Geophysical investigation of resistivity and groundwater quality in Ogbe-Ijoh coastal area of the western Niger Delta of Nigeria

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Abstract

Groundwater quality assessment is essential for groundwater resource management, especially as it concerns the health of those that consume it. Consequently, we assembled resistivity and hydrogeochemical data to assess the adverse effect of anthropogenic sources on groundwater quality in Ogbe-Ijoh, a coastal area of the western Niger Delta. Geoelectrical data showed no evidence of quality degradation as reflected by high resistivity values that ranged from 29.3 to 349.9 Ωm . Aquiclude of adequate thickness capping aquifers was uncovered in most areas assessed, with the exception of areas near the bank of the river. The delineated clay sedimentary horizon probably enhanced groundwater quality sustainability by acting as a barrier to migrating contaminants, especially from leachate and septic tanks. The physical properties of groundwater sampled indicated moderate pH, TDS and EC magnitudes, with a majority having magnitudes lesser than the requisite standards. The geochemistry of groundwater revealed cations and anions with magnitudes that are distinctively lesser than the desired ranges. Piper plot revealed two different water types: NaCl^- and $\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Cl}^- + \text{SO}_4$, which implied that cation exchange has a weighty effect on quality of groundwater. Overall, the hydrogeochemical results are consistent with resistivity data and revealed the efficacy of the pairs in groundwater quality assessment in the absence of lithologic information. The groundwater condition is relatively safe for consumption; nevertheless, due to health implications we recommend that pH should be increased to the required standard before drinking.

Keywords Groundwater · Anthropogenic · Niger Delta · Ogbe-Ijoh · Resistivity · Cation exchange

Introduction

Groundwater is the water existing beneath subsurface and can be harnessed by hand-dug wells and boreholes. The easy of harnessing to a large extent is influenced by the geotechnical strength of rock and depth. In all rock types, groundwater exists in pore spaces and its flows are usually controlled by the interconnectivity of pore spaces and other sedimentary structures. In igneous and metamorphic rocks, flow is mainly influenced by induced tectonic structures such as fractures, joints and faults.

Pristine groundwater quality is affected and altered by rock media and anthropogenic impact; it may interact with

during flows. Since groundwater exists in the subsurface of the earth, its quality is sometimes affected by its flow from the surface through the vadose to the saturated zones at the time of recharge. Studies have revealed that leachates from refuse dump site and sanitary landfills, septic sewage disposal system, mine tailings, underground storage tanks and oil spillage as well ingress of saltwater in coastal regions have had tremendous effects on groundwater quality, especially among shallow aquifers (Ebraheem et al. 1997; Sidhardhan et al. 2015). The quality of groundwater is essential and directly related to the health of those who drink it. In 2000, WHO and UNICEF revealed that of the 4 billion peoples infested with diarrhea from drinking poor-quality water, 2 million died yearly. The cause is related to the poor sanitation practices ubiquitous in most developing and poor countries (UNESCO 2006).

Groundwater quality condition study in coastal regions of the western Niger Delta has not attracted the needed impetus. However, few studies involving interpreted resistivity data acquired from some coastal parts of the western Niger

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Delta (Ohwoghere-Asuma et al. 2017) revealed that groundwater quality around Burutu is poor due to anthropogenic sources, while Ogidigben is characterized by poor-quality water caused by saltwater intrusion (Ohwoghere-Asuma and Essi 2017). In Egypt, Ebraheem et al. (1997) adduced groundwater contamination to sewage, irrigation drainage, leachate from old lagoonal deposits and saltwater intrusion from resistivity data and geochemistry in the northern part of the Nile Delta. Similar study near dumpsite by Sidhardhan et al. (2015) depicted significant impact of leachate on groundwater quality.

The poor sanitation practice that is prevalent in the study area is driven by the absence of functioning waste disposal system. Consequently, this has given rise to unsystematic refuse dumping which is a threat to groundwater quality. The study area is also characterized by cluster development with attendant proliferation of septic tanks without adequate spacing among houses and open defecation. Obviously, these are probably unfavorable for groundwater quality that may be consumed by the people because of contaminations. Consequently, resistivity and hydrogeochemical data were assembled to assess to what extent the adverse effect of anthropogenic sources has impacted negatively on groundwater quality.

