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Implications of Excess Iron in the groundwater of Igbokoda Areas, SW Nigeria

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ABSTRACT

The groundwater of Igbokoda Coastal Area of Nigeria is characterized by high iron concentrations. Excess iron (Fe) at concentrations above 0.3mg/L in water can give an unpleasant metallic taste and its health effects may include warding off fatigue and anemia. This study therefore assessed the implications of excess Fe in Igbokoda coastal groundwater. The research was carried out using the WHO recommended guideline values, the Langelier Saturation Index (LSI) and Larson Index (LI). Hydrochemical results revealed that the pH ranged from 6.8 – 9.8, EC from 67 – 2440(µS/cm), TDS from 43.55 – 1586 (mg/L) and TH from 66.36 – 369.22mg/L. In addition, the selected anions (mg/L) including HCO_3, SO_4 and Cl ranged from 15.25 – 152.50, 0.00 – 5.32 and 72.00 – 2592.00 respectively. Calcium varied from19.21 – 104.32mg/L and Mg from 3.36 – 75.01mg/L. Iron ranged between 0.01 and 13.74(mg/L) with Mn from 0.00 – 1.00(mg/L). The hydrochemical contents are within approved WHO standard values for potable water except for EC, TH, Cl, Fe and Mn concentrations that exceeded the standard values in some locations. About 97% of the groundwater samples for this research have TH>80mg/L and may not be suitable for domestic purposes as it coagulates soap lather. The chloride values were higher than approved WHO standard of 250mg/L in twenty one locations representing 54% of the groundwater samples. The high chloride values were attributed to saltwater intrusion in the area and could accelerate corrosion of stainless steel even at values as low as 50mg/L. In this research, all LI values in all groundwater samples were greater than 0.5 while 78% have negative LSI values indicating corrosive water. Both LI and LSI revealed significantly that the groundwater of Igbokoda coastal area is corrosive. High levels of Fe and Mn in the groundwater of the study area can result in discoloured water, stain plumbing fixtures and inflict unpleasant metallic taste on the water. In addition, it could result into diseases of aging (Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis, diabetes mellitus). The groundwater in the coastal area of Igbokoda must be treated by aeration or chlorination which should be followed by physical filtration to allay the health risks of excess iron in the groundwater of the study area.

Introduction

Groundwater contamination can occur in many ways and from many sources, both natural (geogenic) and human-induced (anthropogenic). The geogenic sources constitute one or more naturally occurring chemicals leached from soils or rocks into the groundwater system while the anthropogenic sources are any addition of undesirable substances to groundwater caused by human activities. Contamination of groundwater results from overabundance of either the geogenic or anthropogenic materials above approved standard values [1], [2]. In coastal areas, natural contamination could arise from saltwater intrusion into the groundwater system. The major anthropogenic sources of heavy metals are industrial wastes from mining sites, manufacturing and metal finishing plants, domestic waste water and run off from roads. Many of these trace metals such as Hg, Pb, Cd, Ni, As, and Sn are highly toxic to humans. . Their presence in surface and underground water at above background concentrations is undesirable. Some heavy metals such as Hg, Pb, As, Cd, Fe, Co, Mn, Cr etc., have been identified as deleterious to aquatic ecosystem and human health [3]. The earth's underground rock formations contain about 5% irons; thus it is common to find iron in many geographical areas around the globe. The presence of iron in ground water is a direct result of its natural existence in underground rock formations and precipitation water that infiltrates through these formations. As the water moves through the rocks some of the iron dissolves and accumulates in aquifers which serve as a source for groundwater [4]. Iron in water is typically found in three major forms including insoluble iron, clear water iron (dissolved iron) and iron bacteria. Insoluble iron is common in lakes and rivers where there is sufficient oxygen to react with dissolved iron to form insoluble compounds that sinks out of the water. The clear water iron is a non-visible ferrous (Fe^{2+}) form of dissolved iron found in water that is not exposed to oxygen, such as in wells and springs. The iron bacteria form dark-coloured slime layers on the inner walls of the well's pipes and dissolved iron contributes greatly to its growth.

Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Essential for good health, iron helps transport oxygen in the blood. However, iron and

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manganese in concentrations greater than the [1] approved standards for drinking water (0.3 mg/L for iron and 0.05 mg/L for manganese) can impair the taste of water; stain plumbing fixtures, glassware and laundry; and form encrustations on well screens, thereby reducing well-pumping efficiency.

[5], worked on "assessment of impact of climatic change on groundwater quality around Igbokoda coastal area, southwestern Nigeria" and observed high concentrations of Fe and Mn above approved [1] standards in the groundwater of the study area. In this study, the occurrence of relatively high iron and manganese contents above the normal permissible level in relation to incrustative and/or corrosive potentials of the groundwater at Igbokoda are highlighted.

Location and Geology

Igbokoda town is the headquarter of Ilaje Local Government Area in Ondo State, Nigeria. Ilaje is bounded to the west by the Ijebus, the Ikale to the North, the Itsekri to the East, the Apoi and Arogbo Ijaw to the North-East while the Atlantic Ocean formed the southern boundary. Igbokoda is located 6^o 10′ to 6^o 25′N latitude and 4^o 39′ to 4^o 53′E longitude (Fig. 1). It is covered by undulating low land surfaces. Occurrence, movement and storage of groundwater are influenced by lithology, thickness and structure of rock formations. The Study area is covered by Quaternary alluvium deposits underlain by the Quaternary coastal plain sands (Fig. 1). The coastal sands serve as the aquiferous layer of the area in view of its high porosity and permeability.

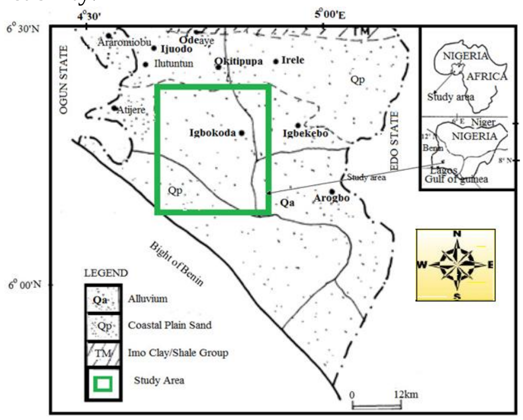

Figure 1. Location and Geology of the study area (After Talabi et al., 2012)

Methodology

Data for this study was extracted from the research of [5] on "Assessment of impact of climatic change on groundwater quality around Igbokoda Coastal Area, Southwestern Nigeria". Excess iron above WHO (2008) approved standard value warranted the present research. The effects of excess irons in groundwater of Igbokoda coastal area were assessed employing approved standard values of WHO (2008), Langelier Saturation Index [6, 7] and Larson Index (LI) proposed by [8]. LI as indicated in equation 1 represents the ratio of the sum of the twice sulphate and chloride concentrations to that of bicarbonate [8, 9]. The concentrations of the ions are in meq/L.

$$LI = \frac{2(SO_4) + Cl}{HCO_3} \quad (1)$$

The Langelier Saturation Index (LIS) is one of the corrosive indexes of water employed in this research. The formular for LIS is given in equation 2.

$$LSI = pH - pHs \quad (2)$$

Where pH = Field pH (measured in-situ).

$$pHs = (9.3 + E + F) - (G + H) \quad (3)$$

Where $E = \frac{Log_{10}(TDS) - 1}{10}$

$F = -13.2 Log_{10}(t°C + 273) + 34.55$

$G = Log_{10}$ (Ca2= as $CaCO_3$) – 0.4

$H = Log_{10}$ (alkalinity as $CaCO_3$)

