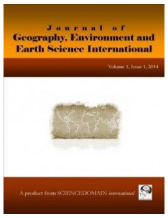

Journal of Geography, Environment and Earth Science International

14(2): 1-16, 2018; Article no.JGEESI.40438
ISSN: 2454-7352

Characterization of Groundwater Quality Using Water Quality Index in Umuebulu IV Oyigbo, Rivers State

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2018/40438
Editor(s):
(1) Wen-Cheng Liu, Department of Civil and Disaster Prevention Engineering, National United University, Taiwan and Taiwan Typhoon and Flood Research Institute, National United University, Taipei, Taiwan.
Reviewers:
(1) Peiyue Li, Chang'an University, China.
(2) Ashish Kumar, Agra College, India.
(3) C. R. Ramakrishnaiah, Visvesvaraya Technological University, India.
(4) Basak Taseli, Giresun University, Turkey.
Complete Peer review History: http://www.sciencedomain.org/review-history/23921

Original Research Article

Received 15th January 2018
Accepted 27th March 2018
Published 31st March 2018

ABSTRACT

This study evaluated the groundwater quality in Umuebulu IV, Oyigbo, using water quality index (WQI) with a view to ascertain its suitability for domestic and drinking water purposes. Groundwater samples were collected from ten (10) functional boreholes in the study area. These water samples were subjected to a comprehensive physicochemical analysis using standard method. The water quality index of the area was calculated using weighted arithmetic mean. Fifteen (15) parameters were analyzed but only nine (9): pH, Electrical conductivity, Total Dissolved Solids, Chloride, Nitrate, Sulphate, Phosphate, Total Hardness and Sodium which were detected during the analysis was used for the WQI calculation. The WQI values of 18.69, 13.86, 17.67, 16.01, 16.99, 14.69, 12.94, 16.50, 13.09 and 11.78 were recorded from BH1 to BH10 respectively which shows that that all the water samples were in the excellent category. The pH values ranging from 5.47 - 5.82 shows slight acidity and as such would require treatment to bring it to an acceptable limit. However, the

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low values of the WQI have been found to be mainly due to the low values of the chemical parameters analyzed suggesting that the groundwater is suitable for domestic and drinking purpose.

Keywords: Groundwater; borehole; pollution; water quality index; physico-chemical; umuebulu.

1. INTRODUCTION

Water is described as an elixir of life and a fundamental resource, central to a lot of social and environmental processes. A country's security is also dependent on it and has the capacity to affect its development. Accessing adequate safe drinking water is of paramount importance to the government of countries and international organizations because of its role in human development and primary health care [1].

The Niger- Delta region in Nigeria which Rivers State is a part of is endowed with groundwater resources. According to Edet et al. [2] the estimated total groundwater resources in Nigeria are about 6 x $10^{18}m^3$. The landscape of the Niger Delta is composed of swamps and creeks, and this helps in recharging groundwater aquifers within this region Udom et al. [3].

The water supply source in Nigeria is groundwater, surface water or rainwater. The component of groundwater depends on factors like hydrological, geological, topofical, and biological properties in the aquifer and differs due to a seasonal difference in runoff water, climatic conditions [4]. According to Amadi et al. [5] "Groundwater can be said to be all water located under the surface of the earth and it passes via porous spaces between various rocks and interacts with certain minerals that are constituents of rocks during its movement". It can be recharged or replenished through natural processes like percolation of atmospheric water, therefore, it is a renewable resource in nature. Surface and groundwater sources can be polluted by biochemical pollutants that arise from various sources [6].

Quality of groundwater and its appropriateness for drinking could be ascertained by investigating its quality rating.

Water Quality Index can be described as a ranking that reveals the weight or power of various physicochemical parameters on water quality. It is designed to evaluate the fitness of groundwater for human utilization [7].

In Rivers State, groundwater is vulnerable due to different land uses like municipal waste dumping site, mechanic villages, industrial and oil and gas facilities. A study on water services provided by the State Water Agencies in Nigeria revealed that Nigeria is on a downward spiral regarding access to adequate infrastructure, despite significant growth in the economy and the enormous funds at its disposal to ensure safe, affordable and dependable water supply [8].

Some areas must rely on inadequate private water supplies as their groundwater supply is significantly exposed to possible contaminants because of improper town planning and this is an obvious problem in Umuebulu IV Oyigbo Local Government Area, Rivers State.

Umuebulu is a residential area that is highly populated, with a lot of auto- repair workshops. Materials like rings, rims, piston and engine parts; and other automobile parts are all over the place. Paints, thinners, and spray which are composed of chromium, lead and condemned oil are recklessly dumped. The resultant particles generated are dispersed by rain and this helps in moving some of the pollutants in these areas where private water supplies are present in various homes. Also due to inadequate solid waste collection systems, there is unobstructed and unfettered dumping of refuse at various locations within the environment; these refuse sites are loaded with both organic and inorganic waste and generate leachates in these areas.

The result of the study will; Provide town planners with insights on the probable consequence of specific land use activities; Make a gateway in determining the likely causes of a sudden disease outbreak; Provide information that will encourage pollution monitoring and control and also surveillance strategies to the ministry of environment.

Consequently, this research sought to establish the groundwater quality in Umuebulu IV, Oyigbo LGA using Water Quality Index (WQI).

2. MATERIALS AND METHODS

2.1 Study Area

The study area is Umuebulu IV Oyigbo Local Government Area of Rivers State which lies between longitude 7º07º01' E and latitude 4º53' N as shown in Fig. 2.1. The area houses several mechanic workshops, refuse dumpsite and a gas flare/ flow station built by Shell Petroleum Development Company all of which have the capacity of polluting groundwater. The Umuebulu region has an annual rainfall between 2000-3000 mm/yr while the mean annual temperature is 27ºC. The vegetation is majorly tropical rain forest. [9].

2.2 Sample and Sampling Technique

Ten functional boreholes were sampled randomly in Umuebulu IV Oyigbo LGA, Rivers State. The sampling points were spread within a 200km radius of the Shell Petroleum Development Company facility as shown in Fig. 2.2. All the samples were collected on the same day after running the borehole for 10 minutes and transferred to a 1.5 litres eva water bottle which previously contained sealed water. The eva water bottles were labeled and sealed properly.

The materials used were:

i. 1.5 litres eva water bottle
ii. Geographic Positioning System
iii. Notebook and marker

The ten(10) borehole samples were analyzed for fifteen parameters: Temperature, pH, Electrical conductivity, Total dissolved solids, Magnessium, Calcium, Iron, Chloride, Sodium, Nitrate, Sulphate, Phosphate, Zinc, Copper and Lead.

The APHA procedure was used for the determination of these physico- chemical parameters.

