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Archives of Applied Science Research, 2013, 5 (2):266-272
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Iron (Fe^{2+}) occurrence and distribution in groundwater sources in different geomorphologic zones of Eastern Niger Delta

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ABSTRACT

This study is an attempt to characterize the distribution and occurrence of iron in the groundwater sources in parts of eastern Niger Delta, Nigeria. The study sites were chosen from the five (5) geomorphologic units that make up the area. Iron is a major chemical issue in groundwater from the area as nearly all the analysis returned a value for iron. Iron concentration was mapped with a view to relating the high occurrence to depth of boreholes. There is no definite relationship between the depth of boreholes and iron content. Therelationship is rather haphazard and probably related to the geologic history of the Niger Delta region. For instance, the boreholes with highest concentration of iron in the area of 10mg/l are located atIdama (Saltwater Swamp) and Umuoji (Coastal Plain Sands) and are 100m and 81m deep respectively. Ahoada (Coastal Plain Sands) has 0.04 from a borehole 65m deep.The deep wells at Onne (264m) has iron concentration of 0.06mg/l, Joinkrama (Freshwater Swamp) has 6.2mg/l from a borehole 176m deep. Toru-Ndoro (freshwater swamp) has 6.2mg/l from 176m-deep borehole while Forupa (Freshwater Swamp) has 0.3mg/l from a borehole 215m. The high iron concentration appears to be more prevalent in the boreholes drilled in Freshwater Swamps/Backswamp/Meander Belt region as well as the mangrove swamps and coastal ridges. Here, the values range from 0.4 – 10mg/l. It was less than 0.4mg/l in 50% of the samples, 0.4mg/l – 1.0mg/lin 22% of the samples and >1.0mg/l in 20% of the samples. The highest value of 10.0mg/l occurs at Rumuokachi and Umuoji while the groundwater from Harry's Town has 8.0mg/l. The WHO (2008) recommended a range of 0.1mg/l – 0.3mg/l as highest desirable and maximum permissible limits respectively. The implication therefore is that most water boreholes in the study area deliver water with iron in objectionable concentration. Most of the water in its natural state are not fit for human consumption.

Key words: Iron, groundwater, geomorphologic zones, Niger Delta

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INTRODUCTION

Although iron is the second most abundant metallic element in the earth's crust, its concentration in water is small. The origin of iron in groundwater is due to dissolved iron from the soil and rock formations as rainwater seeps, percolates and drains down the soil and rocks [1]. The chemical behaviour of iron and its solubility in water depends strongly on the oxidation intensity in the system in which it occurs [2].pH also has a strong influence [3].Since iron is a transition element which has a specific stable range of pH – Eh in aqueous solution, so the redox condition of groundwater exerts obvious influence on iron. The prevalence of transition elements in specific form may be used to identify the redox character in the ambient environment [4].

Iron is an essential element in the metabolism of animals and plants, for nutrition and in the formation of mammalian haemoglobin and if it is present in water in excessive amount, it forms red oxy-hydroxide precipitate that stains laundry and plumbing fixtures, dish wares and glasses owing to its very reactive nature. Iron concentration in excess of

0.3mg/l in water can be very deleterious as it impacts a stringent odour to drinking water [5]. Iron also impacts on infrastructures used in groundwater abstraction and these includes fouling of air strippers used in treating iron in groundwater as well as fouling of well screens and piping systems in poorly designed recovery wells. It therefore becomes an objectionable impurity in domestic and industrial water supplies. Hence iron determination is commonly included in chemical analysis. Iron actually presents no health hazards even in excess concentration except for impacting a metallic taste to water if the concentration is above 1.8mg/l. It is mainly for aesthetic reasons that large concentrations of iron in water are undesirable [6].