Study area

Ogbe-Ijoh is situated on geographical coordinates that range from $E05^{\circ} 44' 10.4''$ – $05^{\circ} 44' 14.0''$ to $N05^{\circ} 28' 40.1''$ – $05^{\circ} 29' 02.2''$ (Fig. 1). It is part of the coastal area of Delta State and the administrative headquarter of the Warri South West Local Government. It is located in the bank of one of the distributaries of the Warri River and shares boundary with Aladja in the north. The river joins and empties into the Forcados River, which in turn flows into the sea. It is a low-lying area with elevation that rarely exceeds 5 m above mean sea level, and gradient tends to decrease toward the river. The bank of the river consists of freshwater vegetation which predominantly gives way to more mangrove swamp vegetation toward the sea. Beyond the bank are wetlands that are often flooded during rainy seasons. Rainfall amount varies from low to high during the dry and the wet seasons, respectively. Rainfall amount is greater than 3000 mm per annum (Ohwoghere-Asuma et al. 2018). Temperature rarely exceeds 34°C and is influenced by the prevailing climatic conditions (Ohwoghere-Asuma et al. 2018). Low and high temperatures are experienced during the rainy and dry season, which range from as low as 24°C to 34°C . The occupation of the people is mostly fishing and water transportation and sand dredging.

Fig. 1 Map showing the study location

Geology and hydrogeology

Apart from climate change, geology has dominant and significant effect on groundwater resource in the Niger Delta (Nwankwoala and Ngah 2015). The ease of groundwater withdrawal, quality and the intricacy associated with distribution of groundwater within the Niger Delta region are attributable to the geology (Nwankwoala and Ngah 2015). The sequence of deposits of Niger Delta basin from the top to base in order of increasing age with depth consists of Benin, Agbada and Akata Groups (Reijers 2011). Sediments underneath Ogbe-Ijoh belong to one of the geomorphological units called Sombreiro Warri Deltaic plain. The Sombreiro Warri Deltaic plain consists of sediments whose sizes vary from medium through fine to silt clay.

Groundwater is extracted from shallow hand-dug wells and boreholes in the area under investigation. It is used basically for domestic purpose only. The depth to groundwater varies from 3 to 4 m. Direction of groundwater flow is probably toward the river. Most of the hand-dug wells partially penetrate the aquifers as their total depths terminate at the clays with the exception of those nearer the river bank. Consequently, most wells are without water, especially during the driest months of the year. Pumping data are scarce and hard to come by; however, recovery from pumping is very rapid; in fact, in matters of seconds, it indicates the absence of heavy pumping. Though information concerning transmissivity, hydraulic conductivity and storativity of aquifers in the area is not available, aquifers are arguably not different from others in the western Niger Delta and reasonably very copious as others.

The rate of recovery probably suggests that aquifer parameters are perhaps not significantly different from those associated with aquifers of Sombreiro Warri Deltaic plain sands. Considering heterogeneity of aquifers which characterized the Niger Delta geology, there might be slight variation in aquifer parameters which is yet to be determined. The watershed of the area is drained by the networks of river systems and the adjoining wetlands.

Methodology

Field acquisition of resistivity data

A 4light power 10-W earth resistivity meter equipment was used for the measurements of resistivity of the subsurface. It has an interior battery that is chargeable by alternating current and very portable. It can be used for a day, if fully charged. During acquisition of resistivity data, it generates its own current from stored current, measured resulting voltage between the two potential electrodes and presents results

in apparent resistivity. It has a microprocessor that enables it to automatically carry out measurements and self-potential correction as well as digital stacking for signal improvement. The field procedure and processing for the Schlumberger array in the acquisition of resistivity data are abundant in the literatures (Ohwohere-Asuma et al. 2014, 2017; Ayers 1989; Zohdy 1989; Al-Sayed and El-Qady 2007; Orellana and Mooney 1996). A total of nine vertical electrical sounding (VES) stations were covered, processed and interpreted in accordance with standard procedures that have been used by researchers including Vander (2004), Orellana and Mooney (1996), Keller and Frischknecht (1979).

Laboratory analysis of groundwater samples

Field measurements included groundwater sampling, determination of pH with the Schott Gerate model pH meter, electrical conductivity and total dissolved solids were carried out at sampling points with the HACH conductivity TDS meter. Only groundwater samples from borehole were pump for a while, 10 min precisely, before collected in clean plastic containers and placed in cooler in the field containing ice block. Groundwater samples for cations were acidified by diluting with NO_3^- acid from measured pH of water to pH of 2. Laboratory analysis was conducted in accordance with standard methods specified by APHA (2011). The elements analyzed include: Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , PO_4^{3-} , SO_4^{2-} and Cl^- . A total of 20 groundwater samples were collected, and it consists of 15 boreholes and 5 hand-dug wells.