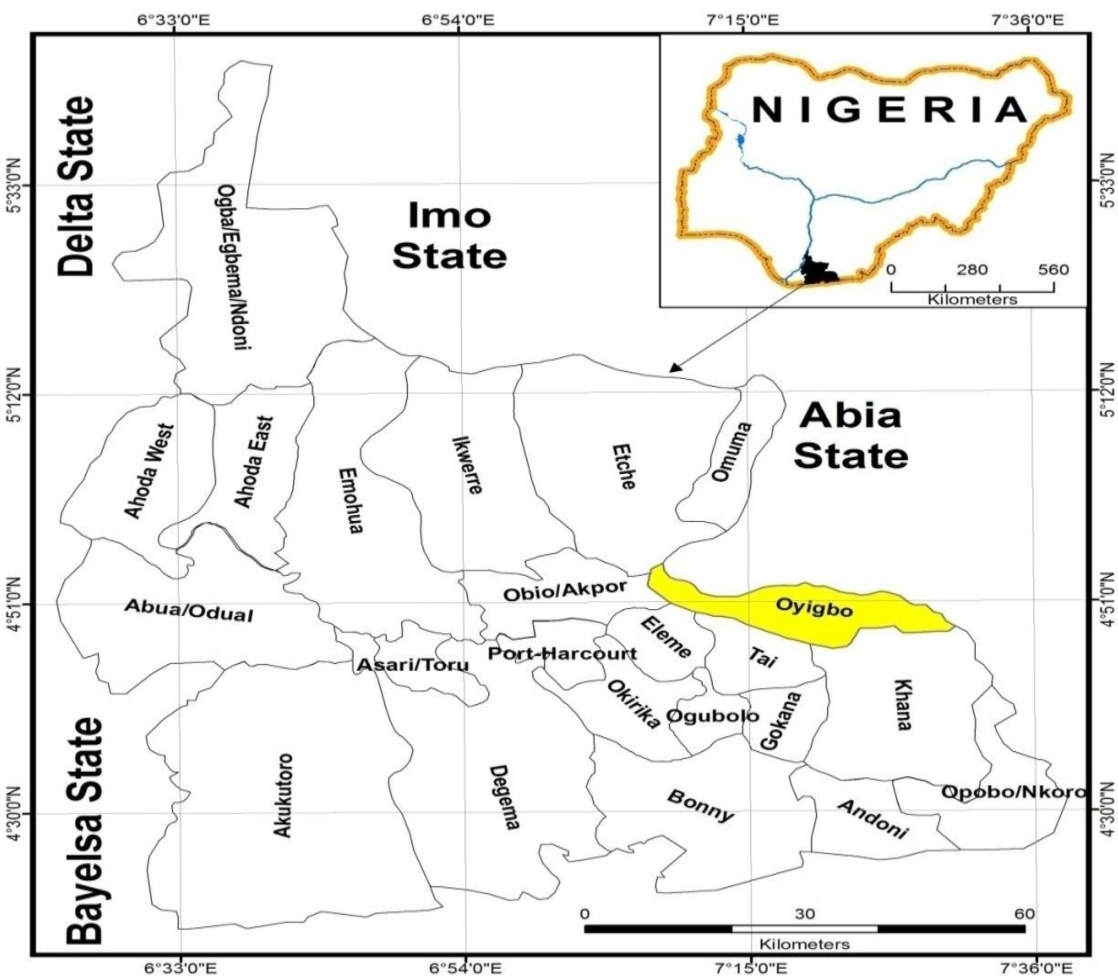

Fig. 2.1. Map of Rivers State showing the location of Oyigbo

Table 2.1. Coordinates of sampled boreholes in Umuebulu IV

Borehole Code	Borehole Location	Borehole Coordinate	
		Latitude	Longitude
BH1	Road 2 diamond estate	N4°53'38.4''	E 7°6'58.1
BH2	School road junction	N4°53'33.9''	E 7°7'01.1
BH3	Road 1 diamond estate	N4°53'41.2''	E 7°6'59.0
BH4	Messiah street	N4°53'45.8''	E7°7'19.7
BH5	Sunlight estate	N4°53'45.1''	E7°7'25.7
BH6	Divine street	N4°53'45.5''	E7°7'31.0
BH7	Innocent Njoku Avenue	N4°53'37.0''	E 7°7'26.6
BH8	Jesus market	N4°53'43.8''	E 7°7'19.3
BH9	Jilord Close	N4°53'22.8''	E 7°7'28.6
BH10	Priston International School	N4°53'19.5''	E 7°7'33.5

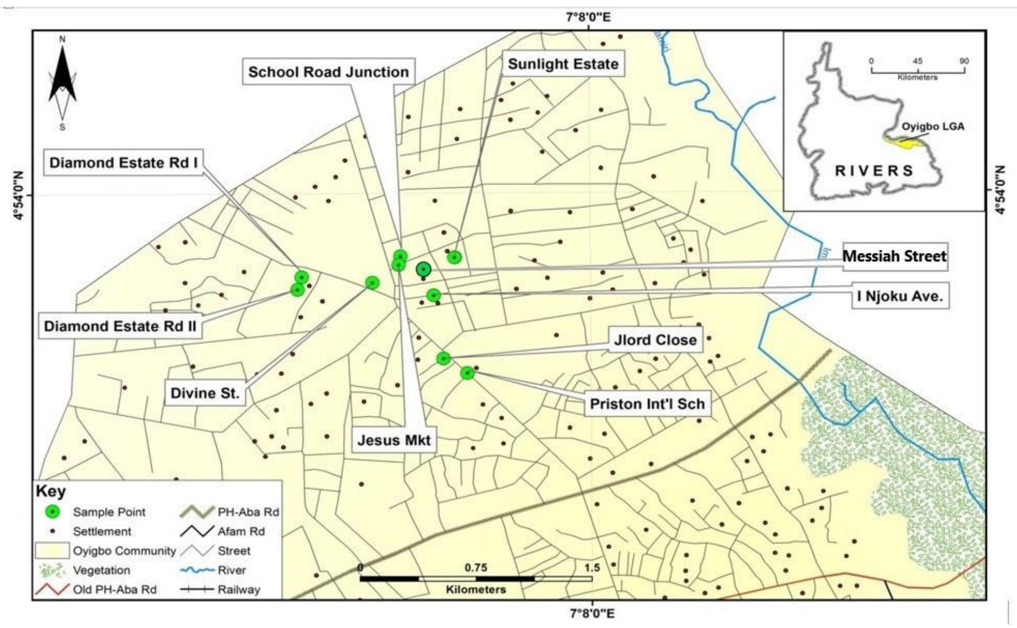

Fig. 2.2. Map of the study area showing the sampling points

2.3 Data Acquisition

The following data were gathered in the field

I. Precise locations of the borehole
II. Co-ordinates of the sampling locations

All groundwater samples were labeled appropriately. The coordinates of the borehole locations were taken using Geographic Positioning System (GPS) Garmin Channel 78 Model.

2.4 Field Measurement

The parameters that were measured in the field are temperature and pH

2.4.1 Temperature

The temperature was measured in the field using mercury in glass thermometer. The thermometer was immersed in the water sample and the reading recorded in the field note.

2.4.2 pH

The pH of the groundwater samples were gotten during the field work by means of a pH meter.

