



Assessment of the Water Quality of Boreholes in Selected Areas in Benin City, Edo State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author DEO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors UDA and IEC managed the analyses of the study. Author EEI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The water quality of selected boreholes in Oredo, Egor and Ovia North-East Local Government Areas in Benin City metropolis was assessed in terms of their physical, microbial and chemical parameters. A total of nine water samples (three per local government) were collected from randomly selected public boreholes in the month of July, 2018. The physicochemical parameters determined and values obtained are as follows: Electrical conductivity ranged 12.85 to 101.94 $\mu\text{S}/\text{cm}$, Temperature 25.00 to 25.01 $^{\circ}\text{C}$, pH of 4.32 to 5.55, TDS 0.67 to 4.00 mg/l, COD 3.20 to 16.00 mg/l, Turbidity 1.14 to 5.38FTU, Cl^{-} 106.50 to 426.00 mg/l, SO_4^{2-} 0.41 to 2.87 mg/l, TSS 0.33 to 1.67 mg/l, TS 1.33 to 4.33 mg/l, NO_3^{-} 23.73 to 41.48 mg/l, Mg 0.03 to 0.61mg/l, Ca 0.10 to 0.41 mg/l, HCO_3^{-} 7.00 to 22.00 mg/l, Na 0.20 to 7.75 mg/l, K 0.41 to 1.20 mg/l, Mn 0.01 to 0.11 mg/l, Fe 0.01 to 0.02 mg/l, Zn 0.01 to 0.65 mg/l, PO_4^{-} 0.07 mg/l for all locations, while some metals like Cd, Pb were not detected. Microbial evaluation was done on the samples to assess the level of E. coli, coliforms and bacteria. The principal component analysis result extracted two components each

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from the three LGAs; In Oredo LGA, Factor 1 accounted for 84.9% while Factor 2 accounts for 15.1%. In Egor LGA, Factor 1 accounts for 51.1% while Factor 2 accounts for 48.9%. In Ovia North-East LGA, Factor 1 accounted for 59.0% while Factor 2 accounts for 49.0% contributions.

Keywords: Microbial; conductivity; boreholes; physicochemical; metropolis.

1. INTRODUCTION

Water is one of the most abundant and essential resources of man, and occupies about 70% of the earth's surface. About 97% of this volume of earth's surface water is contained in the oceans, 21% in polar ice and glaciers, 0.3-0.8% underground, 0.009% in inland freshwaters such as lakes, while 0.00009% is contained in rivers [1]. Water has been regarded as a universal solvent that can dissolve many chemicals which may or not be beneficial to man and its environment [2]. It is however essential to all living things and its environment [3].

Ground water is the water beneath the surface where all the voids in the rocks and soil are filled. It is a source of water for wells, boreholes and springs. A borehole is an hydraulic structure which when properly designed and constructed, permits the economic withdrawal of water from an aquifer. It is a narrow well drilled with machine [4].

Apart from the essential role played by water in supporting human life, if polluted, it also has a great potential for transmitting a wide variety of diseases. Portable water for human consumption does not always occur in nature because of the presence of impurities in most natural water bodies [5,6], and this has been attributed to its high solvating capacity. Water in its pure state is acclaimed key to health and the general contention is that water is more basic than all other essential things to life [7].

Hence, human activities often result in water pollution making such water unfit for use. Water pollution is a change in the quality of water which renders it unstable or dangerous as regards foods, man and animal health, industry, agriculture, fishing or leisure.

There are different ways of assessing the quality of water: physical (such as Temperature, pH, Electrical conductivity), chemical (such as chlorides, nitrates, sulphates, phosphates, total dissolved solids, trace of metals), and biological parameters (microbes such as *E.coli*, coliform and other bacteria) [8].

2. MATERIALS AND METHODS

2.1 Site Description

This study was carried out in Benin City between July 14, 2018 to July 16, 2018. The City is the capital of Edo State, Nigeria and is located in the south-south geopolitical zone of Nigeria; bounded by latitudes 6°06' N, 6°30' N and longitudes 5°30' E, 5°45' E and area of about 500 square kilometers. The major business is transportation, Education, and petty trading.

The coordinates, elevation and name of the specific locations where the sampling was done is shown in the Table 1.

2.2 Sampling

Sampling was done in the month of July, 2018. Each sample was collected from 3 functional private borehole water supply sources per local Government areas from July 14 to July 16 by 9:00am to 11:00 daily. The private boreholes were selected using the Random Sampling Technique. This was achieved through the use of table of random numbers, bringing the total number of samples to 9.

2.3 Collection of Water Samples

Water samples were collected using clean HDPE bottles dry-washed with dilute hydrochloric acid and rinsed three times with the water samples before filling them to capacity and labeling them accordingly then transported immediately to the laboratory in a container of ice for physicochemical analysis. For bacteriological analysis, 5 drops of aqueous sodium thiosulphate solution were added to the sample bottles and sterilized in a hot box oven at 160°C for one hour. The addition of the solution was to neutralize any available chlorine in the samples. The taps were disinfected, opened fully and the water allowed rushing for two minutes before collection. The samples were labeled and transported to the laboratory in a cooler (container) of ice. These were then stored in a temperature of -4°C in the laboratory for analysis. The Physicochemical analysis was carried out at

the Department of Chemistry, Faculty of Physical Science, University of Benin, Benin- City while microbial analysis was done at the Department of

Plant Biology and Biotechnology, Faculty of Life Science, University of Benin, Benin City. Analysis was completed within a period of 14 days.

