correlated with OH^- (r = 0.544), HCO_3^{2-} (r = 0.558) and PO_4^{2-}(r = 0.699); OH^- correlated with HCO_3^{2-} (r = 0.589) and PO_4^{2-} (r = 0.592); HCO_3^- correlated with PO_4^{2-} (r = 0.641).

A positive correlation was an indication of a direct relationship between the variables. The correlation values of the physicochemical parameters of the sampled borehole water during the rainy season indicated a moderately positive correlation between the samples.

Turbidity also showed a negative relationship with Cl^-(r = – 0.259); TDS with NO_2^- (–0.235) and PO_4^{2-}(–0.236); NO_3^- with EC (r = – 0.257) and OH^- with EC (r = – 0.210) which means that an increase in Turbidity leads to a decrease in the other parameters and since the value is less than 0.05 the relationship between the two is weak. The other parameters were negatively correlated; they were poorly correlated with r values of less than 0.7 (at $P< 0.05$ or < 0.01).

From Table 6, at $P < 0.05$, parameters that correlated positively with one another include: COD correlated with TH ($r = 0.202$); TSS correlated with TS ($r = 0.232$); BOD with EC ($r = 0.217$).

At $P< 0.01$, parameters that strongly correlated with one another include: TDS correlated with TS ($r = 0.962$). Most of the other parameters were negatively correlated; they were poorly correlated with r values of less than 0.7 (at $p < 0.05$ or < 0.01).

4. Conclusion

The results revealed that sampled borehole water in the study area was mostly affected by flooding and industrial discharges as indicated by the values of BOD and COD.

Pearson's correlation analysis showed that physicochemical parameters of borehole water are moderately and strongly correlated with one another at either $P < 0.05$ or < 0.01. All other water quality parameters examined were within the respective WHO limits for safe drinking water. The high values of BOD and COD obtained in both seasons indicate that the water from the borehole contains high levels of inorganic and organic matter, is unsafe for drinking, and thus constitutes a health hazard. The source of contamination of the borehole water is both geogenic and anthropogenic.

It is therefore recommended that borehole water from the study area should be properly treated before human consumption. Routine monitoring of the borehole water within the industrial (study) area is also recommended to ascertain its water quality.

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References

[1] World Health Organization (WHO) (2006). Guidelines for Drinking Water Quality, First Addendum to 3rd ed. Recommendations, Geneva, pp 105-110. http://www.who.int/water-sanitation-health/dwq/gdwq0506.pdf. Accessed June 2014.

[2] World Health Organization (WHO) (2011). Guidelines for Drinking Water Quality, 4th ed. Acceptability aspects: taste odour and appearance. Geneva Switzerland, pp 1-541.

[3] Rajaram, T. and Ashutosh, D. (2008). Water Pollution by Industrial Effluents in India: Discharge Scenarios and Case for Participatory Ecosystem Specific Local Regulation. Environ 40 (1): 56-69. https//doi.org/10.1016/j.futures.2007.06.002

[4] Aralu, C. C., Okoye, P. A. C., Abugu, H. O. and Eze, V. C. (2022). Pollution and water quality index of boreholes within inlined waste dumpsite in Nnewi, Nigeria. Discover Water 2:14. https://doi.org/10.1007/s43832-022-00023-9

[5] Onwughara, N. I., Ajiwe, V. I. E. and Nnabuenyi, H. O. (2013). Physicochemical Studies of Water from Selected Boreholes in Umuahia North Local Government Area of Abia State, Nigeria. Int J Pure Appl. Biosci 1 (3): 34-44.

[6] Rahmanian, N., Ali, S. H., Homayoonfard, M., Ali, N. J., Rehan, M., Sadef, Y. and Nizami A. S. (2015). Analysis of physicochemical parameters to evaluate the drinking water quality in the State of Perak, Malaysia J. Chem. https://doi.org/10.1155/2015/716125

[7] Meinhardt, P. L. (2006). Recognizing waterborne disease and the health effects of water contamination: A review of the challenges facing the medical community in the United States. J Water Health 4 (S1): 27-34. https:doi.org/10.2166/wh.2006.0041

[8] Ukah, B. U., Igwe, O. and Ameh, P. (2018). The impact of industrial waste water on the physicochemical and microbiological characteristics of groundwater in Ajao-Estate Lagos, Nigeria. Environ Monit and Assess 190: 1-17. https://doi.org/10.1007/s10661-018-6600-z