Iron is present in groundwater as ferrous bicarbonate, $Fe(HCO_3)_2$, ferric hydroxide, $Fe(OH)_3$, organic complex iron or corrosion product such as Fe_3O_4 (Herman, 2005). In groundwater systems, iron occurs in one of two oxidation states: reduced soluble divalent ferrous iron (Fe^{2+}) or oxidized insoluble trivalent ferric iron (Fe^{3+}). Iron readily participates in subsurface redox reactions and under certain conditions can cause problems with groundwater remediation.

The method of iron removal adopted for treatment of borehole water supplies depends on the form the iron is present in the water. Such methods includes water softener using cation exchanger [7], complete aeration and filtration with pH adjustment [8], chlorination and aeration with pH adjustment/coagulation and filtration [9], ozonation and chelation [5]. Most of these conventional methods have their limitations and disadvantages, among which includes pH limitation, temperature dependence, cost effectiveness, oxygen-free or airtight medium and time limitation [10].

Several researchers have observed iron as a serious threat to the quality of groundwater systems in many parts of the Niger Delta [11-18]).None of these studies have been able to determine the definite trend and relationships between the borehole depths, concentrations as well as the geologic history of the area. This study therefore, attempts to characterize the distribution and occurrence of iron in the groundwater sources from the five (5) geomorphologic units that make up the Niger Delta.

Description of the Study Area

The study area is the Niger Delta Sedimentary Basin. Lithostratigraphically, these rocks are divided into the oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the Youngest Benin Formation (Miocene to Recent). Generally, the present knowledge of the geology of the Niger Delta was derived from the works of the following researchers [19-22], as well as the exploration activities of the oil and gas companies in Nigeria. The formation of the so called proto-Niger Delta occurred during the second depositional cycle (Campanian-Maastrichtian) of the southern Nigerian basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigerian basin which started in the Paleocene.

The geologic sequence of the Niger Delta consists of three main Tertiary subsurface lithostratigraphic units [20] which are overlain by various types of Quaternary deposits (Table 1).

Table 1: Quaternary deposits of the Niger Delta, [23].

Geologic/Geomorphologic Unit	Lithology	Age
Alluvium	Gravel, Sand, clay, silt	
Freshwater Backswamp, meander belt	Sand, clay, some silt, gravel	
Saltwater Mangrove Swamp and backswamp	Medium-fine sands, clay and some silt	Quaternary
Active/abandoned beach ridges	Sand, clay, and some silt	
Sombreiro-warri deltaic plain	Sand, clay, and some silt	

The major aquiferous formation in the study area is the Benin Formation. It is about 2100m thick at the centre of the basinand consists of coarse-medium grained sandstones, thick shales and gravels. Overlying the Benin Formation is the quaternary deposits which is about 40 – 150m thick and comprises of sand and silt/clay with the later becoming increasingly more prominent seawards [23]. The formation consists of predominantly freshwater continental friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystone/shales. The sands are fine to coarse-grained, gravelly, poorly sorted and sub-angular to well rounded. The rocks of the Benin Formation are made up of about 95 – 99% quartz grains, Na+K – Mica 1 -2.5%, feldspar 0.5 1.0% and dark minerals 2.3%, [24]. These minerals are loosely bound by calcite and silica cement. The clayey intercalations have given rise to multi-aquifer systems in the area.

The main source of recharge is through direct precipitation where annual rainfall is as high as 2000 – 2400mm. The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers. Groundwater in the study area occurs principally under water table conditions except in the multilayered aquifer systems where the lower aquifers are confined. The Benin Formation is highly permeable, prolific and productive and is the most extensively exploited aquifer in the Niger Delta. All the boreholes in the study area are drilled into the Benin Formation.

Fig.1: Location Map of the Study Area

MATERIALS AND METHODS

Data Gathering

In this study, available literature were gathered and categorized on the basis of the different geomorphologic zones in the Niger Delta area of Nigeria. In categorizing these, only iron (Fe^{2+}) data with depth range were utilized. The data were also compared with the World Health Organization [25] standards to assess their concentrations in the various geomorphic zones in the study area. Data were sourced from the following: Niger Delta Basin Development Authority (NDBDA), Rivers State Ministry of Water Resources (RMWR), Rivers State Water Board (RSWB) and Rural Water Supply and Sanitation Agency (RUWSSA) and from some borehole companies operating in the area. Table 2 shows the summary of iron concentrations and locations in the different geomorphic zones of the Niger Delta.

