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Hydrochemical Characteristics and Potability Indices of Groundwater from Ogbia Local Government Area of Bayelsa State, Nigeria

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Abstract

Groundwater samples from five locations in Ogbia Local Government Area of Bayelsa State were analyzed for the physicochemical properties and trace metals concentration using American Standard for Testing and Materials methods while the trace metals were determined using Atomic absorption spectroscopy. Results show pH ranged from 7.10 to 7.30; conductivity 14.00 to 20.00 μScm^{-1}; alkalinity 3.00 to 4.60 mg/L, total dissolved solid 6.00 to 105.00 mg/L; total suspended solids 0.50 to 0.90 mg/L, hardness 3.00 to 5.00 mg/L; sulphates 0.02 mg/L; nitrates 0.02 mg/L; chloride 11.80 to 31.20 mg/L. The concentrations of the trace metals were: Ca 2.00 to 3.00 mg/L; Mg 1.00 to 2.00; Fe 0.84 to 1.26 mg/L; Zn 0.02 to 1.00 mg/L; Cu 0.06 mg/L; Cr 0.19 mg/L; Ni 0.19 mg/L, Cd 0.02 to 0.32 mg/L; Pb 0.38 mg/L; Na 6.45 to 3.74 mg/L. The concentration of trace metals such as Ni, Cd, and Pb were above World Health Organization (2006) permissible limit for drinking water. The Computed Water Quality Index (WQI) and Metal Pollution Index (MPI) of groundwater samples from the five locations shows that they require mild treatment before they can be suitable for drinking because trace metals which are regarded as systemic toxicants are known to cause various organ damage.

Keywords: Groundwater; Trace metals; Water quality index; Metal pollution index; Toxicity

Introduction

Groundwater being the major source of borehole water is a significant resource for the agricultural, industrial sectors and serve as a major source of potable water for most developing countries. It is vulnerable to pollution by hazardous chemicals, trace metals and microbial activities due to its continuous interaction with surface water [1]. Research has shown that industrial and agricultural activities are sources of pollutants in both surface and ground water with surface water accumulating higher concentration of trace metals than groundwater. The direction of water flow determines trace metal concentration [2]. Water pollution does not only impact water quality, but adversely affect human health, economic development, and social prosperity [3]. Groundwater pollution has become a serious environmental problem in our contemporary time, because metal and chemical contamination shows high toxicity even at small concentration.

The Niger Delta area in recent years have experienced indiscriminate discharge of effluent, non-consumables, unused raw materials from pharmaceutical, cement, paint, steel, brewery and other manufacturing industries. This have led to the release of hazardous chemicals and trace metals into the urban aquifers which serves as the major source of drinking water for inhabitants in the area [4,5].

Hydrochemical assessment of water quality is important because it reveals the suitability of water for drinking, agriculture and industrial purposes. Also determination of the quality plays a major role in supporting agricultural production and human health.

Ground and surface water for drinking purposes must meet quality standard requirement.

Groundwater in a muddy aquifer, possibly the prevailing type of aquifer in the coastal areas such as the Niger Delta area is comparatively susceptible to the contamination by seawater intrusion which affect the portability. The resultant effect of chemical and biochemical interaction between groundwater and contaminants from industrial, municipal activities and with geological materials through which it flows, it contains a wide variety of dissolved inorganic chemical constituents in various concentrations. When seawater intrusion is the only cause for the salinity of groundwater in an aquifer system, the groundwater does not only exhibit high total dissolved solids (TDS) but also shows high concentrations of most major cations and anions [6]. Hydrochemical data helps in estimating the extended of mixing, the circulating pathways and residence time of groundwater. The physical, chemical and microbial characteristics of water are considered when determining the portability indices.

Water quality indices are one of the most effective means of obtaining data on the quality of any water body [7]. Water Quality Index (WQI) is one of the current methods of assessing the quality of any water body. It is a contemporary mathematical tool which can provide a distinct number for the enormous quantities of water quality data in an all-inclusive manner. Therefore, it is a modest tool of choice for assessing the quality and possible usages of a particular water body [8-10].