[9] Ukaogo, P. O., Loai, A., Anthony, O., Ojah E. O. and Nwaogwugwu, J. C. (2021). Evaluation of physicochemical characteristics and health risk of polycyclic aromatic hydrocarbons in borehole waters around automobile workshops in Southeastern Nigeria. Groundwater for Sustainable Development 14: 1-9. http://doi.org/10.1016/j.gsd.2021.100615

[10] Sumant, K. N. C., Ghosh, R. P., Singh, M. M., Sonkusare, S. S. and Sanjay, M. (2015). Assessment of water quality of lakes for drinking and irrigation purposes in Raipur City, Chhattisgarh, India. IJERA 5: 42-49.

[11] Mohsin, M., Safdar, S., Asghar, F. and Jamal, F. (2013). Assessment of drinking water quality and its impact on residents health in Bahawalpur City. Int J HumanitSocSci 3 (15): 114-128.

[12] World Health Organization (WHO) (2017). Guidelines for Drinking Water Quality, 4th ed. incorporating the first Addendum Geneva, pp 1-631.

[13] National Bureau of Statistics (NBS) (2007). Legal notice on publication of the details of the breakdown of the national and state provisional totals 2006 census. National Bureau of Statistics official gazette (FGP.71/52007) 2500 (OL24) pp 1-10.

[14] Obeta, M. C. (2015). Industrial water supply in Nnewi Urban Area of Anambra State, South Eastern Nigeria. J Geo Environ Earth SciInt 2 (1): 12-23.

[15] American Public Health Association (APHA) (2005). Standard Methods for Examination of Water and Waste Water, 21th ed. APHA, AWWA, AEF Washington, DC, USA.

[16] Akpoveta, O. V., Okoh, B. E. and Osakwe, S. A. (2011). Quality Assessment of Borehole Water used in the Vicinities of Benin, Edo State and Agbor, Delta State of Nigeria. Cur Res Chem 3: 62-69.

[17] Saleem, A., Dandigi M. N. and Vijay, K. K. (2012). Correlation and regression model for physicochemical quality of groundwater in the South Indian City of Gulbarga. Afr J Environ SciTechnol 6 (9): 353-364.

[18] Edori, O. S., and Nna, P. J. (2018). Determination of physicochemical parameters of effluents at discharge points into the New Calabar River along Rumuolumeni axis, Niger Delta, Nigeria. J. of Environ. Anal. Toxico 8 (3): 132-157 DOI: 10.4172/2161- 0525.1000585.

[19] Chukwu, G. U. (2008). Water Quality Assessment of Borehole in Umuahia South Local Government Area of Abia State, Nigeria. The Pacific JSciTechnol 9 (2): 592-598.

[20] Eboagu, N. C., Ajiwe, V. E. and Odidika, C. C. (2018). Physicochemical Parameters of Water from Selected Boreholes Utilized as Potable Water. Int J Environ SciTechnol 16 (7): 3605-3614 DOI 10.1007/s13762-018-1931-4.

[21] Edwin, N., Ibiam, U. A., Igwenyi, I. O., Ude, V. C. and Eko, S. N. (2015). Evaluation of physicochemical properties, mineral and heavy metal content of drinking water samples in two communities in South-East, Nigeria: a public health implication. J. Environ. Earth Sci 5 (9): 89-94.

[22] Akpabio, J. J. and Ekpo, F. E. (2013). Physicochemical and Heavy Metals Quality Assessment of Borehole Water in Different Residential Areas of Uyo Metropolis. A Case Study of G. R. A and Low Income Residential Areas. Int J Sci Res 4 (2): 37-44.

[23] Tiwari, A. K., Singh, A. K, and Singh MP (2015). Hydrogeochemical analysis and evaluation of surface water quality of Pratapgarh District. Appl Water Sci Uttar Pradesh 3 (2): 16-28. https://doi.org/10.1007/s13201-015-0313-z.

[24] Dhanakumar, S., Murthy, K. R. and Mohanra, R. (2015). Phosphorous fractionation in surface sediments of the Cauvery Delta region, Southeast India. Environmental Management of River Basin, pp. 477-489.