Table 2: Iron concentrations ingroundwater samples in different geomorphologic zones

S/No.	Borehole Location	Geomorphic Zone	Depth (m)	Iron (mg/l)
1.	Ahoada	CPS	65.53	0.04
2.	Ogbo	"	186	0.0
3.	Edeocha	"	185	0.5
4.	Udiereke-Ubie	"	76.20	0.08
5.	Abua	"	60.96	0.02
6.	Joinkrama	"	176.22	6.2
7.	Ndoni	"	382	0.4
8.	Ebubu	"	91.44	0.0
9.	Onne	CPS	264	0.06
10.	Bien Gwara	"	60.96	0.01
11.	Bodo	"	80.56	0.25
12.	Baen	"	60.96	0.0
13.	Kongho	"	60.96	0.0
14.	Lubara	"	60.96	0.1
15.	Baun	"	60.96	0.5
16.	Opuoko	"	60.96	0.1
17.	Kono	"	60.96	0.2
18.	Kanni	"	60.96	0.00
19.	Beeri	"	60.96	0.00
20.	Sii Babbe	CPS	60.96	0.01
21.	Isiokpo	"	70.1	2.0
22.	Aluu	"	60.96	0.2
23.	Umuoji	"	81	10.0
24.	Ogbakiri	"	78.03	0.01
25.	Ndele	"	72.5	0
26.	Omerelu	"	70.1	0.4
27.	Ubima	CPS	70.1	0.0

S/No.	Borehole Location	Geomorphic Zone	Depth (m)	Iron (mg/l)
28.	Elele	"	60.96	0.0
29.	Ibaa	"	60.96	0.0
30.	Obelle	"	81.0	0.3
31.	Rumuewho	"	54.86	0.15
32.	Egwi	"	61.28	0.30
33.	Rumuoyo	"	57.3	0.0
34.	Ulakwo	"	67.06	0.0
35	Opiro	"	138	10
36.	Rumuokochi	"	91	0.30
37.	Umuechem	"	132	0.0
38.	NDBDA	"	170	0.1
39.	Borokiri	CPS	176.8	0.02
40.	Govt. House	"	110	0.01
41.	Moscow Road	"	180	0.04
42.	Central Police Stn	"	176.8	0.02
43.	Choba	"	140	0.0
44.	Rumuomasi	"	131.0	0.0
45.	Rumuokoro	"	152.0	0.0
46.	Rumuodamaya	"	168.0	0.1
47.	Elelenwo	"	171.8	0.8
48.	Iriebe	"	163.0	0.0
49.	Mbiama	FWS	175	5.6
50.	Obibi	"	76.22	0.4
51.	Ogbia	"	101	0.4
52.	Amakalakala	"	160.96	0.9
53.	Sangana	"	60.96	0.0
54.	Oruma	"	101.59	0.25
55.	Aagbere Odoni	"	76.2	0.5
56.	Peretorugbene	"	211.0	0.2
57.	Ekeremor	"	202	1.5
58.	Toru Ndoro	"	211	4.5
59.	Torofani	"	165	3.5
60.	Ofoni	"	186	0.8
61.	Toro Anjiama	FWS	215	0.4
62.	Forupa	"	215	0.3
63.	Asamabiri	"	81.0	0.0
64.	Amarata	"	180	3.0
65.	Ukubie	"	85.3	0.2
66.	Tebidaba	"	171.0	0.2
67.	Aguobiri	"	79	3.0
68.	Okolobiri	"	75	2.0
69.	Amassoma	"	180	2.0
70.	Agudama-Epie	"	242.67	2.4
71.	Oporoma	"	42.7	0.5
72.	Peremabiri	"	300	4.5
73.	Amatolo	"	161.0	0.1
74.	Yenagoa	"	185.34	4.5
75.	Oyorokoto	"	-	3.6
76.	Zarama	SWS	89	4.2
77.	Bassambiri	"	250	0.02
78.	Atubo	"	193	0.7
79.	Nembe	"	193	0.6
80	Soku	"	95.0	0.00
81.	Tombia	SWS	59.44	0.0
82.	Idama	"	100	10.0
83.	Abonnema	"	9.24	0.0
84.	Harry's Town	"	95	8.0
85.	Kula	"	183.0	0.7
86.	Bukuma	"	60.96	1.5
87.	Kanana	"	186	0.0
88.	Kala Degema	"	40.96	0.0
89.	Krakrama	"	75	2.5
90.	Abalama	"	60.96	2.0
91.	Buguma	"	60.96	0.0
92.	Okrika Mainland	"	320	0.0
93.	Ibuluya-Dikibo	"	180	0.0
94.	Bolo I	"	91.44	0.0
95.	Bolo II	"	91.44	0.0
96.	Kalio-Ama	"	82.88	0.5
97.	Abam-Ama	"	128.02	0.0
98.	Okujagu	"	30.0	0.8
99.	George-Ama	"	109.73	1.8