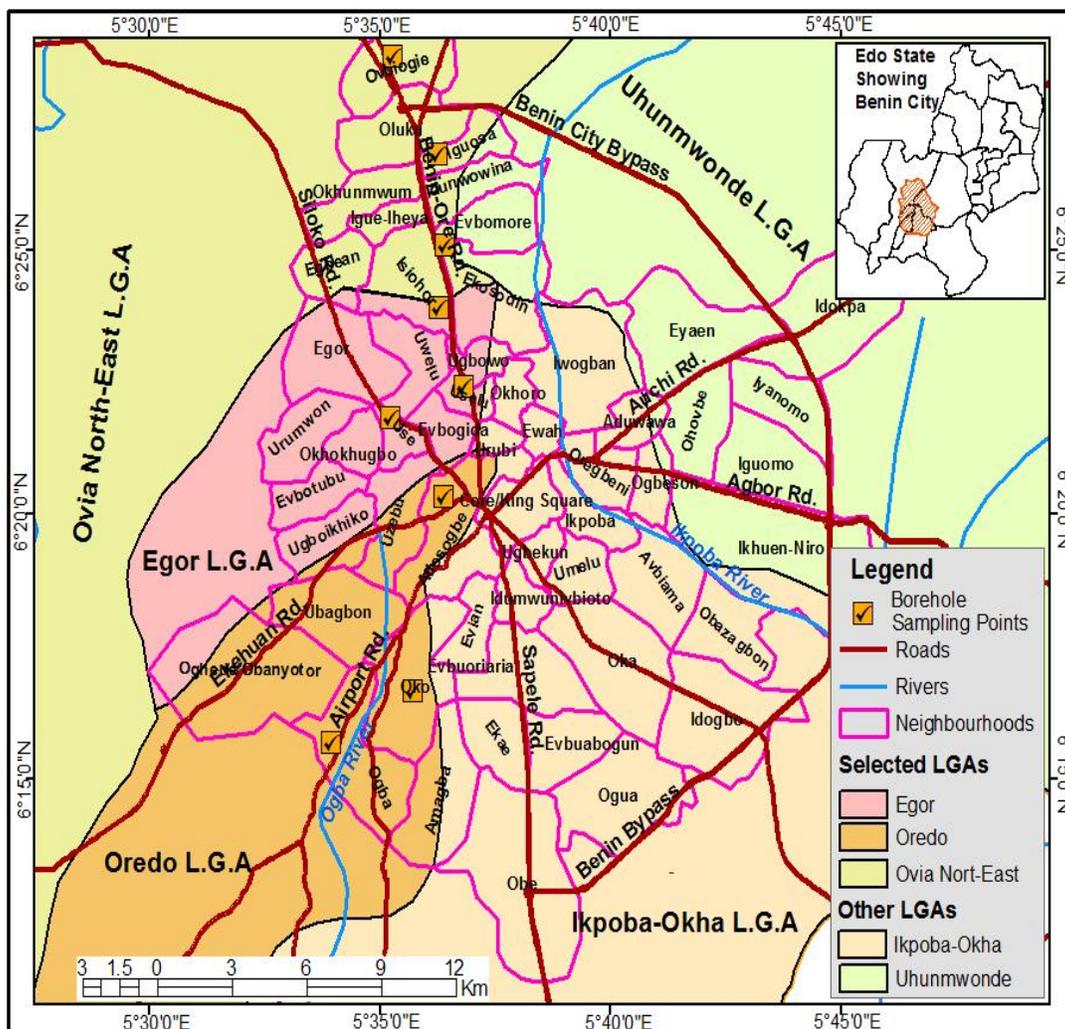


Fig.1. Map of Benin city showing local government areas and borehole water sampling locations
(Source: Go to School Limited, 2018)

Table 1. Borehole water sampling locations and geographic coordinates

L.G.A	Name of neighbourhood	Latitudes (N)	Longitudes (E)	Elevation
Ovia North-East	Iguosa Housing Estate	6° 26' 46.81"	5° 36' 13.823"	127m
	Ovbiogie	6° 28' 39.385"	5° 35' 13.68"	140m
	Isiehor Near Agent	6° 23' 55.633"	5° 36' 16.908"	120m
Egor	Near Ogida Police Station	6° 21' 49.179"	5° 35' 10.596"	92m
	Near Uselu Market	6° 22' 021"	5° 36' 47.75"	99m
	Near Reebok, Ugbowo	6° 23' 54.091"	5° 36' 15.366"	111m
Oredo	Ogba	6° 15' 39.067"	5° 33' 58.116"	46m
	Oko	6° 16' 43.837"	5° 35' 41.439"	52m
	Adesogbe	6° 20' 19.735"	5°36' 21.534"	86m

Source: Field Work, 2018

Table 2. location and identification of samples from private boreholes

Sample location	Sample identification
Oredo	1
Oredo	2
Oredo	3
Egor	4
Egor	5
Egor	6
Ovia North-East	7
Ovia North-East	8
Ovia North-East	9

2.4 Sample Preservation

Samples for cation analysis were preserved by adding acid immediately after collection to pH of about 2 using concentrated analytical nitric acid [9]. Collected samples were placed in icebox container before transportation to laboratories for analysis.