Results and discussion

Resistivity data

The results of the computer iterated model, resistivity values, geoelectric layers, thickness and depths are presented in Table 1. The resistivity values obtained from interpretation of computer iterated models are relatively variable with depth as reflected by different curve types. Overall, the resistivity values ranged from 29.3 to 349.9 Ωm . The absence of very low resistivity value that is less than 29.3 Ωm nearly in all VES stations suggests that the subsurface under investigation is probably devoid of materials of low resistivity, such as leachate. Moderate resistivity values that varied from 29.3 to 104.5 Ωm were recognized as clay sedimentary layers. The clay horizon interpreted is common to almost all VES stations except 4, 8 and 9, which are sandy sedimentary layers. Remarkably, VES stations 4, 8 and 9 were acquired from different places near the bank of the Ogbe-Ijoh River. Resistivity values in the range of 117.2 to 349.9 Ωm are probably sand sedimentary layers, which are probably related to point bar deposit. In VES stations 4, 8

Table 1 Summary of computer iterated resistivity data (ρ represents the resistivity, h the thickness of layer and d depth)

VES station no.	Coordinates	Parameters	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
1	E05 43 54.1E N5 28 56.4N	ρ (Ω m)	92.0	55.0	125.0	179.0	221.0
		h (m)	1.0	7.0	15.0	18.0	
		d (m)	1.0	8.0	23.0	41.0	
		Interpretation	Top soil	Clay	Sand	Sand	Sand
2	E5 43 52.2E N5 28 47.8N	ρ (Ω m)	66.5	41.0	125.1	241.2	170
		h (m)	1.0	6.4	12.4	18.8	
		d (m)	1.0	7.4	19.7	38.6	
		Interpretation	Top soil	Clay	Sand	Sand	Sand
3	E 5 2849.7E N5 43 57.2N	ρ (Ω m)	100	65	189.9	298.7	180.9
		h (m)	1.0	7.0	15.0	21.4	
		d (m)	1.0	8.0	23.1	44.4	
		Interpretation	Top soil	Clay	Sand	Sand	Sand
4	E5 44 00.2E N5 28 41.3N	ρ (Ω m)	74.6	136.4	134.8	131.3	210.
		h (m)	1.1	8.0	15.6	19.2	
		d (m)	1.1	9.1	24.7	44.0	
		Interpretation	Top soil	Sand	Sand	Sand	Sand
5	E5 44 09.0E N5 28 53.6N	ρ (Ω m)	95	47.5	117.5	161.3	229.4
		h (m)	1.0	7.2	13.4	17.8	
		d (m)	1.0	8.3	21.7	39.5	
		Interpretation	Top soil	Clay	Sand	Sand	Sand
6	E5 44 21.6E N5 28 43.8N	ρ (Ω m)	50.7	103.8	231.7	118.0	160.7
		h (m)	1.1	5.7	14.7	20.4	
		d (m)	1.1	6.8	21.6	42.2	
		Interpretation	Top soil	Sand	Sand	Sand	Sand
7	E5 44 14.0E N5 28 40.1N	ρ (Ω m)	41.8	104.5	276.7	81.2	255.3
		h (m)	1.0	6.8	20.3	25.6	
		d (m)	1.0	7.8	28.1	53.7	
		Interpretation	Top soil	Sand	Sand	Sand	Sand
8	E5 44 12.9E N5 28 58.6N	ρ (Ω m)	29.3	127.2	440.3	169.0	349.3
		h (m)	0.8	4.8	15.7	23.5	
		d (m)	0.8	5.8	21.5	44.0	
		Interpretation	Top soil	Sand	Sand	Sand	Sand
9	E5 44 10.4E N5 29 02.2N	ρ (Ω m)	38.0	126.7	208.3	85.3	253.3
		h (m)	0.9	5.4	14.3	20.9	
		d (m)	0.9	6.3	20.6	21.5	
		Interpretation	Top soil	Clay	Sand	Sand	Sand

and 9, sand is found at depth of 1.2 m, in others above 6.7 m. Geologically, plausible explanation is probably attributable to moderate energy of environment deposition operating at the bank of the River at the time of deposition. The extensiveness of clay sedimentary layer buttressed low energy of deposition, probably deposited from suspension, particularly when the river overflowed its bank in geologic past as levee deposits. Its thickness varied from 7.4 to 8.3 m in the areas where it occurs. Aquifer is confined by the clay layer except areas around VES stations 4, 8 and 9, where the aquifer is unconfined. This also underpinned the protective nature of the aquifers and therefore not susceptible to contamination.

The areas surrounding VES stations 4, 8 and 9 are absolutely liable to contamination from anthropogenic sources.