Heavy metal pollution index (HPI) is used to rate the collective contributions of the individual heavy metals on the general quality of water and can be used in obtaining a combined influence of all the metals on overall pollution [11]. In recent times, numerous researchers

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have been assessing water quality and its suitability for drinking purposes using water quality indices methods [12-15].

Some researchers have used metal pollution index (MPI) to classify water as very pure, pure, slightly affected, moderately affected, strongly affected, seriously affected depending on the result from empirical data [16,17].

The aim of this study was to investigate the quality status of some groundwater samples from Ogbia Local Government area in Bayelsa State using the hydrochemical characteristics and some portability indices.

Materials and Methods

Description of study area

The sampling site is Ogbia Local Government Area of Bayelsa State in the Niger Delta region of Nigeria between latitudes 4° 39' and 50° 2′N and longitudes 6° 15′E and 6° 45′E (Figure 1). The study area enjoys tropical climate with well-defined wet and dry seasons. It has an area of 695 km^2 and a population of 179,926. Its historic value stems from the fact that it is the area where Oloibiri is located. A reasonable land area of Bayelsa State lies under water at high tide considering the fact that the topographical map of the state indicates land surfaces between 12 and 15.5 meters above sea level [18]. The main drainage system of the state has deltaic plains that lie below 2.5 meters above sea level which implies that as much as 60% of the region is overrun by very high tide. The topography of the entire Niger Delta is made up of creeks and swamps passing through low lying plains in different dimensions however, the study area is basically drained by the Ogbia and Ekoli creeks which empty into the brass River. The clayey insertions within the Benin formation gives rise to various aquifer systems within the study area [19,20]. The average depths for boreholes in the study area are between 60 and 90 meters [18]. Deep boreholes in the study area obtain water from the confined aquifer from depths up to about 200 meters. There is arguably a high concentration of certain ground water parameters and gradual sliding of saltwater or brackish water into the fresh water aquifers [21]. Due to high industrial and agricultural activities, the area is exposed to both surface and groundwater pollution.

Sample collection and analysis

Groundwater samples from five different locations were collected in triplicate from Ogbia Local Government area of Bayelsa state (3 samples from each location) were obtained using 1.5 litres plastic bottles which were pre-rinsed with HNO_3 and deionized water. The depth of the groundwater is between 90-180 m. Samples were labeled A to E corresponding to the sampling locations. Samples were placed in a container with ice packs and transported to the Laboratory and preserved in the refrigerator prior to analysis. Physicochemical parameters such as pH, conductivity, total suspended solids (TSS) were analyzed quantitatively using pH meter, innolab conductivity meter and pressure millipore vacuum pump assembly respectively while alkalinity and total hardness were determined with a metroohm titrator. Anions such as sulphates, nitrates and chlorides were measured using a DR 2800 spectrophotometer, whereas trace metal concentration with the use of an Atomic Absorption Spectrophotometer. Samples for each location were run in triplicates and the mean recorded and relative standard deviation for the triplicate analyses was less than 10%. All parameters were determined based on American Standard for Testing and Materials (ASTM) [22].

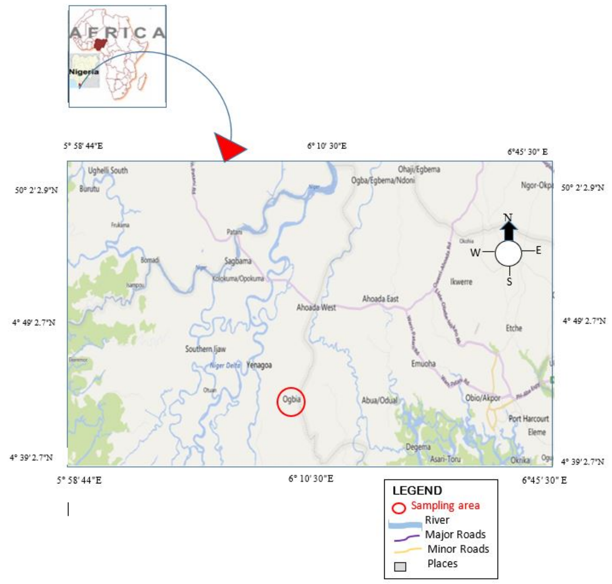

Figure 1: Map of the study area.