Results and Discussion

The results of selected parameters from [5] are presented in Table1. The result revealed that the pH ranged from 6.8 – 9.8, EC from 67 – 2440(μS/cm), TDS from 43.55 – 1586 (mg/L) and TH from 66.36 – 369.22mg/L. In addition, the selected anions (mg/L) including HCO_3, SO_4 and Cl ranged from 15.25 – 152.50, 0.00 – 5.32 and 72.00 – 2592.00 respectively. Calcium varied from19.21 – 104.32mg/L with a mean value of 43.33mg/L and Mg from 3.36 – 75.01mg/L. Iron ranged between 0.01 and 13.74(mg/L) with Mn from 0.00 – 1.00(mg/L). Figure 2 represents average values of physico-chemical parameters of water samples from Igbokoda groundwater. The figure revealed low average values for SO_4, Fe and Mn. However, the mean value of 2.58mg/L >0.3mg/L approved standard value of [1]. The major cations contributing to total hardness are Ca and Mg while SO_4, Cl and HCO_3 constitute the major anions. Total hardness in the present study are within approved potable water standard value of 300mg/L [1] except in three locations representing less than 8% of the sampled water. This observation revealed that TH has no significant impacts on the encrustation of groundwater of the study area (Fig. 3). However about 97% of the groundwater samples for this research have TH>80mg/L and may not be suitable for domestic purposes as it coagulates soap lather [10]. The chloride values were higher than approved [1] standard of 250mg/L in twenty one locations representing 54% of the groundwater samples. The high chloride values were attributed to saltwater intrusion in the area [5] and the high chloride ions accelerate corrosion of stainless steel even at values as low as 50mg/L [11]. The TDS values in this research were greater than 1000mg/L in 3 locations representing less than 8% of sampled groundwater (Fig. 4). Values of TDS>1000mg/L in water signifies ability of the water to conduct electric current which can cause serious electrolytic corrosion [12]. The TDS values at the 3 locations indicated that the groundwater in the locations could corrode metal pipes used in water supply system.

Apart from the chemical concentrations evaluated, corrosiveness of the Igbokoda groundwater was further examined by calculating the LI and LSI. The corrosive nature of particular water is expressed by the LI with respect to rate of metal corrosion. The Larson Ratio was developed from the relative corrosive behavior of chlorides, sulphate and the protective properties of bicarbonate. Subsequently, it was deduced that the corrosivity of air saturated waters is dependent on the proportion of corrosive agents and their concentrations [13]. [14] observed that calcium in the presence of alkalinity, regardless of pH or saturation index is an effective inhibitor of corrosion. According to [15], LI>0.5 indicates high corrosive water. In this research, all LI values in all groundwater samples were greater than 0.5 indicating the corrosive nature of the water.

The Langelier Index of Saturation (LSI) indicates if conditions are suitable for the precipitation of calcium carbonate.

Table 1. Selected chemical constituents and estimated corrosion/encrustation parameters of Groundwater from Igbokoda.