Aquifer with unpolluted groundwater is typically characterized by possession of high resistivity values, compared to polluted equivalent with low resistivity values. Having moderate resistivity values that are more than the lowest resistivity value indicates somehow that the groundwater from the study area is probably devoid of any contaminants that may deteriorate it, the quality of which is attributable to the delineated clay sedimentary layer which is capping most of the aquifers in almost all areas covering VES stations 1,

2, 3, 5 and 6. It actually acts in the prevention of migrating leachates and maybe other contaminants from the surface.

The preventive function of the clay sedimentary layer is not only restricted to leachates, but also to wastewater and effluents from septic tanks as well as contaminants from open defecations. The contamination of groundwater in the Niger Delta region is very prevalent as a result of the water table that in most places is close to the surface. Thus, most shallow aquifers within depth range of 4 m to 10 m are vulnerable. The total depth of septic tanks is within the neighborhoods of 3–4 m (9–12 ft); most of it is entrenched in the aquifer. In case of failure where there is direct release of effluents and leakage, areas within the proximity to the circumference of the river bank are prone to contamination, such as area having VES stations 4, 8 and 9. However, areas with thickness of clay below septic tank are less prone to contamination because the clay is capable of sorping contaminants in areas where VES stations 1, 2, 3, 5 and 6 are acquired from.

Physicochemical properties of groundwater

Physicochemical and descriptive statistics of groundwater samples analyzed are presented in Table 2. A low pH of groundwater enhances and promotes unhealthiness, while moderate high pH encourages healthiness for those who drink such waters. As a result of the health implication, it is often required that we drink water with pH that ranges from 6.5 to 8.5 (WHO/UNICEF 2004). Of the samples analyzed, 65% has pH values lower than the 6.5 requisite standards. The trend of pH with depth is such that the deeper boreholes possessed higher pH values representing about 30% of the sample analyzed. The values for these boreholes (BH2, BH5, BH6, BH8, BH11 and BH12) ranged from 7.30 to 10.8, while dug wells ranged from 4.7 to 7.1. Generally, most of the groundwater samples are more acidic than being alkaline. Possession of low pH by groundwater is major characteristics of shallow aquifers in the Niger Delta (Etu-Efeotor and Odigi 1983). Low pH values obtained are not different

Table 2 Physio-chemical properties of groundwater obtained from borehole and hand-dug wells in the study area

	pH	EC	TDS	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻	PO ₄ ⁻	NO ₃ ⁻	Ca ³⁺	Mg ²⁺	K ⁺	Na ⁺	Fe ²⁺	Depth (ft)
BH1	5.7	27.84	19.57	7.71	0.62	3.18	0.06	0.37	2.47	0.85	0.97	4.13	0.02	70
BH2	10.8	28.90	20.74	9.16	0.24	2.53	0.02	0.14	2.82	1.11	0.47	2.22	0.05	80
BH3	4.5	19.45	13.90	8.81	1.32	1.76	0.05	0.19	1.60	0.13	0.64	1.82	0.01	65
BH4	4.3	29.04	18.13	5.24	0.33	2.77	0.03	0.10	1.16	0.45	0.75	2.32	0.02	70
BH5	7.8	25.28	18.95	3.84	0.19	3.87	0.07	0.28	1.86	1.21	0.53	3.94	0.04	90
BH6	7.3	18.42	10.86	4.75	0.35	1.58	0.23	0.29	1.33	0.43	0.49	2.08	0.06	100
BH7	5.6	26.75	18.54	22.34	0.22	2.33	0.01	0.12	2.61	1.09	0.28	2.00	0.10	70
BH8	7.9	20.72	15.52	17.54	0.98	3.73	0.18	1.02	4.52	2.88	1.23	7.41	0.09	80
BH9	5.1	13.38	8.98	10.89	1.12	1.24	0.03	0.17	1.39	0.36	0.69	3.48	0.17	65
BH10	4.8	20.94	21.65	11.74	0.16	1.88	0.08	0.26	1.21	0.28	0.98	2.56	0.21	75
BH11	7.4	30.61	28.72	7.80	0.46	6.65	0.06	0.14	1.24	1.53	0.59	6.75	0.13	90
BH12	7.5	16.57	18.38	3.98	0.53	1.32	0.09	0.05	1.53	0.24	0.35	1.94	0.18	100
BH13	5.4	35.36	10.88	10.55	2.76	0.02	0.38	1.14	2.86	1.69	1.75	4.55	0.03	60
BH14	5.6	20.19	14.82	5.52	0.53	3.21	0.03	0.09	4.68	2.18	0.56	3.56	0.08	65
BH15	6.2	28.56	12.16	7.80	3.29	3.14	1.08	0.82	3.24	0.85	1.34	3.88	0.15	79
DW1	5.8	115.7	82.13	31.85	0.77	5.07	0.11	1.10	6.52	2.97	1.35	9.13	0.10	9
DW2	6.0	112	79.43	27.54	1.54	4.13	0.09	0.55	3.28	0.78	0.39	5.08	0.24	9
DW3	5.5	33.92	42.22	0.83	0.46	2.54	0.06	0.57	3.25	1.49	0.67	4.57	0.08	9
DW4	7.1	62.20	56.31	6.16	0.38	2.67	0.08	0.33	2.16	0.63	0.37	1.62	0.19	8
DW5	4.7	62.57	82.13	2.06	1.02	2.07	0.04	0.24	2.10	0.53	0.34	4.93	0.14	9
MIN	4.30	13.38	8.98	0.83	0.16	0.02	0.01	0.05	1.16	0.13	0.28	1.62	0.01	
MAX	10.80	115.70	82.13	31.85	3.29	6.65	1.08	1.14	6.52	2.97	1.75	9.13	0.24	
MEAN	6.25	37.44	27.88	10.71	0.86	2.78	0.14	0.40	2.59	1.08	0.74	3.90	0.10	
STD	1.56	29.12	21.93	8.4	0.84	1.47	0.24	0.35	1.39	0.83	0.42	2.04	0.08	
RIVER	6.10	124.32	628.5	154.9	4.76	45.5	9.67	10.8	9.45	1.12	3.67	12.6	1.74	
WHO	6.5–8.5	2500	1000	250	–	250	–	50	75	50	50	200	0.3	