2.5 Physico-chemical Analysis of Basic Groundwater Quality Parameters

Physico chemical analysis of groundwater samples was evaluated while referring to the 'standard methods' APHA [10]. Various methods used are listed in Table 2.2. The collected sample were then brought to the scientific laboratory and analyzed immediately.

2.6 Water Quality Index Calculation from Parameters Determined

The calculation of the WQI was done by weighted arithmetic index method. The water quality index was calculated using the following simple steps.

In the 1st Step, nine of the parameters were given a weight (*wi*) according to the significant role it has in the overall quality of water for drinking. The highest weight of five (5) was assigned to Nitrate because of its significance when found in water at elevated levels while Sodium, Chloride and Total hardness were assigned lowest weight of three (3).

In the 2nd Step, the calculation below was used to get the relative weight (*Wi*)

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \qquad (1)$$

Where *Wi* is the relative weight; *wi* is the weight in terms of significance linked with the specific parameter; n is the number of parameters being used for the calculation.

In the 3rd Step, a quality rating scale (*qi*) for each parameter was assigned by dividing its concentration in each groundwater sample by the World Health Organization (WHO) standard and the result gotten multiplied by 100.

$$qi = \left(\frac{ci}{si}\right) \times 100 \qquad (2)$$

Where qi is the quality rating, *ci* is the concentration of each parameter in water sample measured in mg/l, *si* is the World Health Organization standard for each parameter measured in mg/l.

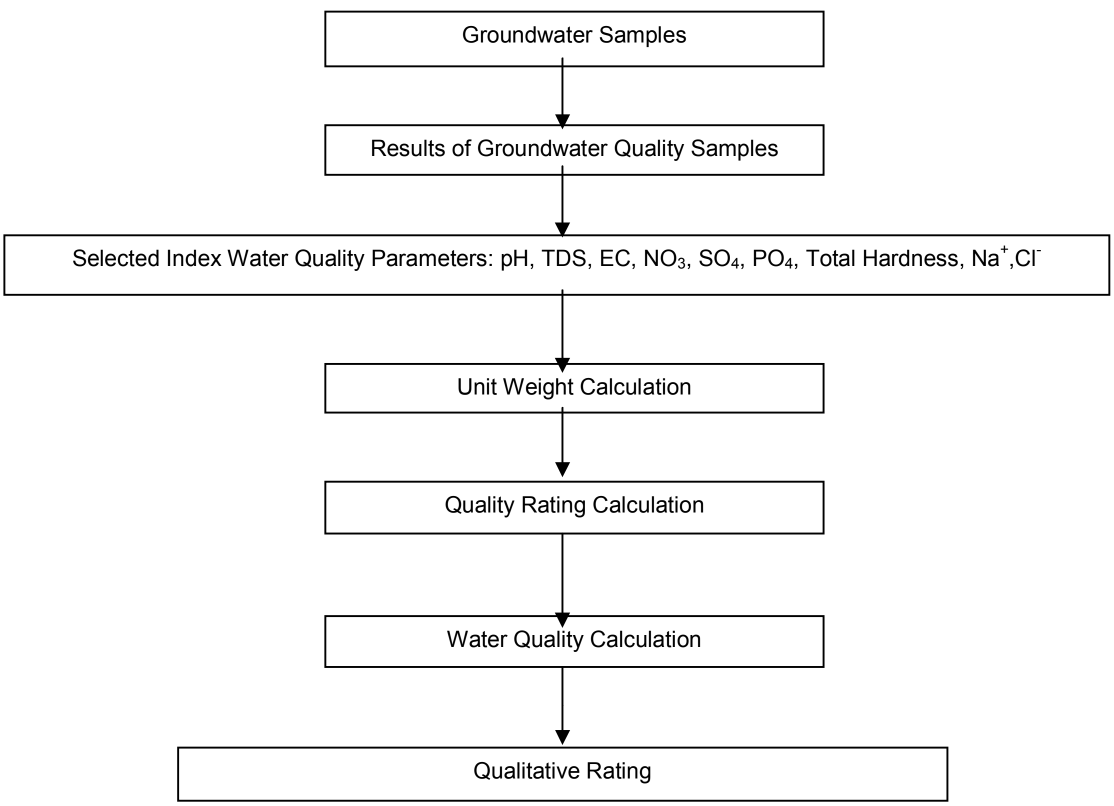

Fig. 2.3. Model for water quality index (WQI) calculation

Table 2.2. Physico-chemical analysis of basic water quality parameters by different methods

Parameter	Method/Equipment used
pH	Digital pH meter
EC	Digital conductivity meter
Fe^{2+}, Ca^{2+}, Mg^{2+}, Na^{+}	Spectrophotometric
TDS	Filtration followed by weighing
NO^{3-}, SO_4^{2-} PO_4^{2-}, Cl^{-}	Titrimetric
Lead, Zinc, Copper	AAS (Automated)

For calculating the WQI, the *SIi* was calculated for each of the nine (9) parameters and at the end the nine (9) *SIi* values were then summed up to get the WQI value.

$$SIi = Wi \times qi \quad (3)$$

$$WQI = \sum SIi \quad (4)$$

Where *SIi* is the sub index, *qi* is the rating based on concentration of parameters, *n* is the number of parameters. The computed WQI values would then be used to classify the water types that were found in Umuebulu IV.

Nevertheless water quality classification based on WQI value is grouped into five major types: Excellent water which is class I, good water which is class II, poor water which is class III, very poor water which is class IV and water that is unsuitable for drinking which make up the final class V. Brown et al. [11] and this is shown in Table 3.2.

3. RESULTS AND DISCUSSION

3.1 Basic Groundwater Quality Parameters

The results obtained from the physico-chemical analysis of basic groundwater quality parameters carried out in Umuebulu IV are shown in Table 3.1. The chart for levels of pH, Electrical conductivity, Chloride, Total Dissolved Solids can be found in Figs. 3.1- 3.9.