Metal pollution index (MPI)

One of the indices applied in determining the quality of water is the Metal pollution index (MPI), it shows the impact of each metal concentration on the overall quality of water [23]. It is usually rated between zero and one showing the relative importance individual parameters has on water quality. The higher the metal concentration compared to its maximum allowable unit the worse the water quality. MPI can be applied in determining the quality of sea, river as well as drinking water.

The total metal content at the different sites where compared using MPI according to the equation stated in Equation 3 below:

$$MPI=(Cf_1 \times Cf_2 \ldots . Cf_n)^{1/n} \ldots\ldots\ldots\ldots(3)$$

Where, Cfn=Concentration of the metal in the sample

MPI value>1 is a threshold of warning.

Water quality index (WQI)

Whilst MPI indicates the influence of each metal concentration on the overall quality of water, the WQI indicates the influence of natural and man-made activities on the key parameters of ground water which happens to be the primary source of borehole water. WQI gives a holistic view of the impact of the individual (not just metallic ions) on the overall water quality [24]. The WQI is calculated by assigning a weight (w_i) within the range of 1 to 5 to physiochemical parameters according to their relative importance. The maximum weight of 5 was assigned to nitrate and TDS, TSS and hardness, 4 for pH, electrical conductivity, alkalinity and sulphate, 3 for chloride, 2 for calcium, sodium and zinc and weight 1 for the other trace metals as shown in Table 3 [25].

The relative weight is calculated with the equation below:

$Wi = \frac{wi}{\sum_{i=1}^{n} wi}$.....................................(4)Where,

W_i=*relative weight*

w_i=*weight of a parameter*

n=number of parameters

The quality rating which is based on the concentration of the i^{th} parameter is obtained by dividing the concentration of each parameter in the water sample by the respective standard as stipulated by World Health Organization (WHO) and the result multiplied by 100 as shown in the equation below:

$q_i=(C_i/S_i)\times 100$……(5)

Where, q_i=*quality rating*

C_i=*Concentration of each parameter in mg/l*

S_i=*WHO Standard for each parameter.*

To finally calculate WQI the standard is determined for each parameter using the equation below:

$Sl_i=W_i\times q_i$………(6)

The sum of the Sli values gives the WQI for each sample as shown in Equation 6 below.

$WQI=\sum Sl_i$………(7)

WQI is an important rating that gives an incline on the impact of individual parameter on the overall quality of water.

Results and Discussion

Results of physicochemical parameters for water samples obtained from the study area are presented in Table1.

	Samples					
Parameters	**A**	**B**	**C**	**D**	**E**	**WHO permissible limit**
pH	7.3	7.2	7.2	7.3	7.1	6.5-8.5
Conductivity	14	224	19.2	17.1	20	1000
Alkalinity	4.6	3	4	4.3	3.7	<5.000
TDS	6	105	9	8	9	500
TSS	0.9	0.5	0.5	0.5	0.75	500
Hardness	5	4	4	3	3.5	180
Sulphates	0.02	0.02	0.02	0.02	0.02	250
Nitrates	0.02	0.02	0.02	0.02	0.02	45
Chloride	15.1	31.2	17.9	11.8	12.7	250

Table 1: Mean Water Quality Variables of the Groundwater samples.

The range values of pH, conductivity, alkalinity, TDS, TSS, hardness, sulphates, nitrates and chloride are 7.1-7.3, 14.0-224.0 mg/L, 3.0-4.6 mg/L, 8.0-105.0 mg/L, 0.5-0.9 mg/L, 3.0-5.0 mg/L, 0.02 mg/L, 11.80-31.2 respectively. Table 2 shows the mean concentration of metals and the metal pollution indices (MPI) of water samples from the study area where as Table 3 shows the mean concentration of the physiochemical parameters and metal concentration in water samples from the five sampling sites.