All parameters are in mg/l except pH with no unit and EC with unit of $\mu\text{S}/\text{cm}$ (DW is hand-dug well, and BH is borehole)

from those reported by Ohwoghere-Asuma et al. (2014) for aquifers in Burutu areas of the Niger Delta. The source of low pH in groundwater is not clearly understood, but direct relationships with rainwater are probably not rule out or organic matter composition of the unsaturated zones. The pH of the river is 6.10, which is slightly acidic and similar to most of the groundwater samples analyzed, mainly the dug well samples. The low pH of the river water could have been due to the excessive gas flaring common with the Niger Delta from oil exploration and exploitation companies. This assertion is similar to the suggestion of Olobaniyi and Efe (2007); they attributed low pH of river water to gas flaring. Since then, the power situation in the region has deteriorated to the level that almost every household generates its power. It would not be out of place to underpinned low pH of river to emission of gases from fossil fuel generators. The possibility of soil organic matter constituents of the vadose zone may also be responsible for low pH of groundwater observed in the study area.

Electrical conductivity (EC) of groundwater describes its conductivity and its influence by amount of dissolve substance it contains. Water with high EC more than the desirable minimum 1000 $\mu\text{S}/\text{cm}$ (WHO/UNICEF 2004) may not be suitable for consumption due to health reasons. Generally, all samples analyzed returned values lesser than the desirable minimum values. Comparatively, the dug wells returned higher values of 33.92–115.70 $\mu\text{S}/\text{cm}$ to boreholes, whose values ranged from 13.38 to 35.63 $\mu\text{S}/\text{cm}$ and river sample 124.3 $\mu\text{S}/\text{cm}$. The slight difference between groundwater and river samples evidently indicates that river water quality has been affected by runoff and anthropogenic source of contamination.

Total dissolve solid (TDS) expresses aggregate of inorganic dissolved in groundwater or the inorganic filtrate after filtration. Usually, high proportion of TDS in groundwater tends to enhance taste and odor, thus rendering it unhealthy for consumption. As the concentration of TDS increases, its usefulness diminishes, especially the specific purpose of drinking. All samples analyzed are similar to EC values, in being lesser than the requisite minimum standard of 500 mg/l. Again, the dug wells were characterized by possessing higher values that ranged from 42.22 to 82.13 mg/l than boreholes samples, which is from 8.98 to 28.72 mg/l. These values are essentially lesser than the 628.5 mg/l content of river samples. The source of TDS in groundwater can either be related to natural properties of the aquifer or anthropogenic effects, while the river sample is probably affected by anthropogenic sources.

Consequently, though the elevated level of TDS recorded in the dug wells is lesser than desirable standard, it may have been derived naturally from the aquifer media. This may be so because the thick clay layers which mantled the aquifer in

several places and as revealed from VES interpretation may have protected the aquifer from contaminations.