3.2 Water Quality Index from the Parameters Determined

Water Quality Index (WQI) is used to establish the quality of groundwater in other to shrink the bulkiness of data produced from water quality analysis and generalize it into a distinct numerical value. It also represents the significant role the water quality parameter plays in determination of water quality for drinking and

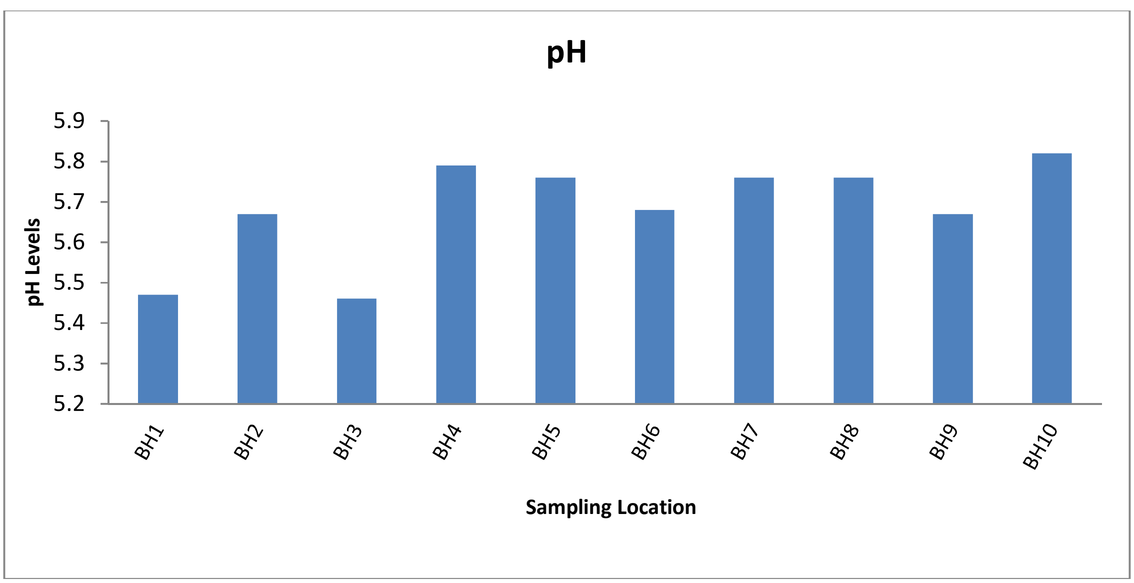

Fig. 3.1. pH levels in the ten (10) Sampling locations

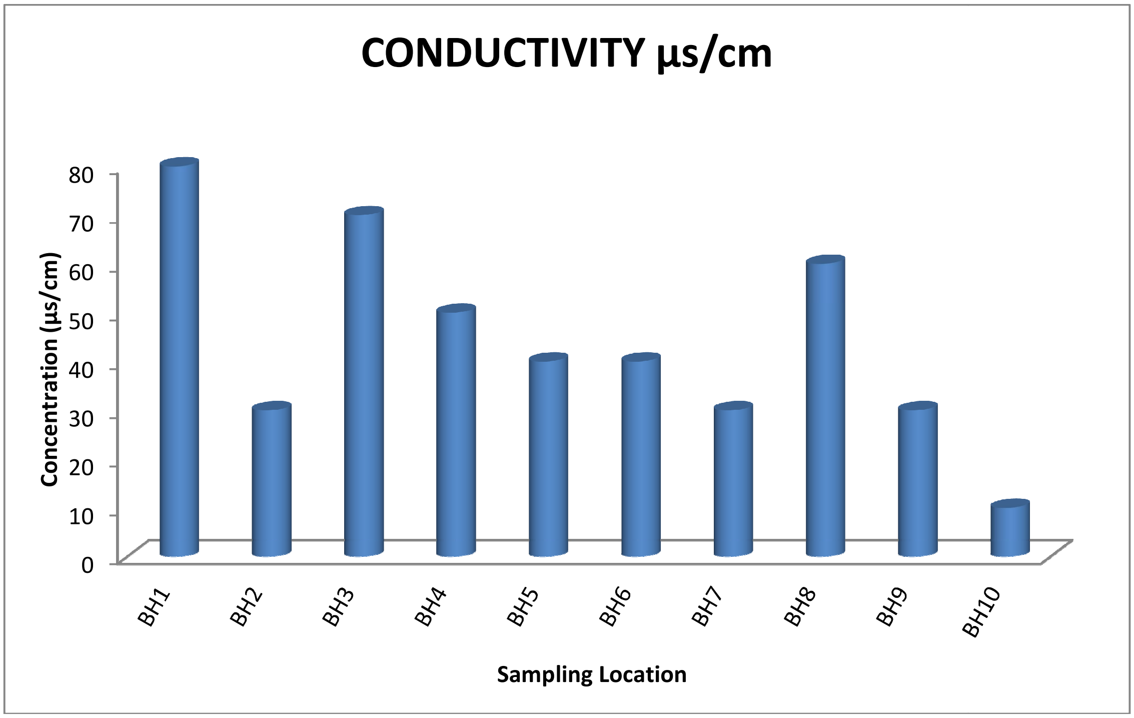

Fig. 3.2. Electrical conductivity levels in the ten (10) sampling locations

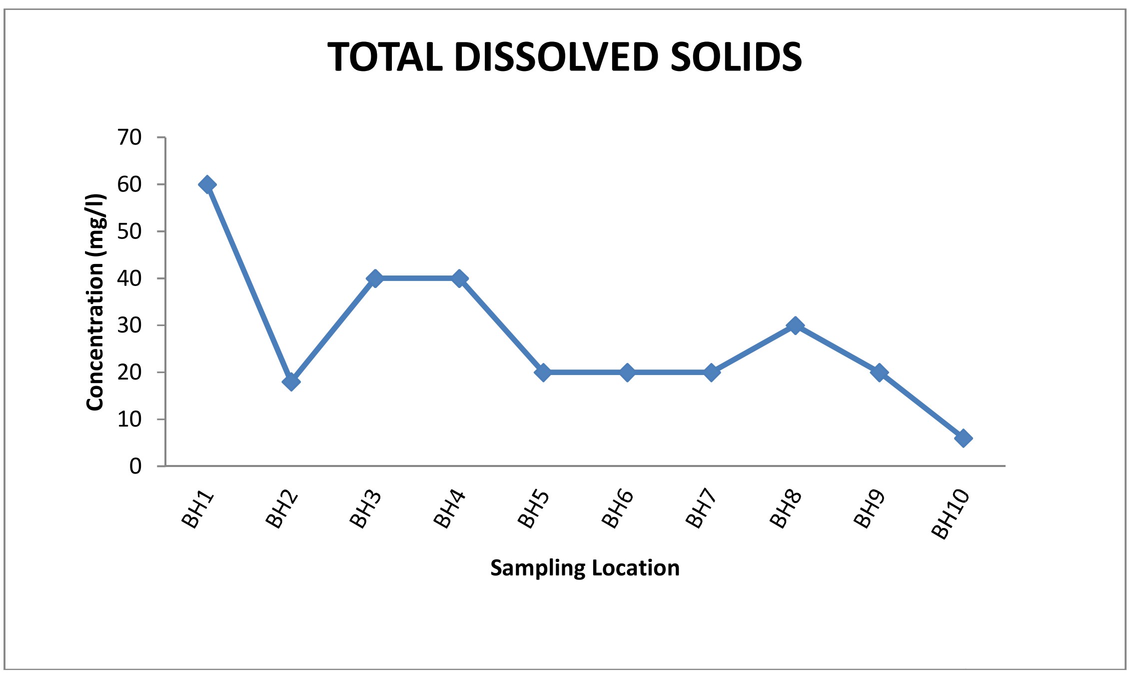

Fig. 3.3. Total dissolved solids value in the ten (10) borehole samples

domestic use. WQI values in Umuebulu IV were calculated and the values obtained are shown on Table 3.3. The WQI values from the study area ranged from 11.78 to 18.69 all within the class of Excellent water which indicates that the water can be used suitably for drinking and domestic purpose.