Code	pH	EC (µS/cm)	TDS (mg/L)	TH (mg/L)	HCO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Mn (mg/L)	LI	LSI
PL1	9.8	546	354.9	159.25	45.75	1.56	468	45.55	11.06	7.29	0.36	10.30	1.28
PL2	8.6	329	213.85	121.51	45.75	0	198	24.52	14.65	13.74	1	4.33	-0.45
PL3	7.9	729	473.85	173.4	61	1.46	504	49.62	12.03	3.84	0.11	8.31	-0.57
PL4	7.6	452	293.8	119.53	61	1.7	450	32.33	9.43	1.3	0.05	7.43	-1.24
PL5	7.7	211	137.15	110.22	45.75	0.37	810	30.81	8.09	3.49	0.18	17.72	-1.12
IY6	8.2	116	75.4	104.15	30.5	0.65	239	25.94	9.57	5.36	0.28	7.88	-0.74
0K7	7.4	67	43.55	76.26	30.5	0	108	20.11	6.33	0.69	0.04	3.54	-1.74
OK8	7.3	462	300.3	175.71	30.5	2.46	234	55.62	8.95	0.41	0.07	7.83	-1.05
OK9	7.4	90	58.5	96.65	61	0	72	27.98	6.51	0.99	0.03	1.18	-1.47
OK10	7.8	129	83.85	94.99	30.5	0.01	90	27.66	6.3	0.88	0	2.95	-1.10
OK11	7.8	330	214.5	152.55	30.5	2.65	180	44.81	9.88	0.35	0	6.08	-0.72
OK12	8	600	390	146.32	30.5	0.4	486	40.14	11.2	12.35	0.75	15.96	-0.64
EB13	9	2440	1586	369.22	122	0	2592	24.25	75.01	1.55	0	21.25	-0.08
EB14	9.3	1870	1215.5	195.99	76.25	1.67	1944	63.94	8.83	4.07	0.03	25.54	1.04
EB15	8.4	516	335.4	232.43	30.5	1.91	234	69.45	14.34	5.09	0.34	7.80	0.24
KE16	9.2	1739	1130.35	358	152.5	0.34	1332	26.45	70.95	1.98	0	8.74	0.17
KE17	8.5	390	253.5	179.08	61	0.78	234	51.12	12.5	7.68	0.32	3.86	0.07
IW18	7.9	370	240.5	157.5	45.75	0.94	288	45.82	10.47	2.77	0.22	6.34	-0.62
IW19	8.4	392	254.8	148.71	15.25	1.39	288	42.35	10.44	1.72	0.13	19.07	-0.20
AR20	9.3	641	416.65	235.53	45.75	5.32	396	75.01	11.72	0.29	0.02	8.89	1.16
OG21	8.4	531	345.15	168.27	30.5	4.92	288	52.31	9.15	0.41	0.01	9.77	-0.03
LA22	8.4	773	502.45	319.78	30.5	5.01	360	104.32	14.41	2.75	0.34	12.13	0.55
LA23	8.8	516	335.4	191.23	45.75	0.6	324	58.11	11.21	0.86	0.04	7.11	0.45
IL24	8.3	194	126.1	134.24	30.5	0	72	40.41	8.1	1.85	0.06	2.36	-0.30
IL25	8.4	316	205.4	179.57	30.5	1.02	288	59.24	7.69	2.3	0.1	9.51	0.11
IL26	8.4	473	307.45	188.62	30.5	0.69	324	59.01	10.03	1.37	0.13	10.67	0.10
KU27	7.3	253	164.45	78.52	30.5	0	288	19.21	7.44	1.51	0.05	9.44	-1.98
KU28	7.2	1311	852.15	99.76	91.5	0.32	1152	28.35	7.04	1.73	0.35	12.60	-1.81
WE29	8	593	385.45	178.74	91.5	1.08	324	51.92	11.93	0.65	0.11	3.56	-0.43
WE30	9.1	237	154.05	118.15	45.75	0.09	252	35.04	7.45	0.01	0	5.51	0.38
WE31	8	717	466.05	241.91	76.25	0.27	432	78.57	11.11	0.31	0.07	5.67	-0.09
KO32	7.9	122	79.3	104.17	61	0.3	180	31.14	6.42	0.65	0	2.96	-0.91
KO33	6.8	106	68.9	80.7	76.25	0.07	162	23.24	5.51	0.3	0	2.13	-2.23
JE34	7.6	98	63.7	66.36	61	0.48	162	21.04	3.36	0.87	0	2.67	-1.54
GR35	7.8	297	193.05	111.17	45.75	0.14	162	33.58	6.64	0.23	0	3.55	-0.96
GR36	7.6	209	135.85	113.95	45.75	0.54	144	33.95	7.09	0.17	0	3.17	-1.15
GR37	8.1	186	120.9	139.95	45.75	0.12	189	43.87	7.39	0.36	0	4.14	-0.42
GR38	7.4	227	147.55	116.94	30.5	0.11	216	36.22	6.44	0.17	0	7.09	-1.28
GR39	7.9	289	187.85	175.39	76.25	0.16	162	57.04	8.01	0.39	0.03	2.13	-0.37
Min	6.80	67.00	43.55	66.36	15.25	0.00	72.00	19.21	3.36	0.01	0.00	1.18	-2.23
Max	9.80	2440.00	1586.00	369.22	152.50	5.32	2592.00	104.32	75.01	13.74	1.00	25.54	1.28
Mean	8.13	509.41	331.12	159.34	52.01	1.01	426.36	43.33	12.43	2.38	0.13	7.98	-0.51
Stdev	0.67	511.31	332.35	71.27	27.71	1.38	510.60	18.62	14.50	3.16	0.21	5.61	0.85