3. RESULTS AND DISCUSSION

3.1 Temperature

In all locations in Oredo, the temperature values are the same and thus have no difference in temperature. The mean temperature levels of the water samples ranged from 25.00 ± 0.01 to 25.01 ± 0.01 in Oredo. Similar trend was observed for Egor. All three locations have the same temperature values with a mean value of 25.00 ± 0.00 . Ovia North-East had the highest mean value of 25.01 ± 0.01 at points 1 and 2, while point 3 had a low value of 25.00 ± 0.01 similarly to the values obtained in Oredo. There was no statistical difference amongst all the study areas in the temperature recorded for the borehole water samples.

Temperature is regarded as the degree of hotness or coldness of a body. The temperature of water is not particularly the main issue when considering it as a physical parameter, but its effect on other properties e.g. changing solubility of gases [10]. The Groundwater temperature values in the study areas ranged from $25.00 \pm 0.00^\circ\text{C}$ to 25.01 ± 0.01 and the mean average value of the Borehole water samples from all the locations is 25.00°C . This temperature range indicates an ambient groundwater temperature and therefore good for consumers who prefer cool to warm water. Furthermore, this low temperature range is particularly important for good water quality; since, high temperature negatively impact water quality by enhancing the growth of micro-

organisms which may increase taste, odour, colour and corrosion problems. Therefore, it is important that groundwater temperature is not too high in order to have microbial proliferation. Temperature has also been known to affect biological, chemical and physical activities in water and an increase in temperature of water decreases the solubility of gases such as O_2 , CO_2 , N_2 and CH_4 [11]. The temperature range of the samples are within permissible limit of WHO and thus the water samples could be said to be safe for drinking and other domestic purposes such as cooking.

3.2 pH

The pH recorded at points 1 and 2 in Oredo were similar while that of point 3 was higher with a value of 5.55. Thus the water obtained at points 1 and 2 are much more acidic than point 3. The values recorded at all 3 points in Egor were all similarly, and the mean value was higher than for Oredo and Ovia North-East. The pH for all the borehole water from all sampling areas were found to be acidic with a mean value ranging from 4.32 ± 0.01 to 5.55 ± 0.01 recorded for Oredo, 5.07 ± 0.00 to 5.16 ± 0.02 for Egor and 4.88 ± 0.01 to 5.09 ± 0.02 for Ovia North East. Thus, the highest pH value (least acidic) was recorded in Egor while Oredo had the lowest (most acidic). Generally, the Niger delta is noted for high acidity (low pH) in the mangrove swamp areas [12]. Acidity in the groundwater may be attributed partly to gas flaring in the area. This industrial activity releases carbon dioxide which reacts with atmospheric precipitation to form carbonic acid ($\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$). This acid infiltrates underground into the groundwater system, reduces pH of the water, and increases acidity.

The WHO has recommended a mean pH value of 6.50 to 8.50 and all the pH values recorded at the sampling sites were well below the WHO recommended standards. Though pH has no direct effect on human, all the biochemical reactions are however pH dependent. The analyzed borehole water samples are therefore slightly too acidic for human consumption. Acidic water may occur naturally as a result of mixture of volcanic gases, gaseous emanations in geothermal areas [13] or due to alteration of groundwater as stated by [14], and may result in serious health complications such as irritation in the eyes, skin and mucous membrane [15].

3.3 Total Dissolved solids

In Oredo, point 3 had the highest TDS value followed by point 2 and 1. For Egor, point 3

recorded the lowest TDS value followed by point 1 and then 2. Similar trend was observed in Ovia North-East as in Egor. The mean values ranged from 0.68 ± 0.01 to 1.33 ± 0.01 in Oredo, 0.67 ± 0.00 to 2.00 ± 0.01 in Egor and 1.00 ± 0.01 to 4.00 ± 0.02 in Ovia North-East indicating a higher mean concentration of total dissolved solids in Ovia North-East than the other local Government. The difference however, between all local Governments was not statistically significant at 95% confidence interval.

It has been suggested by [16], 1966, that a high TDS value limits the suitability of water to be used for domestic purpose. The [17] has set a standard of allowable limit of 1000mg/L for drinking water. This is because high water with high dissolved solid is generally of inferior palatability, may induce an unfavourable physiological reaction in the transient consumer [18,19], and has been shown to be responsible for certain other properties such as hardness, turbidity, odour, colour, alkalinity, and taste [18]. All TDS values recorded in this study are below the WHO permissible limit and thus the water samples are therefore suitable for use as drinking water and for other domestic purposes. The low values may also indicate the low mineral content of water [20].