3.3 Delineation of Area of Different WQI

From the WQI values obtained, there is only one class of water that can be delineated in the area which is shown by a 100% of the water samples being in the excellent water class and this is shown in Table 3.4.

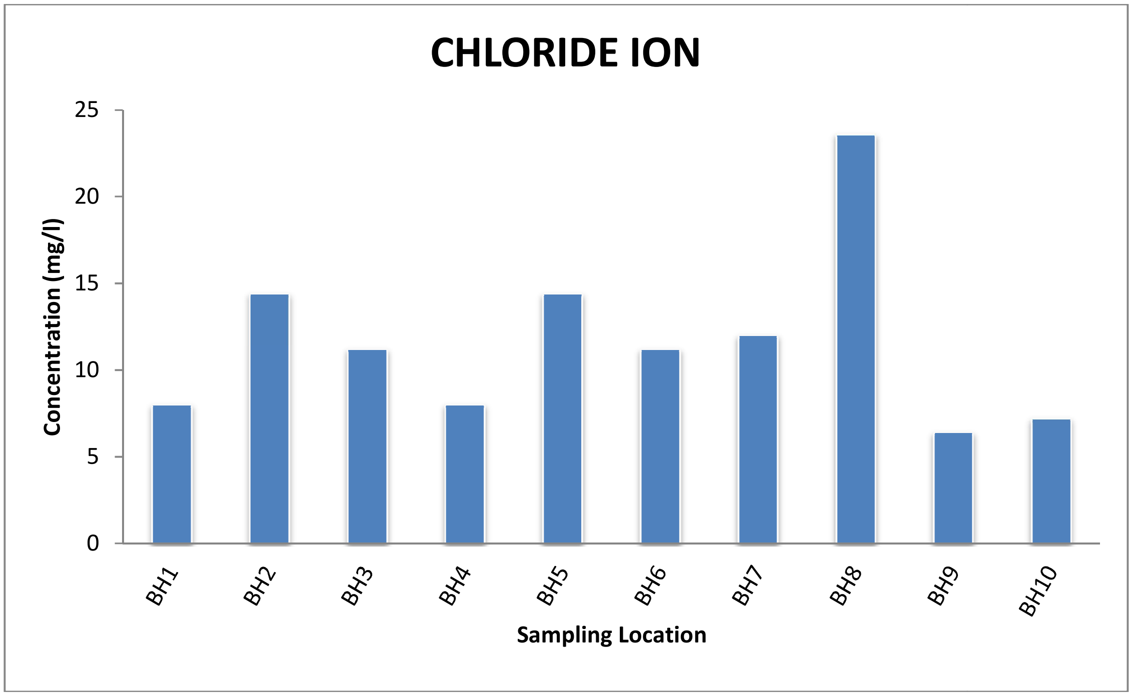

Fig. 3.4. Chloride Ion levels in the ten (10) Sampling locations

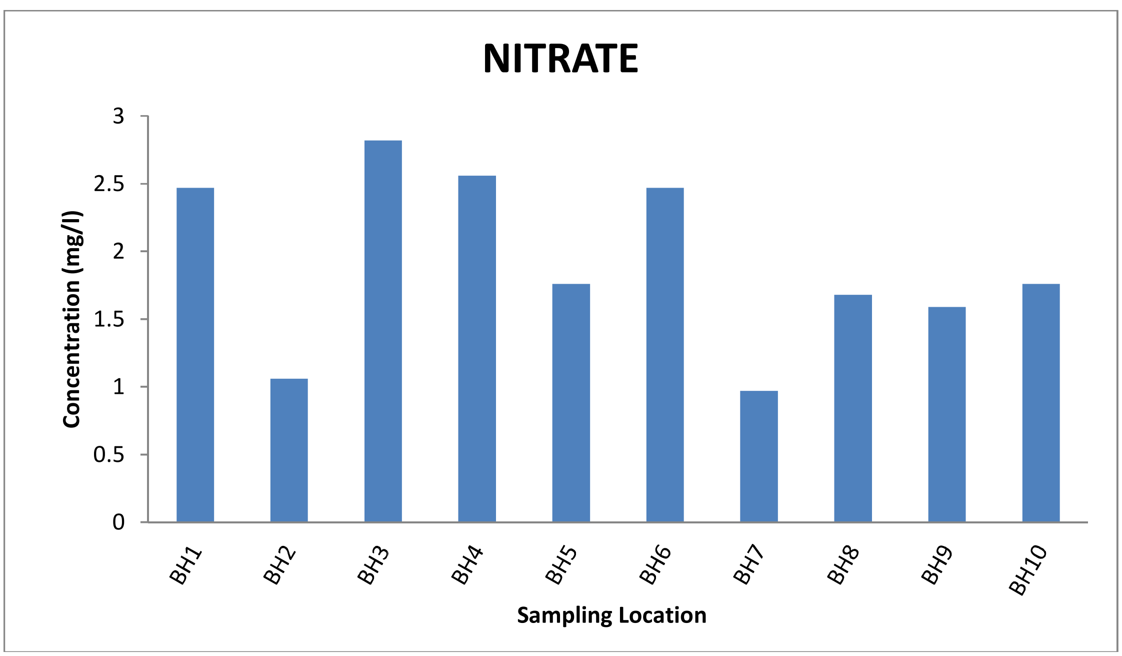

Fig. 3.5. Nitrate Levels in the ten (10) Sampling locations

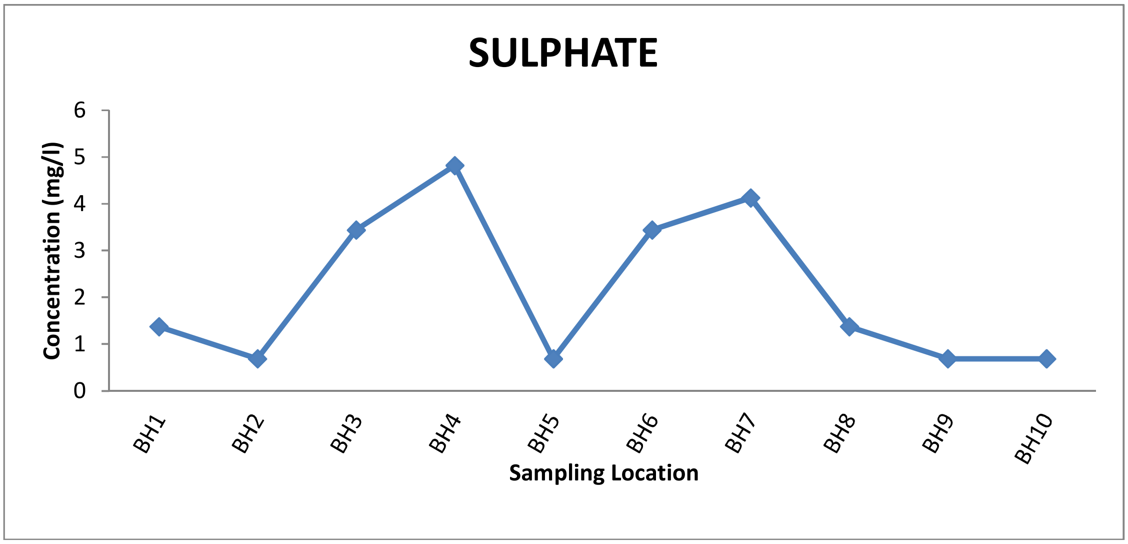

Fig. 3.6. Sulphate levels in the ten (10) Sampling locations

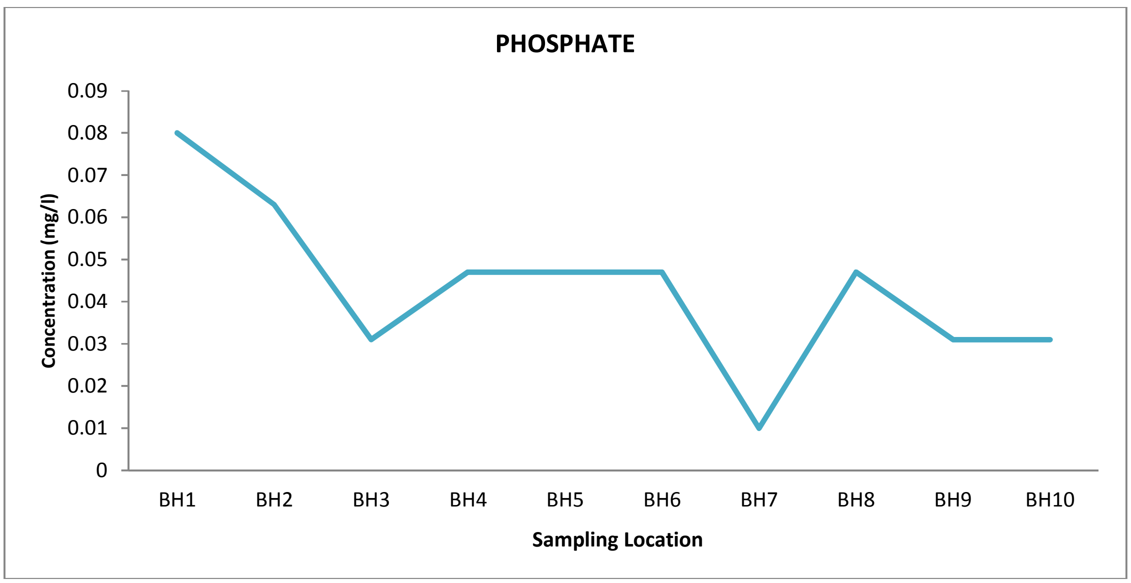

Fig. 3.7. Phosphate levels in the ten (10) sampling locations

3.4 Discussion

3.4.1 Basic groundwater parameters

3.4.1.1 pH

pH affects certain processes involved in treating water and it plays a huge role in rusting of distribution lines and household plumbing fixtures. It also determines the solubility as well as the reaction rate of metal ions involved in corrosion. This corrosion can add metals like iron, lead, copper etc. Irrespective of the WQI values being in the Excellent water class, the pH levels in the ten (10) samples were below WHO [12] and NSDWQ [13] standard for values for drinking water. The values obtained are from BH1 to BH10: 5.47, 5.67, 5.46, 5.79, 5.76, 5.68, 5.76, 5.76, 5.67, and 5.82 and this suggests the presence of acidity in the water samples. The results obtained from this research are similar to that reported by Adindu et al. [14] in groundwater samples analyzed in Osisioma Local Government Area, Abia State. They reported pH levels ranging from 6.0 to 6.3 which also suggest presence of acidity in water. Yisa et al. [15] also reported pH levels within the range of 5.81 to 6.83 in ten well samples analyzed in Maikunkele area, Niger state which also suggests the unsuitability of the well water for drinking purpose. All these results are in contrast with Onwughara et al. [16] reported pH levels ranging from 6.79 to 7.24 in Abia State which lie within the WHO [11] standard for drinking water. Also Balogun et al. [17] reported elevated pH levels of between 8.1 and 8.3 in boreholes at several locations in parts of Lagos state.