	Metals									
Sample	**Ca**	**Mg**	**Fe**	**Zn**	**Cu**	**Cr**	**Ni**	**Cd**	**Pb**	**Na**	**MPI**
A	3	2	0.84	0.02	0.06	0.19	0.2	0.28	0.38	6.72	0.42
B	2	2	1.16	0.02	0.06	0.19	0.2	0.23	0.38	21.5	0.46
C	2	2	0.95	1	0.06	0.19	0.2	0.02	0.38	6.45	0.46
D	2	1	1.26	0.02	0.06	0.19	0.2	0.32	0.38	7.45	0.4
E	2.5	1.5	0.95	0.02	0.06	0.19	0.2	0.02	0.38	13.7	0.33

Table 2: Mean Concentration of metals (mg/L) and Metal Pollution Index (MPI) of Groundwater samples.

Parameters	**WHO limit**	**Mean Conc. (Ci)**	**Quality Rating (qi)**	**Weight (wi)**	**Relative Weight (Wi)**	**Sli**
pH	6.5-8.5	7.22	84.94	4	0.08	6.456
Conductivity	1000	58.86	5.89	4	0.08	0.45
Alkalinity	4.9	3.92	80	4	0.08	6.08
TDS	500	27.4	5.48	5	0.1	0.52
TSS	500	0.63	0.13	5	0.1	0.01
Hardness	180	3.9	2.17	5	0.1	0.21
Sulphates	250	0.02	0.01	4	0.08	0
Nitrates	45	0.02	0.04	5	0.09	0
Chloride	250	17.74	7.1	3	0.06	0.4
Ca	75	2.3	3.07	2	0.04	0.12
Mg	50	1.7	3.4	2	0.04	0.13
Fe	50	1.03	2.06	1	0.02	0.04
Zn	3	0.22	7.2	2	0.04	0.27
Cu	2	0.06	3	1	0.02	0.06
Cr	0.05	0.19	380	1	0.02	7.22
Ni	0.02	0.19	950	1	0.02	18.05
Cd	0.003	0.17	5800	1	0.02	110.2
Pb	0.01	0.38	3800	1	0.02	72.2
Na	200	11.17	5.59	2	0.04	0.21
				∑wi=53.00	Wi=wi/∑wi	WQI=222.63

Table 3: Relative Weight of Physiochemical Parameters and Water Quality Index (WQI) of Groundwater samples.

Table 2 shows that sampling site A has the highest MPI as such the worst water quality in terms of metal concentration while the sampling site E has the lowest MPI as such the best water quality.

Comparing results obtained from Table 2 and 3 it can be deduced that all the trace metals from the individual sites were within specification except chromium, nickel, cadmium and lead. Table 3 also indicates that the mean concentrations of the individual metallic ions from the five sampling sites were within specification except those highlighted [26].

Table 4 shows the WQI of water from the individual location. From Table 4 it can be deduced that water from locations A and B are classified as 'very poor water' this is not unconnected with the high concentration of trace metals especially Cd and Pb in these water samples.

Sample	WQI	Water Classification Type
A	290	Very Poor Water
B	260	Very Poor Water
C	125	Poor Water
D	315	Water unsuitable for drinking
E	124	Poor Water

Table 4: Water Quality Index Classification of Groundwater Samples from individual Sites.

The suitability of the groundwater in the study area for drinking and other purposes were determined by comparing the analytical results of the groundwater samples with the World Health Organization permissible limits [27]. The mean of physiochemical parameters and the metal concentration of the groundwater samples from the different locations are shown in Table 1 and 2 respectively. Table 1 shows that pH of the water samples from the five sampling locations ranges from 7.10 to 7.30. The pH of the groundwater samples from each of the location is within World Health Organization (WHO) permissible limit for good quality. Drinking water with an elevated pH above 11 can cause irritation of the eye, skin and mucous membrane whereas consuming water with pH below 4 can result in serious health defects due to the corrosive nature of the water [28].

The WHO permissible limit for alkalinity<5.00 mg/L for potable water. The results from Table 1 shows that all groundwater samples from the five sampling locations were within specification [26].

The stipulated permissible limits by WHO for conductivity is<1000 µS/cm, TDS is 500 mg/L, TSS of 500 mg/L, sulphates and chlorides is 250 mg/L while nitrate of 45 mg/L. Results from groundwater analysis as shown in Table 1 indicates groundwater samples from the five sampling locations were within WHO specification. Drinking water with high conductivity could lead to different forms diseases especially kidney disease [5].