Major ions

The order of dominance of the major cations in groundwater samples is $\text{Na} > \text{Ca} > \text{Mg} > \text{K} > \text{Fe}$ in both boreholes and dug wells. The order is compatible with that of Akpoborie and Aweto (2012) for similar environment of Ughoton. The mean for Na, Ca, Mg and K for all groundwater samples is 3.51 mg/l, 2.30 mg/l, 1.02 mg/l and 0.77 mg/l, respectively. 55% of groundwater samples have Na values higher than median concentration; 50% of the samples have concentration of Ca greater than the median concentration; 80% of the samples have Mg values greater than the median concentration; and lastly, 60% of samples have K values greater than the median concentration. The dominance of Na stems from cation exchange and weathering of silicate (Akpoborie and Aweto 2012; Ohwoghere-Asuma et al. 2014). The results did indicate significantly variation among values of cations from dug wells and boreholes. This may arise from anthropogenic sources for some of these cations with enhanced level, as revealed more noticeably in sample DW₁ and others with high magnitudes (Table 2). Despite the variations, the cation values in the groundwater are below the stipulated standard. Consequently, groundwater samples from the study area are relatively safe for drinking, especially those from boreholes.

Concentration of dissolved Fe in groundwater is of major concern not only in the coastal areas but also inland areas of the Niger Delta. Many boreholes have been abandoned consequent upon high concentration of dissolved Fe. The concentration of Fe in this study varies from 0.01 to 0.24 mg/l and with a mean of 0.10 mg/l. 40% of the samples have values higher than the mean, while 60% are with values lesser than the mean. These values are significantly lower than the 0.3 mg/l required standard. The river sample has Fe content of 1.74 mg/l, which is distinctively higher than both borehole and hand-dug groundwater samples.

Major anions

The order of dominance of the major cation in groundwater samples is $\text{Cl} > \text{SO}_4 > \text{HCO}_3 > \text{NO}_3 > \text{PO}_4$ in both boreholes and dug wells. The concentration of chloride in groundwater is very significant because it influences taste of groundwater, especially in the presence of dominant Na. The importance of chloride cannot be overemphasized as very minute concentration of it with dominant Na may introduce salty taste when its concentration is more than 250 mg/l. The concentration of Cl in the groundwater samples varied from 3.84 to 9.22.34 mg/l with a mean of 9.72 mg/l. Fourteen of the samples have concentration of Cl higher than the mean. Two of the dug wells (DW₁ and DW₂) have values of Cl greater

than the highest borehole value, but significantly lower than the desirable minimum concentration of 250 mg/l. These two samples were collected from area near the bank of the Ogbi-Ijoh River, where sedimentary layer of clay is prominently absent. Though Cl concentrations are within regulated limit, the groundwater quality from this area is probably affected by contamination as evidenced by the relative increase in concentration of Cl in dug wells. The river sample returned 154.9 mg/l and may be connected to contamination arising from anthropogenic activities as the some people defecate on the river water.

Groundwater with sulfate (SO_4) concentration greater than specified limits coupled with moderate concentration of magnesium and sodium causes conveniences and disturbances of the stomach (Bertram and Balane 1996; Bundel et al. 2012). The concentration of SO_4 in excess of the requisite minimum limit imposes a bitter taste and rotten egg smell on the groundwater. The concentration of SO_4 for all groundwater samples falls within the required specified limits; they ranged from 0.07 to 6.65 mg/l with a mean of 2.26 mg/l; 13 of the samples have concentration higher than the mean. Similar to Cl, SO_4 in dug wells is also higher than that of boreholes, more pronounced in DW₁ and DW₂.

Bicarbonate (HCO_3) is a product of the percolation of rainwater rich in carbon dioxide (CO_2) through the soil to groundwater aquifers. Very high concentration of HCO_3 in groundwater has attendant effect on taste, unpleasant one for that matter. The concentration of HCO_3 varied from 0.16 to 3.29 mg/l with mean of 0.86 mg/l; 35% of the samples have concentrations greater than the median concentration. HCO_3 in the groundwater samples analyzed exhibits a trend in which its concentration increases with pH and depth of aquifers. Samples with low pH are characterized by low HCO_3 concentration and conversely. The observed trend is probably attributable to the acidity of the groundwater, which most likely may not promote the formation of bicarbonates in aquifers, but enhances the alkalinity of groundwater.

Nitrate (NO_3) is essential in discriminating the quality of groundwater, and thus, it is frequently used as an indicator of pollution and contamination, especially in revealing the influence of anthropogenic activities on groundwater quality. The occurrence of elevated level of (NO_3) in groundwater confirms the availability of decomposing organic matter, human and animal wastes in groundwater. The values of (NO_3) varied from 0.05 to 1.14 mg/l with mean of 0.35 mg/l, and 35% has its values greater than the median concentration. These concentrations are relatively lower than the 10 mg/l required as the stipulated standard (NSDWQ 2007). It has been reported that drinking groundwater with concentration of (NO_3) greater than 45 mg/l is responsible for methemoglobinemia in infant children.