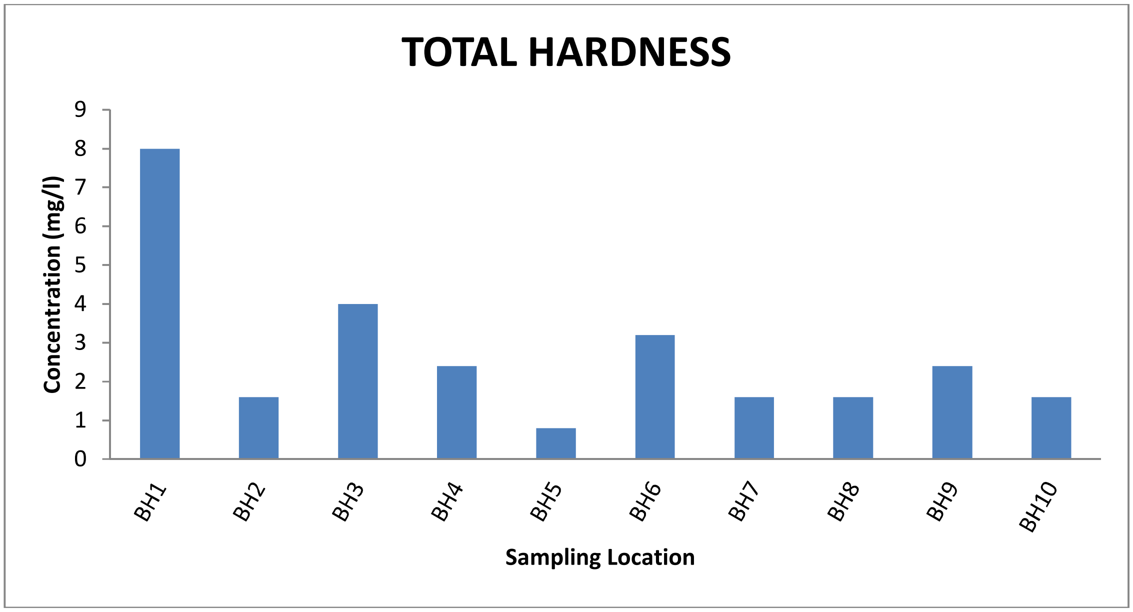

Fig. 3.8. Total hardness concentration in the ten (10) sampling locations

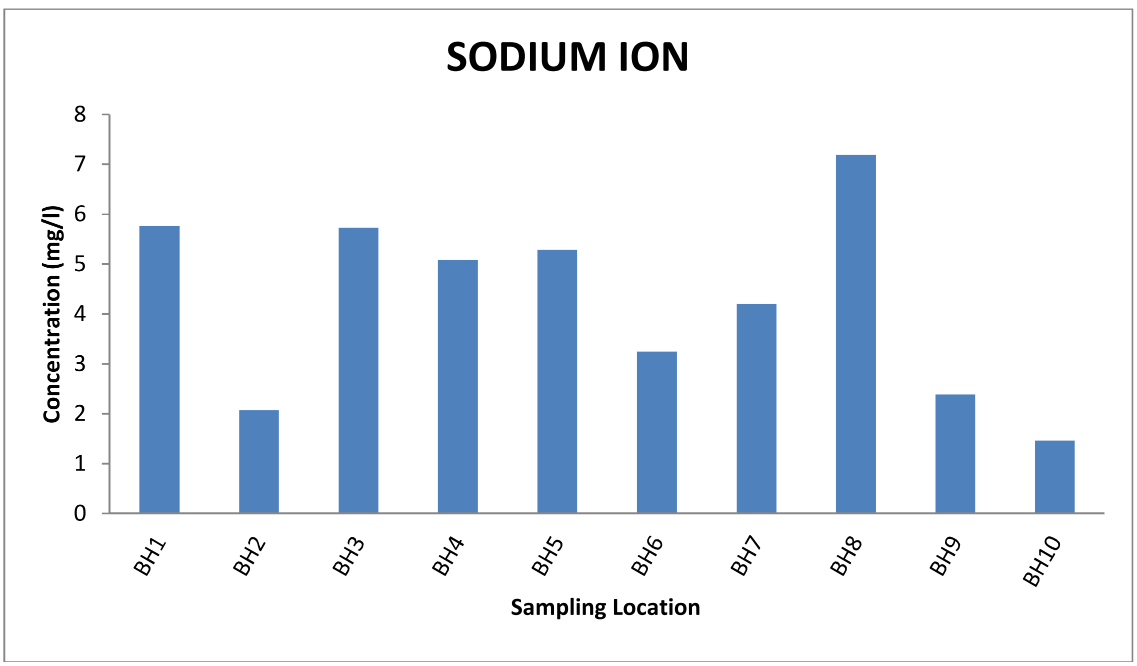

Fig. 3.9. Concentration of sodium ion in the ten (10) sampling location

Table 3.1. Results of physico- chemical analysis measured in Umuebulu IV

LOCATION	pH	CONDUCTIVTIY(µs/cm)	TEMPERATURE (°C)	TOTALDISSOLVED SOLIDS	CHLORIDE (Cl^-)	NITRATE (NO_3^-)	SULPHATE (SO_4^-)	PHOSPHATE (PO_4^-)	TOTAL HARDNESS	MAGNESSIUM	SODIUM	CALCIUM	IRON	LEAD	COPPER
				Mg/l											
ROAD 2 D. ESTATE(BH1)	5.47	80	29	60.00	8.00	2.47	1.378	0.080	8.00	ND	5.762	ND	ND	ND	ND
SCHOOL ROAD J.(BH2)	5.67	30	29	18.00	14.40	1.06	0.689	0.063	1.60	ND	2.070	ND	ND	ND	ND
ROAD 1 D. ESTATE(BH3)	5.46	70	29	40.00	11.20	2.82	3.440	0.031	4.00	ND	5.730	ND	ND	ND	ND
MESSIAH STREET(BH4)	5.79	50	29	40.00	8.00	2.56	4.820	0.047	2.40	ND	5.084	ND	ND	ND	ND
SUNLIGHT ESTATE(BH5)	5.76	40	29	20.00	14.40	1.76	0.689	0.047	0.80	ND	5.286	ND	ND	ND	ND
DIVINE STREET(BH6)	5.68	40	29	20.00	11.20	2.47	3.440	0.047	3.20	ND	3.249	ND	ND	ND	ND

Table 3.1. Results of physico- chemical analysis measured in Umuebulu IV (Contd.)

LOCATION	pH	CONDUCTIVTIY(µs/cm)	TEMPERATURE (°C)	TOTALDISSOLVED SOLIDS	CHLORIDE (Cl^-)	NITRATE (NO_3^-)	SULPHATE (SO_4^-)	PHOSPHATE (PO_4^-)	TOTAL HARDNESS	MAGNESSIUM	SODIUM	CALCIUM	IRON	LEAD	COPPER
				Mg/l											
INNO AVE(BH7)	5.76	30	29	20.00	12.00	0.97	4.130	0.010	1.60	ND	4.205	ND	ND	ND	ND
JESUS MKT(BH8)	5.76	60	29	30.00	23.60	1.68	1.378	0.047	1.60	ND	7.185	ND	ND	ND	ND
JILORD CLOSE (BH9)	5.67	30	29	20.00	6.40	1.59	0.689	0.031	2.40	ND	2.388	ND	ND	ND	ND
PRISTONSCH OOL(BH10)	5.82	10	29	6.00	7.20	1.76	0.689	0.031	1.60	ND	1.467	ND	ND	ND	ND
WHO (2011)	6.5-8.5	NGV	27	500	250	50	250	0.5	150	50	200	75	0.5	0.01	2
NSDWQ (2007)	6.5-8.5	NGV	27	500	250	50	100	NGV	150	0.20	200	75	0.3	0.01	2

Table 3.2. The assigned and relative weight of the nine (9) parameters

Parameters	Weight (*wi*)	Relative weight (*Wi*)	WHO Standard	NSDWQ Standard
pH	4	0.12	6.5-8.5	6.5-8.5
EC (µs/cm)	4	0.12	NGV	NGV
TDS (mg/l)	4	0.12	500	500
Cl^- (mg/l)	3	0.09	250	250
NO_3^- (mg/l)	5	0.15	50	50
SO_4^- (mg/l)	4	0.12	250	100
PO_4^- (mg/l)	4	0.12	0.5	0.5
TH (mg/l)	3	0.09	NGV	150
Na^+ (mg/l)	3	0.09	200	200
	∑wi= 34	∑Wi=1.02		

Table 3.3. Summary of water quality index of Umuebulu IV

Borehole code	Location	WQI value	Class
BH1	Road 2 D. Estate	18.69	Excellent
BH2	School road	13.86	Excellent
BH3	Road 1 D. Estate	17.67	Excellent
BH4	Messiah Street	16.01	Excellent
BH5	Sunlight Estate	16.99	Excellent
BH6	Divine Street	14.69	Excellent
BH7	Innocent Njoku Avenue	12.94	Excellent
BH8	Jesus Market	16.50	Excellent
BH9	Jilord Close	13.09	Excellent
BH10	Priston Int'l School	11.78	Excellent

Table 3.4. Water quality classification of umuebulu IV based on WQI

Water Quality Index Value	Class	Water quality status	Percentage of water samples
< 50	I	Excellent Water	100%
50 – 100	II	Good Water	0%
100 – 200	III	Poor Water	0%
200 – 300	IV	Very Poor Water	0%
>300	V	Unsuitable Water	0%

From the pH values obtained it suggests that the water is slightly acidic and requires treatment with either a dolomite or calcite in other to bring it to the acceptable limit of pH for drinking water purpose.