3.4 Electrical Conductivity

Conductivity is a function of temperature, types of ions present and the concentrations of the ions present [15]. Conductivity measurement has been reported to provide an indication of ion concentration [10]. Electrical conductivity gives an indication of the amount of total dissolved solids in water [11]. At high levels of electrical conductivity, drinking water may have an unpleasant taste or odor, or may even cause gastrointestinal distress in humans.

The electrical conductivity at points 1 and 2 in Oredo had a values of $101.94 \mu\text{mhos/cm}$ and $90.20 \mu\text{mhos/cm}$ respectively, while that of point 3 was distinct from the other and had a low value of $16.94 \mu\text{mhos/cm}$. In Egor, point 1 recorded the highest value of $30.11 \mu\text{mhos/cm}$ followed by points 2 and 3, while point 3 had the highest value of $32.00 \mu\text{mhos/cm}$ followed by points 1 and 2 in Ovia North-East Local Government. The mean conductivity recorded from all sample location is $38.10 \mu\text{mhos/cm}$; the recommended a permissible value of $1000.00 \mu\text{mhos/cm}$ for electrical conductivity (EC) of drinking water. The values of electrical conductivity were all below the recommended value stated by WHO. The

highest value (101.94 ± 0.01) was recorded at point 1 in Oredo local Government Area while the lowest value (12.85 ± 0.01) recorded for electrical conductivity was at point 3 in Egor local Government. In all the various points in the three local Governments, the values recorded for electrical conductivity wasn't statistically significant (See ANOVA on EC, Table 3, Table 6). Oredo areas which recorded the highest value could be explained by suggesting that this could probably be due to the difference in altitude, Oredo being far higher altitude-wise and presumably has the lowest water table, therefore probably had a more net leaching effect by comparison. Low values of conductivity also give a picture of very little solute dissolution generally in the groundwater, rapid ion-exchange between the soil and water, or basically a poor and rather insoluble geologic rock and mineral types [21].

3.5 Total Solid (TS) and Total Suspended Solids (TSS)

Point 3 had the highest TSS and TS value followed by point 1 and 2 in Oredo. Similarly point 3 recorded the highest TSS value in Egor followed by points 1 and 2 while point 1 had the highest value of TS. In Ovia North-East, point 3 again recorded the highest value of TSS while points 1 and 2 had the same value. For TS, point 2 has a high value 4.33 followed by points 3 and point 1. The Total Solid and Total Suspended Solid recorded for all the different locations range from 1.33 to 4.33 and 0.33 to 1.34. There was no statistical difference in the mean values of TS and TSS recorded at all the different borehole locations. High TSS can lead to turbidity which is an indication of pollution. TSS composed of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, sodium, potassium, manganese, organic matter, silt and other particles and high TSS has been noted to be aesthetically unsatisfactory for bath and other domestic purposes. The TSS and TS of the studied water samples are well below the WHO recommended limit and thus the water samples are safe drinking and other domestic purpose [2].

3.6 Chemical Oxygen Demand (COD)

In Oredo, point 1 had the highest COD value of 16.00 followed by points 3 while point 2 recorded a very low value of 3.20. Similar results were obtained in Egor with point 1 having the highest value of 16.00 followed by point 3 while point 2 had a similar low value of 6.40. Ovia North-East recorded the highest at point 3 while points 1 and

2 had similar values. The chemical oxygen demand is the amount of oxygen required to decompose/oxidize the oxidizable compound of waste water. It is an index of the organic content of water because the most common substance oxidized by dissolved oxygen in water is organic matter having biological origin i.e dead plant and animal wastes. Chemical Oxygen Demand (COD) was recorded in the water samples collected from all sampling sites. The mean COD value ranged from 3.20 to 16.00 ppm, while the allowed permissible limit according to WHO is 10ppm. A few of the sampled areas had COD values slightly higher than the recommended, while the mean COD value recorded for the area under study is at an average of 9.69mg L^{-1} which is lower than the standard value and thus the water samples are safe for drinking and other domestic uses [10].

3.7 Turbidity

Again, point 1 in Oredo recorded the highest Turbidity value followed by points 2 and 3, whereas in Egor, point 3 recorded the highest followed by points 1 and 2. Ovia North-East turbidity had the highest turbidity value at point 3. The mean value of Turbidity of the borehole water samples ranged from 2.70 to 4.23 in Oredo, 1.14 to 3.46 in Egor and 1.53 to 5.38 in Ovia North-East. The mean of turbidity values from all locations is 2.99NTU. This value falls within the recommended WHO and the Nigerian standard for drinking water quality (5NTU). [22], obtained similar low values in Dutsin-Ma, which were also lower than the recommended standard and they suggested that this could mean that the geology of the study area(s) are safe enough and does not harbor high quantities of particulate matter such as microscopic organisms, soluble colored organic compounds, silt, clay, etc, and the amount of finely divided organic and inorganic matter suspended in the water are very low.