LI = Larson Index, LSI = Langelier Saturation Index

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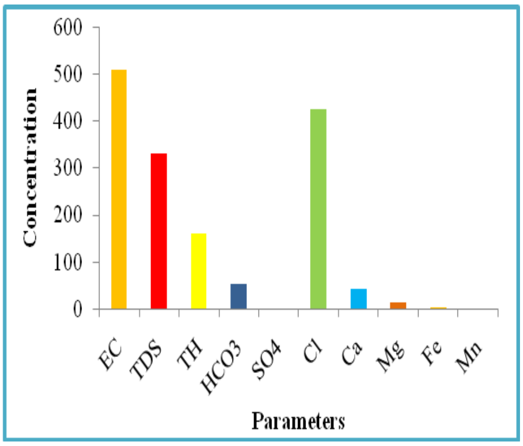

Figure 2. Average values of physico-chemical parameters of groundwater samples from Igbokoda

In addition, the LSI is equally used to show the stability of the source waters due to preponderance of evidence that calcium carbonate films inhibit corrosion to some degree [16]. Negative value of LSI signifies corrosive water, implying that the water will have the tendency to dissolve $CaCO_3$. However, LSI = 0 and LSI >1are indications of equilibrium and non corrosive status of the water respectively. Twenty eight (28) (78%) of the groundwater samples from Igbokoda coastal area have negative LSI values indicating corrosive water while the remaining samples (11) representing 12% of the groundwater have values >0, signifying non corrosive water. Both LI and LSI revealed that the groundwater of Igbokoda coastal area is corrosive. The corrosion of iron arises in moist air, a situation where both water and oxygen are present. Its silvery colour changes to a reddish-brown, because hydrated oxides are formed. Dissolved electrolytes accelerate the reaction mechanism which is as follows;

$4\,Fe + 3\,O_2 + 6\,H_2O \longrightarrow 4\,Fe^{3+} + 12\,OH^- \longrightarrow 4\,Fe(OH)_3$ or $4\,FeO(OH) + 4\,H_2O$

Usually the oxide layer does not protect iron from further corrosion, but is removed so more metal oxides can be formed. Electrolytes are mostly iron (II) sulphate, which forms during corrosion by atmospheric SO_2. Iron (II) hydroxide often precipitates in natural waters.

Other Implications of excess iron and manganese in groundwater of Igbokoda

Iron being an essential mineral found in every cell of the human body, assists in the creation of hemoglobin in red blood cells. According to the [1], over 30 percent of the world's population suffers from anemia, mainly due to iron deficiency. However, too much iron in the body also requires attention. High levels of iron and manganese contaminants can result in discolored water stained plumbing fixtures, and an unpleasant metallic taste to the water.