3.4.1.2 Electrical conductivity

Electrical conductivity values mainly depend on ionic concentration or dissolved inorganic substances. In the present study there is a significant difference in the conductivity of the water samples ranging from 10 µs/cm in BH10 which served as the control to 80 µs/cm in BH1 although it falls within Queensland Health Forensic and Scientific Service guideline value for EC in drinking water of 200µs/cm but this is in contrast to Balogun et al. [17] that reported Electrical conductivity values ranging between 101 and 293 µS/cm with a mean of 172.57 µS/cm in water samples analyzed in Lagos state. Fundamentally, the geology of the area may account for the conductivity levels of the groundwater.

3.4.1.3 Total dissolved solids

The TDS values ranging from; 6mg/l at BH10 to 60mg/l at BH1 suggests that there are very little contaminant present in the samples. The highest TDS value of 60mg/l could be as a result of the nearness of the sample location to the burrow pit (surface depression) in the area; urban runoff or fertilizer residue run- off even though there is no significant difference with WHO [11] and the NSDWQ [12] limit of 500mg/l. According to Todd (1980) in Kwame et al. [18] TDS values of between 20 mg/l and 1000 mg/l, are classified as freshwater, those that lie within the range of 1000 mg/l –10000 mg/l the water is regarded as brackish/estuarine while 10000 mg/l and above is totally unacceptable. The low TDS values also influenced the water quality index of the various water samples analyzed.

3.4.1.4 Chloride

Chloride has an effect on taste and because it accelerates corrosion of distribution systems, elevated chloride levels can cause water to be unfit for human consumption. Chloride originates mostly from natural sources, sewage, urban run-off and saline intrusion into aquifers. Chloride is the dominant anion within Umuebulu IV, the value varies from 8mg/l in BH4 to 23.60 mg/l in BH8. The concentration of Chloride ion within Umuebulu IV was found within the permissible limit of 250 mg/l and similar to those reported by Adindu et al. [14]. As a result of the low levels of chloride it suggests that the groundwater in Umuebulu IV is Freshwater and there is no saline water intrusion within the aquifer.

3.4.1.5 Nitrate

The presence of nitrate recorded may be as a result of leaching from agricultural activities like application of nitrogenous fertilizer leading to leaching of nitrate through the soil to groundwater, also septic tank seepage due to their nearness to the boreholes. Nitrate levels were found to be between concentrations of 0.97 mg/l to 2.82 mg/l in the groundwater samples analyzed which are relatively low values and lie within the guideline/standard value for nitrate in drinking water. During the Calculation of WQI, nitrate was given a weight (wi) of 5 because at levels above 50mg/l in drinking water it becomes toxic and can result in Methaemoglobinemia in infants. It also has the propensity to inhibit intake of iodine into the human body as well as cause gastric cancer.

3.4.1.6 Sulphate

High levels of sulphate occur occasionally in groundwater as a result of industrial waste discharge and through atmospheric deposition. The data gotten from a human volunteer research showed that it has a laxative effect on the body at concentrations of 1000- 1200 mg/l according to WHO [11]. It also has an effect on the gastrointestinal tract of man and gives water a bad taste as well as has the ability to corrode water distribution pipes.

The sulphate values obtained in the ten (10) water samples indicated low sulphate concentration ranging from 0.689 mg/l to 4.820 mg/l and the source of the sulphate is from rainfall. The result obtained is a bit contrasting from results recorded by Kwame et al. [18], where they obtained sulphate levels ranging from 3 mg/l to 38 mg/l in water samples analysed in Ghana.

3.4.1.7 Phosphate

Phosphate is toxic at very high levels when taken into the body; it can lead to digestive problems. Phosphate concentration within Umuebulu IV ranged from 0.010 mg/l to 0.080 mg/l which is below WHO [11] limit of 0.5 mg/l for phosphate in drinking water and the results obtained are similar to that reported by Udom et al. [3]: 0.02 mg/l to 0.19 mg/l in Ogbia. The sources of phosphate recorded could be from atmospheric deposition and sedimentation or from phosphate fertilizers that can enter the groundwater system or aquifer as run off.

3.4.1.8 Total hardness

The values for Total Hardness ranged from 0.8-8mg/l. This varies from results reported by Balogun et al. [17] of total hardness concentration level ranging from 14 to 624 mg/l. The concentration obtained in Umuebulu IV is an indication that the water is soft and therefore good for drinking and use for domestic purposes. The water samples would easily allow soap to form lather while washing. The similarity between the values obtained could be as a result of the hydrogeology and geochemistry of the area.

3.4.1.9 Sodium

The concentration of sodium in drinking water is usually less than 20mg/l and water softener has the ability to add significantly to the sodium content of water. The concentration of sodium in the water samples ranged from 1.46 to 7.1 mg/l. The values fell below the WHO [11] limit for drinking water quality of 200 mg/l. When concentrations exceed this level it gives rise to unacceptable taste. The sodium concentration differs from that reported by Udom et al. [3] of sodium levels ranging from 80mg/l to 106 mg/l in Ogbia.

3.4.2 Water quality index

The pH, Electrical conductivity, Total Dissolved Solids, Chloride, Nitrate, Sulphate, Phosphate, Total Hardness and Sodium in the water samples were determined in other to derive the WQI values after correlation with World Health Organization WHO [11]. The WQI values obtained ranged from 11.78 – 18.69 and the relatively low value of the WQI suggests that there are little or no pollutants present in the water samples analyzed. The WQI values are similar to values reported by Kwame et al. [18] where 84% of the groundwater samples analyzed in Ejisu-Juaben municipality in Ghana were in the Excellent water class for drinking water purpose. In contrast to the results obtained from this study, Dick [19] reported that 100% of the hand dug well water analyzed in Oproama community fell under the poor water class for drinking and domestic use.

According to Brown et al. [11] in Udom et al. [3], the categorization of water quality based on water quality index (WQI) value are as follows: WQI > 300 is an indication that the water is unsuitable for drinking, WQI value between 200-300 is regarded as very poor water, 100 to 200 is regarded as poor water, 50 to 100 is good water and WQI value <50 is an Excellent water as shown in Table 3.3 The summary of water quality of Umuebulu IV is shown in Table 3.4.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The water quality index (WQI) values of Umuebulu IV ranged from 11.78 to 18.44. This was used to categorize the excellent water class. The pH levels obtained in the area showed that the water has a slight acidity and this requires treatment to bring it to WHO [11] standard limit for drinking water.

4.2 Recommendations

i) The slightly acidic water should be treated with calcite which is crushed and screened white marble media which can be inexpensively utilized to neutralize acidic or low pH.
ii) Following the results of this study, there is the need for a regular groundwater quality monitoring in the area by the State Ministry of Environment to ascertain the exact cause of the low levels of pH and also to detect any future abuse or pollution of the groundwater in the area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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http://www.sciencedomain.org/review-history/23921