Unlike NO_3 , phosphate (PO_4) in groundwater is from diverse sources. The sources of PO_4 include soils capping

aquifers, dissolution of PO_4 rich aquifer sediments, fertilizer, animal and septic failures leaking into aquifer (Fuhrer et al. 1999; Carlyle and Hill 2001; Welch et al. 2010). The concentration of PO_4 varied from 0.01 to 1.08 mg/l with a mean of 0.16 mg/l, and only 20% of the samples have concentration above the median concentration. The low values observed may be attributable to the sorption of phosphorus by soil, aquifer sediments and not easily transported in groundwater (Holman et al. 2008).

Groundwater type

A Piper diagram is usually applied in the description of groundwater into types in terms of similarities and dissimilarities of properties of cations and anions (Piper 1994). In Piper diagram, groundwater samples with same or different ion properties often plot together as group in the sub-triangles. Figure 2 depicts non-dominant and dominant types for the groundwater from the study area. Those points which are plotted on the middle triangle are $\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Cl}^- + \text{SO}_4$, and they are the non-dominant type and NaCl^- the dominant type. The presence of non-dominant water type is an indication of cation exchange, which progresses initially from pristine groundwater enriched in Ca water type to Na water type by substitution of Ca with Na in the aquifer. The clusters of points in the Piper diagram, which are plotted together with river sample, evidently imply strong similarities. The similarity is exhibited by groundwater, and the river simply suggests obvious interaction between them, the ground recharging the river. This is evident as the Warri River is known to have its source from a spring, supplied by groundwater, and the study area' river is a distributary of the Warri River.

Fig. 2 Piper diagram showing groundwater types

Conclusions

The acquisition of resistivity data devoid of very low resistivity for deciphering the availability of contaminant plumes in the study area underpinned that groundwater quality has not been affected by any anthropogenic sources. The presence of overlying soils and thick layer of clay sedimentary surface probably promoted sorption of anthropogenic contaminants, which prevent the subsequent migration of same into aquifers. The presence of clay sedimentary layer as shown by the resistivity data has contributed to the overall quality of groundwater in the study area.

The physio-chemical properties of groundwater samples indicated moderate pH, TDS and EC magnitudes, with majority of them having values that fall within the permissible limit. The geochemistry of groundwater revealed cations and anions that are distinctively lesser than the desired minimum range. This did suggest that groundwater quality status is adequately protected from anthropogenic sources of contamination. Piper plot revealed two different water types: NaCl^- and $\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Cl}^- + \text{SO}_4$. Though groundwater quality has not been degraded, different water types obtained in the study suggested that cation exchange has significant impact on groundwater quality.

The cluster of groundwater samples and river sample that is not distinguishable from each other as illustrated by the Piper diagram somehow depicts same source of origin. The differences in concentration of parameters of river sample from groundwater samples may be connected to anthropogenic effects. The study further supports the fact that groundwater is of better quality compared to river waters as shown in river sample geochemistry.

We recommend most importantly that pH of groundwater from the study area should be increased to the required minimum standard before drinking.