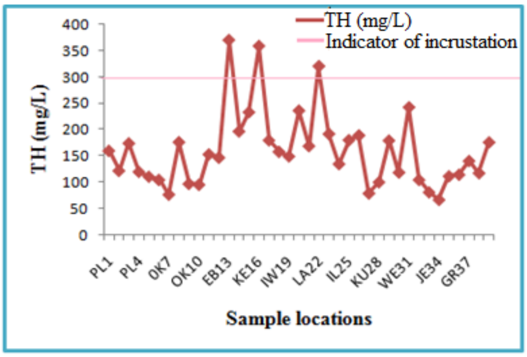

Figure 3. Variation of TDS in groundwater samples of Igbokoda coastal area

When these deposits break loose from water piping, rusty water will flow through the faucet. Iron deposits can buildup in pressure tanks, storage tanks, water heaters and pipelines. Iron-deposit buildup can decrease capacity, reduce pressure, and increase maintenance [17]. Furthermore, water with excess iron when combines with tea, coffee and other beverages, produces an inky, black appearance and a harsh, unacceptable taste. Vegetables cooked in water containing excessive iron turn dark and look unappealing. As for the dissolved manganese in water, blackish particulates in the water arises which cause similar coloured stains on fixtures.

There is no serious health issue attached to excess iron in water as the chemical form of the iron found in water is not readily absorbed by the body. The extent of iron and manganese dissolution in groundwater depends on the amount of oxygen and to a lesser extent its degree of acidity (pH). The pH of groundwater in the study area is alkaline an indication of it having little or no effects on the extent of iron in the groundwater of the area. However, high concentrations of iron in Igbokoda groundwater, may lead to growth of iron bacteria and this is of concern since some pathogenic (harmful) organisms require iron to grow, and the presence of iron particles makes elimination of the bacteria more difficult and this posts iron as a risk factor in the groundwater of the study area. Moreover, though iron is an essential mineral, diseases of aging such as Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis, diabetes mellitus, and others have been linked to excess iron intake [18].

The fact that excess iron in the groundwater of the study area warrants caution in consuming the groundwater untreated. Natural process of aeration could be employed to treat the dissolved Fe and Mn in the groundwater by injecting air into the water so that Fe and Mn can be precipitated. Apart from this method of treating excess Fe and Mn in groundwater, addition of chlorine to the water could be employed as this will equally precipitate the Fe and Mn in the water. In addition, treatment with chlorine provides protection from microbial contamination. Usually, a physical filter follows the treatment to remove particles that constitute health risk.

Conclusion

This study entailed examination of the implications of excess iron in groundwater of Igbokoda coastal area employing literature search, LI and LSI indices. The study reavealed that;

i) About 80% of the sampled groundwater from Igbokoda coasal area has concentrations of Fe>0.3mg/L.

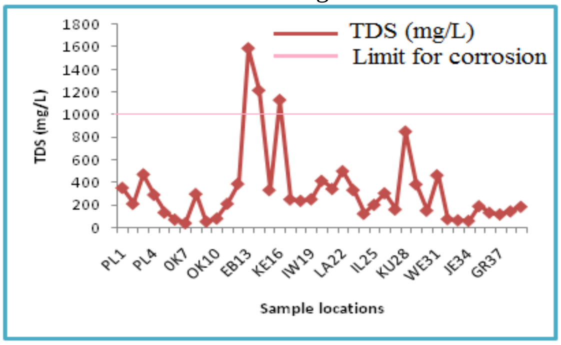

Figure 4. Variation of TDS in groundwater samples of Igbokoda coastal area

ii) The two indices of corrosion indicated that the groundwater in the study area has the tendency to corrode with LI values >0.5 in all water samples and with 78% having negative LSI values.

iii) High levels of Fe and Mn in the groundwater of the study area can result in discoloured water, stain plumbing fixtures and inflict unpleasant metallic taste on the water.

iv) Excess iron in groundwater of Igbokoda can result into diseases of aging (Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis, diabetes mellitus).

v) The groundwater in the coastal area of Igbokoda must be treated by aeration or chlorination which should be followed by physical filtration to allay the health risks of excess iron in the groundwater of the study area.

vi) Visual inspection of wells in the area revealed that about 80% are not cased. The wells are not connected with iron or steel pipes or other plumbing components that can introduce iron to the groundwater of the study area. Thus the excess iron in the groundwater of Igbokoda is of geogenic source arising from dissolution of minerals that constitute the rock units.

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