[25] Shigut, D. A., Liknew, G., Irge, D. D. and Ahmad, T. (2017). Assessment of physicochemical quality of borehole and spring water sources supplied to Robe Town, Oromia Region, Ethiopia. Appl. Water Sci. 7: 155-164. https://doi.org/10.1007/s13201-016-0502-4

[26] Ezeribe, A. I., Oshieke, K. C. and Jauro, A. (2012). Physico-chemical properties of well water samples from some villages in Nigeria with cases of stained and mottle teeth. Sci World J 7 (1): 1-3.

[27] Aremu, M. O., Olaofe, O., Ikokoh, P. P. and Yakubu, M. M. (2011). Physicochemical characteristics of stream, well and borehole water sources in Eggon, Nasarawa State, Nigeria J ChemSocNig 36 (1): 131–136.

[28] Okeke, P. N. and Adinna, E. N. (2013). Water quality study of Otamiri River in Owerri, Nigeria. Uni J Environ Res Technol 3: 641-649.

[29] Behailu, T. W., Badessa, T. S. and Tewodros, B. A. (2017). Analysis of physical and chemical parameters in ground water used for drinking around Konso area, Southwestern Ethiopia, J. Anal Bioanal Tech. 8 (5): 1-7.

[30] Nigerian Industrial Standard (NIS) (2017). Nigerian Standard for Drinking Water Quality, SON Governing Council, NIS 554:

[31] Eid, B. I. (2017). Physi. cochemical properties and the concentration of anions, major and trace elements in groundwater, treated drinking water and bottled drinking water in Najran Area, KSA. Appl Water Sci 7: 401-410.

[32] Sharma, N. and Walia, Y. K. (2017). Water quality investigation by physicochemical parameters of Satluj River (Himachal Pradesh, India). Curr World Environ 12: 174-180.

[33] Obi, C. N. and Okocha, C. O. (2007). Microbiological and Physicochemical Analysis of Selected Borehole Water in World Bank Housing Estate UmuahiaAbia State, Nigeria. J Engr. ApplSci 2 (5): 920-929.

[34] World Health Organization (WHO) (1993). Guidelines for Drinking Water Quality. Revision of the 1984 Guideline. Final Task Group Meeting, Geneva, pp 21-25.

[35] Subramanian, M. S. (2010). Analysis of Major Constituents in Water Environmental Chemistry and Analysis, Indian Institute of Technology Madras pp. 1-18.

[36] Edori, O. S., Kieri, B. S. I. and Festus, C. (2019). Physicochemical Characteristics of Surface Water and Sediment of Silver River, Southern Ijaw, Bayelsa State, Niger Delta, Nigeria. AmericanJ Environ SciEngr 3 (2): 39-46.

[37] Popoola, L. T., Yusuff, A. S. and Aderibigbe, T. A. (2019). Assessment of natural groundwater physicochemical properties in major industrial and residential locations of Lagos Metropolis. Appl. Water Sci. 9, 191. http://doi.org/10.1007/s13201-019-1073-y

[38] Nigeria Standard for Drinking Water Quality (NSDWQ) (2015). Nigerian Industrial Standard, Standard Organisation of Nigeria Governing Council. NIS 554. ICS 13.060. 20: 15-19.

[39] United States Environmental Protection Agency (USEPA) (2015). Human Health Risk Assessment; risk-based concentrationtable http://www.epa.gov/reg3hwmd/risk/human/rb-concentration table/Generic Tables/index.htm.

[40] Environmental Protection Agency (EPA) (2001). Risk assessment guideline for superfund volume 1 human health evaluation manual part A. OERR. Washington, D. C. OERR.92006303894.

[41] Dagim, A. S., Geremew, L., Dejene, D. I. and Tanweer, A. (2017). Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town, Oromia region, Ethiopia. Appl Water Sci 7: 155-164. DOI 10.1007/s13201-016-0502-4

[42] Girl, S. and Singh, A. K. (2015). Human Health Risk and Ecological Risk Assessment of Metals in Fishes, Shrimps and Sediments from a Tropical River. Int J Environ SciTechnol 12: 2349-2362. https://doi.org/10.1007/s13762-014-0600-5

[43] Aralu, C. C., Okoye, P. A. C., Ezugwu, J. A. and Eboagu, N. C. (2021). Assessment of water collected from boreholes within unsanitary landfill in Anambra State. Euro J ApplSci 9 (6): 405-412.