3.8 Mean Nutrients Level in the Water Samples

Nitrates: According to WHO [17], the acceptable standard for nitrates is below $50.0\ \mu\text{g/L}$. All the mean nitrate values recorded in the three local Governments were less than the WHO standard. Nitrate value was highest in Oredo at point 2 and lowest at point 3. In Egor, point 3 recorded the highest value while point 1 was lowest. The mean nitrate level was higher in Ovia North-East than Egor but lower than recorded for Oredo.

Across all locations, the recorded nitrate values ranged between 23.73 in point 3 and 41.48 in point 2 both at Oredo.

Chlorides: Besides the nitrates, the chlorides, phosphates and sulphates values were also determined. Oredo again had very high values of chlorides with point 3 recording a value of 426.00 while point 1 had 117.50. Similar trend was observed for Egor with point 3 recording the highest and point 1 the lowest. Ovia North-East recorded the lowest values of chlorides with point 1 having a value of 142.00, while points 2 and 3 recorded similar values of 106.50. The mean values of chlorides from all locations were within the range 106.50 to 426.00.

Phosphate: The phosphates level recorded in all the points in Oredo were constant and had a value of 0.07. These same low values of phosphates were recorded at all the sampling locations both in Egor and Ovia North-East. No difference of any significance exists between phosphate levels from all sample locations.

Sulphates: Ovia North-East recorded the highest mean sulphate values. Point 3 recorded 2.47 while point 1 was the lowest with a value of 1.23. points 3 recorded a mean value of 2.87 and 1.23 in Oredo and Egor respectively. The mean value recorded for sulphates from all locations was within the range 0.41 to 2.87.

The human body requires essential nutrients for good nutrition, but not in excess quantities as too much of these nutrients have their own health implications. It is worth noting that during the study, all nutrient levels studied were within the WHO limits set for drinking water. Thus, the water samples from all 9 locations are safe for drinking as the nutrient level do not exceed the WHO recommended values.

Carbonates and bicarbonates: Carbonates were not detected in the Borehole water samples from all sampling locations in all the three local Governments. Hydrogen carbonates value ranged from 7.00 ± 0.01 at point 3 to 22.00 ± 0.01 at point 1 both at Oredo local government Area. All recorded values of bicarbonates are also well within the WHO permissible limits and thus are good for drinking purposes.

3.9 Elemental Analysis of the Bore-hole Water Samples

The mean values of the heavy metal Zinc ranged from 0.01 ± 0.00 in point 1 to 0.65 ± 0.02 in point 3

both at Local Government Area. For the Heavy Metals Iron, no significant detection was recorded at the sampling sites in Oredo and Ovia North-East while Egor local Government had a detection of 0.01 ± 0.00 and 0.02 ± 0.00 at point 1 and 2 respectively. The mean levels of Nickel, Lead and Cadmium had a concentration of 0.000mg/l for all the sources of Borehole water in the three local Government Areas. Sodium, potassium, Magnesium and Calcium were detected. Sodium ranged from 0.20 ± 0.01 to 7.75 ± 0.01 . Potassium ranged from 0.41 ± 0.01 to 1.20 ± 0.02 , Magnesium ranged from 0.03 ± 0.01 to 0.61 ± 0.02 , while Calcium ranged from 0.10 ± 0.01 to 0.41 ± 0.02 . The cation concentrations were dominated by Na^+ , followed by K^+ , Mg^+ , Ca^+ , Zn^+ and Mn^+ as shown in table. All values of metal ions detected in the water samples are in accordance with the maximum acceptable limit set by WHO.

3.10 Microbiological Analysis of the Bore-hole Water Samples

E Coli, coliform and other bacteria were tested for in the bore hole water samples. The presence of *E. coli* in some samples is of great concern and implies faecal contamination of such samples. It is recommended by the WHO that no microbial organisms should be found in 100ml of drinking water. The greatest risk from microbes in water is associated with consumption of potable water that is contaminated with human excreta, although other sources of exposure is significant [17].

The three microbes tested for in the water samples were below detection limit. This means that the water samples from all nine borehole sources were hygienic for drinking and other domestic uses.

3.11 Correlation Analysis

Correlation matrix study of the parameters (Table 4) shows a positive correlation between some of the parameters, temperature correlated positively with TS and very positively with TDS and other metal ions present such as Fe^{2+} , Ca^{2+} and to a lesser extent Mn^{2+} . The pH showed strong positive correlations with the levels of TSS, TDS, COD, Fe, and a positive significant correlation with Cl^- , sulphates, TS, and Zn. Other positive correlations are between: EC and COD, Turb., HCO_3^- , Mn, Na, K, Mg and Ca. TDS showed positive correlation with HCO_3^- , Fe, and a strong

significant correlation with TSS. The amount by which EC rises depends on increase in temperature

Water temperature affects the EC so that its value increases from 2 upto 3% per 1°C . However, COD showed weak though positive correlation, with temperature and pH. By interpretation, the temperature of the groundwater impacts significantly on the EC, TDS and COD and vice versa [11].

3.12 Principal Component Analysis

Principal component analysis was conducted on the parameters obtained from the three local government areas. The initial eigenvalue for the extraction was 1. In all the local government areas, two components were each extracted at an extraction communality of 1, with their respective factors loading.