Hardness of water is caused by the presence of Ca^{2+} and Mg^{2+}. It is known that hard water is usually associated with heart disease and unsuitable for domestic use. Hardness of water is classified in degrees as soft 0 to 75 mg/L; moderate 75 to 150 mg/L; hard 150 to 300 mg/L; very hard>300 mg/L [28]. The groundwater study has hardness in the ranges of 3.00 to 5.00 mg/L indicating that they are soft water.

Trace metals and metal pollution index (MPI)

Metals which occurs at 1000 mg kg^{-1} or less in the Earth's crust are referred to as trace metals. They can be classified as light or heavy depending on their densities. Some may have high density (>7g/cm^3) and atomic weight (>20). Some trace metals, such as cadmium, mercury and lead, are remarkably hazardous while others like chromium, copper, iron, nickel and zinc are essential micronutrients which are important to plants and animals, but can be toxic in high concentration or certain forms [4-29]. Trace metals are major source of pollution not just because they are toxic above a relatively certain concentration but also because they are persistent, remaining in the environment long after the source of pollution has been removed [30]. Owing to their high toxicity, Cadmium, Chromium and Lead rank among metals with the highest priority as far as public health is concerned as such they are considered systemic toxicants known to induce multiple organ damage, even at lower levels of exposure [31]. They are also classified as human carcinogens according to the U.S. Environmental Protection Agency, and the International Agency for Research on Cancer [32]. The concentrations of Ni, Cd and Pb were higher than stipulated limits of 0.02, 0.003 and 0.01 mg/L for safe drinkable water by WHO [27].

Results of the analysis of the trace metals concentrations for the groundwater samples were employed to calculate the MPI (Table 2). Water quality has been classified by some researchers using the MPI. Water with MPI<0.3 are grouped in Class I and they are referred to as 'Very Pure', while those with MPI between 0.3 and 1.0 are in Class II and they are referred to as 'Pure'. Those with MPI between 1.0 and 2.0 are grouped in Class III and they are termed as 'Slightly affected' while Class IV are termed 'Moderately affected' with an MPI between 2.0 and 4.0. Water samples with MPI between 4.0 and 6.0 are grouped in Class V and they are termed 'Strongly affected', while those with MPI>6.0 are seriously affected [16,17]. Deduction from the analysis of the MPI as shown in Table 2 shows that groundwater samples from the five sampling sites are between 0.33 and 0.46 (Class II), hence they are not very pure. The groundwater may require mild treatment in order to meet WHO standard for portability.

Water quality index (WQI)

A relative weight was assigned for each parameter based on their importance to water quality as shown in Table 3. An average of the parameters from each of the sampling location was obtained and the overall WQI of water from the 5 sampling locations was calculated as shown in Table 3 using equation 6. Water quality has also been classified based on WQI, water with WQI of <50, 50-100, 100-200, 200-300 and >300 are classified as excellent water, good water, poor water, very poor water and water unsuitable for drinking purposes respectively. The higher the WQI, the poorer the water quality [25-39]. The impact of the high concentration of trace metals such as Cr, Ni, Cd, and Pb were evident in the WQI of the water samples from the individual sites. The sampling location D has the highest concentration of Cd and is classified as unsuitable for drinking, sampling locations C and E are all classified 'poor water' due to their WQI as shown in Table 4.

Conclusion

The suitability of groundwater for both drinking and domestic purposes depends on major factors such as the physicochemical properties and trace metals concentration. The location as well as the depth of groundwater are basic factors that equally affect its quality. Water quality index (WQI) and metal pollution index (MPI) are key performance indicators that determines the quality of water and they are dependent on the physicochemical properties and trace metal level in water. Though most of the parameters of the water samples from the five locations under study were within acceptable standard by WHO, the WQI and MPI of the water samples confirmed the fact that water from the five locations need mild treatment before the groundwater can used for drinking purposes and this is not unconnected with the high concentration of toxic trace metals like cadmium, chromium, nickel and lead which were above WHO 2006 permissible limits for drinking water. Continuous monitoring of these trace metals is therefore advocated to prevent the concentration from reaching alarming level which can constitute possible public health implications on the users.

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