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References

- Akpoborie IA, Aweto KE (2012) Groundwater conditions in the mangrove swamps of the western Niger Delta: case study of the Ughoton area, Delta State, Nigeria. *J. Environ. Hydrol.* 20(6):1–14
- Al-Sayed EA, El-Qady G (2007) Evaluation of sea water intrusion using the electrical resistivity and transient electromagnetic survey: case study at Fan of Wadi Feiran, Sinai, Egypt. In: EMG 2007 international workshop, Capri, Italy
- APHA (2011) Standard methods for the examination of water and waste water, 24th edn. American Public Health Association, Washington, D.C.
- Ayers JF (1989) Conjunctive use of geophysical and geological methods in the study of alluvial aquifer. *Ground Water* 27(5):625–632
- Bertram J, Balane RA (1996) Practical guide to the design and implementation of fresh water quality studies and monitoring programme. United Nations Environmental Programmes (UNEP), Nairobi, pp 172–177
- Bundel PS, Sharma A, Pandey AK, Pandey P, Awasthi AK (2012) Physicochemical analysis of groundwater near municipal solid waste dumping sites in Jabalpur. *Int J Plant Annu Environ Sci* 2(1):217–238
- Carlyle GC, Hill AR (2001) Groundwater phosphate dynamics in a river riparian zone: effects of hydrologic flowpaths, lithology, and redox chemistry. *J Hydrol* 247:151–168. [https://doi.org/10.1016/S0022-1694\(01\)-00375-4](https://doi.org/10.1016/S0022-1694(01)-00375-4)
- Ebraheem AM, Senosy MM, Dahab KA (1997) Geochemical and hydro geochemical studies for delineating ground-water contamination due to saltwater intrusion in the Northern Part of the Nile Delta. *Groundwater* 35(2):216–222
- Etu-Efeotor JO, Odigi MI (1983) Water supply problems in the eastern Niger Delta. *J Min Geol* 20(1, 2):183–193
- Fuhrer GJ, Gilliom RJ, Hamilton PA, Morace JL, Nowell LH, Rinella JF, Stoner JD, Wentz DA (1999) The quality of our nation's water: nutrients and pesticides. *US Geol Surv Circ* 1225:82
- Holman IP, Whelan MJ, Howden NJK, Bellamy PH, Willby NJ, Rivas-Casado M, McConvey P (2008) Phosphorus in groundwater—an overlooked contributor to eutrophication? *Hydrol Process* 22:5121–5127
- Keller GV, Frischknecht FC (1979) Electrical methods in geophysical prospecting. Pergamon Press, New York, pp 91–135
- Nigeria Standard for Drinking Water Quality (NSDWQ) (2007) Nigeria industrial standard. Standard Organization of Nigeria Governing Council, Abuja
- Nwankwoala HO, Ngah SA (2015) Assessing chloride distribution and concentrations in the aquifer systems of the Niger Delta. *J Geosci Geomat* 3(5):128–132
- Ohwoghere-Asuma O, Essi OE (2017) Investigation of seawater intrusion into coastal groundwater aquifers of escravos, western Niger Delta, Nigeria. *J Appl Sci Environ Manag* 21(2):362–369. <https://doi.org/10.4314/jasem.v21i2.18>
- Ohwoghere-Asuma O, Aweto KE, Akpoborie IA (2014) Investigations of groundwater quality and evolution in an estuary environment: a case study of Burutu Island, western Niger Delta, Nigeria. *Environ Hydrol* 22(5):1–14
- Ohwoghere-Asuma O, Chinyim IF, Essi OE (2017) Saltwater intrusion appraisal of shallow aquifer in Burutu Area of the western Niger Delta with 2D electrical resistivity tomography. *J Appl Sci Environ Manag* 21(2):372–377. <https://doi.org/10.4314/jasem.v21i2.19>
- Ohwoghere-Asuma O, Aweto KE, Chinyem FI, Nwankwoala HO (2018) Assessing the protective capacity of aquifers using very-low-frequency electromagnetic survey. *Geosciences* 8(150):1–11. <https://doi.org/10.3390/geosciences8050150>
- Olobaniyi SB, Efe SI (2007) Comparative assessment of rainwater and groundwater quality in an oil producing area of Nigeria: environmental and health implications. *J Environ Health Res* 6(2):111–118
- Orellana E, Mooney HM (1996) Master tables and curves for vertical electrical sounding over layered structures. Interscienia, Madrid, 34 pp
- Piper AM (1994) A graphic procedure in geochemical interpretation of water analysis. *Trans Am Geophys Union* 25:914–923

- Reijers TJA (2011) Stratigraphy and sedimentology of the Niger delta. *Geologos* 17(3):133–162. <https://doi.org/10.2478/v10118-011-0008-3>
- Sidhardhan S, Adishkumar S, Jayganesh D (2015) A geophysical investigation of resistivity and groundwater quality near a corporate solid waste dump. *Pol J Environ Stud* 24(6):2761–2766. <https://doi.org/10.15244/pjoes/59239>
- UNESCO (2006) UNESCO water portal newsletter no. 161: water-related diseases. www.unesco.org/water/news/newsletter/161.shtml. Assessed 2 Aug 2017
- Vander VBPA (2004) WinResist version 1.0. M.Sc. Research Project ITC, Deft, Netherland
- Welch HL, Kingsbury JA, Coupe RH (2010) Occurrence of phosphorus in groundwater and surface water of northwestern Mississippi. In: Mississippi water resources conference. www.wrr.msstate.edu/pdf/welch10.pdf. Assessed 30 Oct 2019
- WHO/UNICEF (2004) Meeting the MDG drinking water and sanitation: a mid-term assessment of progress. World Health Organization, Geneva
- Zohdy AR (1989) A new method for the automatic interpretation of Schlumberger and Wenner sounding curves. *Geophysics* 54(2):245–253

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