In Oredo Local Government Area, two factors were identified in the borehole samples from the three locations. The rotated component matrix shows factor loadings from these locations. Factors with correlation value > 0.5 are considered to be significant. Thus, Factor 1 accounts for 84.9% contributions with high loading in EC, NO_3^- , Turbidity, HCO_3^- , Mn^+ , Na^+ , K^+ , Mg^+ and Ca^+ . Factor 2 is highly loaded in pH, SO_4^{2-} , TSS, TS and COD, accounting for 15.1% of the contributions.

In Egor Local Government Area, two factors were also identified in the borehole samples from the three locations. The rotated component matrix shows factor loadings from these locations. Factors with correlation value > 0.5 are considered to be significant. Thus, Factor 1 accounts for 51.1% contributions with high loading in EC, COD, Mn^+ , Zn^+ , Na^+ and Mg^+ . Factor 2 is highly loaded in pH, SO_4^{2-} , TSS, COD, Turbidity, HCO_3^- , and K^+ accounting for 48.9% of the contributions.

In Ovia North East Local Government Area, two factors were equally identified in the borehole samples from the three locations. The rotated component matrix shows factor loadings from these locations. Factors with correlation value > 0.5 are considered to be significant. Thus, Factor 1 accounts for 59.0% contributions with high loading in EC, Cl^- , NO_3^- , Na^+ , K^+ , Mg^+ and Ca^+ . Factor 2 is highly loaded in SO_4^{2-} , TSS, COD, Turbidity, and Na^+ accounting for 49.0% of the contributions.

Table 3. Results of Physicochemical analysis of the borehole water samples in Oredo, Egor and Ovia North-East Local Government areas of Edo State

Parameters	Oredo			Egor			Ovia North East			WHO Standard
	1	2	3	1	2	3	1	2	3	
Temperature (°C)	25.01±0.01	25.00±0.01	25.00±0.01	25.00±0.00	25.00±0.00	25.00±0.00	25.01±0.01	25.01±0.01	25.00±0.01	-
pH	4.35±0.01	4.32±0.01	5.55±0.01	5.16±0.01	5.07±0.00	5.16±0.02	5.09±0.02	4.95±0.01	4.88±0.01	6.5-8.5
EC (µm hos/cm)	101.94±0.01	90.20±0.02	16.94±0.02	30.11±0.01	19.22±0.03	12.85±0.01	25.90±0.02	13.75±0.01	32.00±0.02	500
Chloride(mg/l)	117.50±0.02	213.00±0.01	426.00±0.01	117.50±0.01	141.99±0.01	142.00±0.01	142.00±0.02	106.50±0.01	106.50±0.01	250
Nitrate(mg/l)	39.31±0.02	41.48±0.01	23.73±0.02	26.26±0.02	29.84±0.01	32.64±0.02	35.57±0.01	28.04±0.01	34.88±0.01	20-45
Phosphate(mg/l)	0.07±0.00	0.07±0.00	0.07±0.00	0.07±0.00	0.07±0.00	0.07±0.00	0.07±0.00	0.07±0.00	0.07±0.00	0-50
Sulphate(mg/l)	1.23±0.01	0.82±0.01	2.87±0.01	0.82±0.01	0.41±0.01	1.23±0.01	1.23±0.01	1.64±0.01	2.47±0.01	150-250
TSS(mg/l)	1.00±0.01	0.33±0.01	1.34±0.01	1.00±0.01	0.33±0.00	1.67±0.01	0.33±0.02	0.33±0.01	1.00±0.01	500
TDS(mg/l)	5.097±0.01	4.510±0.00	1.33±0.01	1.505±0.01	2.00±0.01	0.67±0.00	1.33±0.01	4.00±0.02	1.00±0.01	500
TS(mg/l)	6.097±0.01	4.840±0.01	2.66±0.02	2.505±0.02	2.32±0.01	2.34±0.01	1.66±0.01	4.33±0.02	2.60±0.01	500
COD(mg/l)	16.00±0.02	3.20±0.01	12.80±0.01	16.00±0.00	6.40±0.01	11.20±0.02	4.81±0.01	4.80±0.01	12.00±0.01	10.0-20.0
Turbidity(NTU)	4.23±0.02	3.08±0.01	2.70±0.01	1.92±0.01	1.14±0.01	3.46±0.01	1.53±0.01	3.46±0.02	5.38±0.01	5.0-25.0
Carbonate(mg/l)	-	-	-	-	-	-	-	-	-	-
Bicarbonate(mg/l)	22.00±0.01	16.01±0.02	7.00±0.01	16.00±0.00	8.00±0.02	19.00±0.01	9.00±0.01	21.01±0.00	13.01±0.1	-
Manganese(mg/l)	0.11±0.01	0.08±0.01	0.01±0.00	0.02±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.05-0.50
Zinc (mg/l)	0.01±0.00	0.18±0.01	0.65±0.02	0.20±0.01	0.02±0.00	0.01±0.05	0.02±0.01	0.03±0.01	0.02±0.01	0.30
Iron(mg/l)	-	-	-	0.01±0.00	0.02±0.00	-	-	-	-	0.1-1.0
Nickel(mg/l)	-	-	-	-	-	-	-	-	-	-
Lead(mg/l)	-	-	-	-	-	-	-	-	-	0.30
Cadmium(mg/l)	-	-	-	-	-	-	-	-	-	0.01
Sodium (mg/l)	7.75±0.01	6.80±0.02	1.40±0.02	2.50±0.01	1.20±0.00	0.30±0.01	1.10±0.02	0.20±0.01	2.20±0.01	-
Potassium(mg/l)	0.90±0.01	0.70±0.00	-	0.70±0.00	-	1.00±0.00	1.20±0.02	-	0.41±0.01	-
Magnesium(mg/l)	0.61±0.02	0.55±0.02	0.33±0.00	0.13±0.02	0.08±0.01	0.04±0.01	0.17±0.01	0.03±0.01	0.09±0.01	0.50
Calcium(mg/l)	0.40±0.02	0.41±0.02	-	0.10±0.01	0.20±0.01	-	0.20±0.00	-	0.11±0.01	7.50
<i>E.Coli</i> count	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Coliform count	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Bacteria count	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

Table 4. Correlation analysis

		Correlations																		
		T	pH	EC	Cl ⁻	NO ₃ ⁻	SO ₂	TSS	TDS	TS	COD	Turb.	HCO ₃ ⁻	Mn	Zn	Fe	Na	K	Mg	Ca
T	Pearson Correlation	1																		
pH	Pearson Correlation	-.096	1																	
EC	Pearson Correlation	-.014	-.886**	1																
Cl ⁻	Pearson Correlation	-.098	.432*	-.095	1															
NO ₃ ⁻	Pearson Correlation	-.035	-.868**	.772**	-.364	1														
SO ₂	Pearson Correlation	-.143	.386*	-.255	.530**	-.316	1													
TSS	Pearson Correlation	-.374	.372	-.162	.279	-.262	.436*	1												
TDS	Pearson Correlation	.397*	.148	-.411*	-.130	-.398*	.032	-.538**	1											
TS	Pearson Correlation	.253	.389*	-.579**	.008	-.622**	.291	-.059	.873**	1										
COD	Pearson Correlation	-.280	.183	.089	.040	-.240	.269	.742**	-.527**	-.205	1									
Turb.	Pearson Correlation	-.118	-.400*	.313	-.166	.352	.534**	.379	-.141	.053	.281	1								
HCO ₃ ⁻	Pearson Correlation	-.054	-.569**	.415*	-.529**	.333	-.208	.143	.099	.201	.159	.522**	1							
Mn	Pearson Correlation	.053	-.840**	.968**	-.084	.689**	-.267	-.080	-.355	-.466*	.158	.297	.506**	1						
Zn	Pearson Correlation	-.099	.426*	-.097	.987**	-.406*	.616**	.278	-.063	.086	.078	-.079	-.479*	-.089	1					
Fe	Pearson Correlation	.297	.205	-.240	-.178	-.335	-.577**	-.273	.113	-.027	-.031	-.626**	-.366	-.231	-.225	1				

		Correlations																		
		T	pH	EC	Cl ⁻	NO ₃ ⁻	SO ₂	TSS	TDS	TS	COD	Turb.	HCO ₃ ⁻	Mn	Zn	Fe	Na	K	Mg	Ca
Na	Pearson	-.030	-	.991**	-.031	.702**	-.226	-.109	-.453*	-	.165	.298	.368	.958**	-.029	-	1			
	Correlation		.837**							.598**						.187				
K	Pearson	-.314	-.362	.289	-.513*	.554**	-.313	.007	-	-	.023	.095	.580**	.291	-	-	.202	1		
	Correlation							.625**	.606**					.538**	.492*					
Mg	Pearson	-.034	-	.905**	.314	.567**	-.034	-.053	-.421*	-	.125	.183	.183	.894**	.306	-	.918**	.120	1	
	Correlation		.643**							.528**						.315				
Ca	Pearson	.223	-	.870**	-.228	.720**	-	-	-.052	-	-	-.082	.364	.838**	-.251	.014	.841**	.286	.769**	1
	Correlation		.843**				.566**	.631**		.784**	.319									

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

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

a. Cannot be computed because at least one of the variables is constant

Table 5. Extraction summary for the three local government areas

Parameters	Descriptive statistics						
	Oredo		Egor		Ovia north east		Analysis N
	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation	
pH	4.7400	.70164	5.1300	.05196	4.9733	.10693	3
EC	69.6933	46.06129	20.7267	8.72808	23.8833	9.29063	3
Cl ⁻	252.1667	157.93538	133.8300	14.14220	118.3333	20.49593	3
NO ₃ ⁻	34.8400	9.68253	29.5800	3.19794	32.8300	4.16258	3
SO ₄ ²⁻	1.6400	1.08476	.8200	.41000	1.7800	.63174	3
TSS	.8900	.51391	1.0000	.67000	.5533	.38682	3
TDS	1.0033	.32501	1.2233	.69256	2.1100	1.64508	3
TS	1.8867	.69097	2.2200	.19079	2.6633	1.45335	3
COD	10.6667	6.66133	11.2000	4.80000	7.2033	4.15404	3
Turbidity	3.3367	.79664	2.1733	1.18056	3.4567	1.92500	3
HCO ₃ ⁻	15.0033	7.55050	14.3333	5.68624	14.3400	6.11447	3
Mn	.0667	.05132	.0133	.00577	-	-	3
Zn	.2800	.33151	.0767	.10693	.0233	.00577	3
Na	5.3167	3.42503	1.3333	1.10604	1.1667	1.00167	3
K	.5333	.47258	.5667	.51316	.5367	.60995	3
Mg	.4967	.14742	.0833	.04509	.0967	.07024	3
Ca	.2700	.23388	.1000	.10000	.1033	.10017	3

Table 6. Rotated component matrix for factors loadings^{a,b}

Parameters	Oredo		Egor		Ovia north east		Communality
	Component 1	Component 2	Component 1	Component 2	Component 1	Component 2	
pH	-0.856	0.518	0.347	0.938	0.375	-0.927	1.000
EC	0.923	-0.385	0.979	-0.203	0.864	0.504	1.000
Cl ⁻	-0.977	0.214	-0.986	-0.168	0.658	-0.753	1.000
NO ₃ ⁻	0.805	-0.593	-0.960	0.281	0.994	0.111	1.000
SO ₄ ²⁻	-0.757	0.654	-0.168	0.986	-0.001	1.000	1.000
TSS	-0.332	0.943	-0.168	0.986	0.324	0.946	1.000
TDS	-1.000	0.008	-0.114	-0.993	-0.957	-0.290	1.000
TS	-0.717	0.697	-0.993	-0.116	-0.997	-0.077	1.000
COD	0.239	0.971	0.770	0.638	0.325	0.946	1.000
Turbidity	0.960	0.280	-0.348	0.937	-0.194	0.981	1.000
HCO ₃ ⁻	0.993	-0.115	0.088	0.996	-0.990	0.140	1.000
Mn	0.975	-0.224	0.986	0.168	-0.981	-0.193	1.000
Zn	-0.966	0.260	0.993	0.122	-	-	1.000
Na	0.927	-0.374	0.969	-0.248	0.714	0.700	1.000
K	0.953	-0.305	0.058	0.998	0.872	-0.489	1.000
Mg	0.950	-0.312	0.958	-0.287	0.916	-0.400	1.000
Ca	0.856	-0.518	0.168	-0.986	0.963	-0.269	1.000
% Variance explained	84.9	15.1	51.1	48.9	59.0	49.0	

*Extraction Method: Principal Component Analysis.
 Rotation Method: Varimax with Kaiser Normalization.^a
 a. Rotation converged in 3 iterations*

4. CONCLUSION

The physicochemical parameters of the selected borehole water samples in the study area were within the acceptable limits by WHO standards for drinking water except the pH value which was comparatively low in some of the borehole water samples. Generally speaking, borehole water in Oredo, Egor and Ovia North-East Local Government Areas of Edo state is not harmful to human beings, although a few of the chemical parameters fell below the approved standards, they were judged to be acceptable since they were not above the required maximum permissible limits and thus posed no danger to human health.

The microbial analysis results of the nine selected borehole water samples showed zero (0) colonies which is an indication of excellent status. This means that the water samples from all nine borehole sources were hygienic for drinking and other domestic uses. However, periodic check on the borehole water samples is highly recommended so as to know the amount of different parameters that are above the required maximum permissible limits and thus not to pose any danger to human health.

Statistical analysis done on the values of the analyzed parameters revealed that no significant difference exists between the samples drawn from the three Local Government Areas and thus are all safe as they meet up with WHO standards.

The factors from the principal component analysis, showed that high communalities exist between the factors and the extracted components. Factors with correlation value >0.5 were considered significant. The rotated component matrix score for factors loadings; In Oredo LGA, Factor 1 accounts for 84.9% contributions with high loading in EC, NO_3^- , Turbidity, HCO_3^- , Mn^+ , Na^+ , K^+ , Mg^+ and Ca^+ . Factor 2 is highly loaded in pH, SO_4^{2-} , TSS, TS and COD, accounting for 15.1% of the contributions. Also in Egor LGA, Factor 1 accounts for 51.1% contributions with high loading in EC, COD, Mn^+ , Zn^+ , Na^+ and Mg^+ . Factor 2 is highly loaded in pH, SO_4^{2-} , TSS, COD, Turbidity, HCO_3^- , and K^+ accounting for 48.9% of the contributions. While in Ovia North-East LGA, Factor 1 accounts for 59.0% contributions with high loading in EC, Cl⁻,

NO_3^- , Na^+ , K^+ , Mg^+ and Ca^+ . Factor 2 is highly loaded in SO_4^{2-} , TSS, COD, Turbidity, and Na^+ accounting for 49.0% of the contributions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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