S/No.	Borehole Location	Geomorphic Zone	Depth (m)	Iron (mg/l)
100	Brass	CBR	192	1.6
101.	Emerego	"	78	5.1
102.	Kolo	"	101.59	0.4
103.	Kalibiama	"	281	0.0
104.	Bonny	"	304	0.8
105.	Oloma I	"	91.46	0.8
106.	Oloma II	"	82.88	0.0
107.	Illoma Opobo	"	19.8	0.6
108.	Gbokokiri	"	176.8	0.40
109.	Ikuru	"	190	0.38
110.	G.R.A. P.H.	"	170	0.00
111.	Creek Road	"	170.0	0.02
112	Potts Johnson	"	180.0	0.02

CPS = Coastal Plain Sands, FWS = Freshwater Swamp, SWS = Saltwater Swamp, CBR = Coastal Beaches and Ridges, SWP = Sombreiro -Warri Deltaic Plain

RESULTS AND DISCUSSION

In this study, nearly all the analysis returned a value for iron. The values range from 0 – 10mg/l. In 50% of the samples, the iron content is less than 0.4mg/l, 0.4 – 1.0 at 22% of the sites and >1.0mg/l at 20% of the sites. The highest value of 10.0mg/l occurs at Rumuokachi and Umuoji while the groundwater from Harry's Town has 8.0mg/l. The WHO [25] recommended a range of 0.1 – 0.3mg/l as highest desirable and maximum permissible limits respectively. The implication therefore is that most water boreholes in the study area deliver water with iron in objectionable concentration. Fig. 2 is a map showing the distribution of iron in the area. It would appear, from the map, that the locations north-east and south-east of the region have groundwater with iron in acceptable limits while locations south of these including the freshwater swamps/backswamps/alluvial plains/meander belt complex as well as the mangrove swamps and the coastal ridges have high iron contents in their groundwater. Iron is therefore another major quality issue in groundwater from the study area. Several boreholes are known to have been abandoned in the area as a result of high iron content. In some cases, corrosion occasioned by the high iron content has weakened the fabric of mild steel structures used in borehole construction and pump installation resulting in '*sand pumping*' and '*pump drop*' and a drastic reduction of the lifespan of boreholes completed with mild steel. There was no laboratory analysis of the water samples from the deep wells in Bonny. However, the concrete base around the well casing, the casing projections and the drains were immediately coated with brownish red coloration that was unmistakably a result of oxidation of Fe^{2+} to Fe^{3+} on exposure to ground surface. The iron concentration from the deep well water samples could not have been less than 6mg/l.

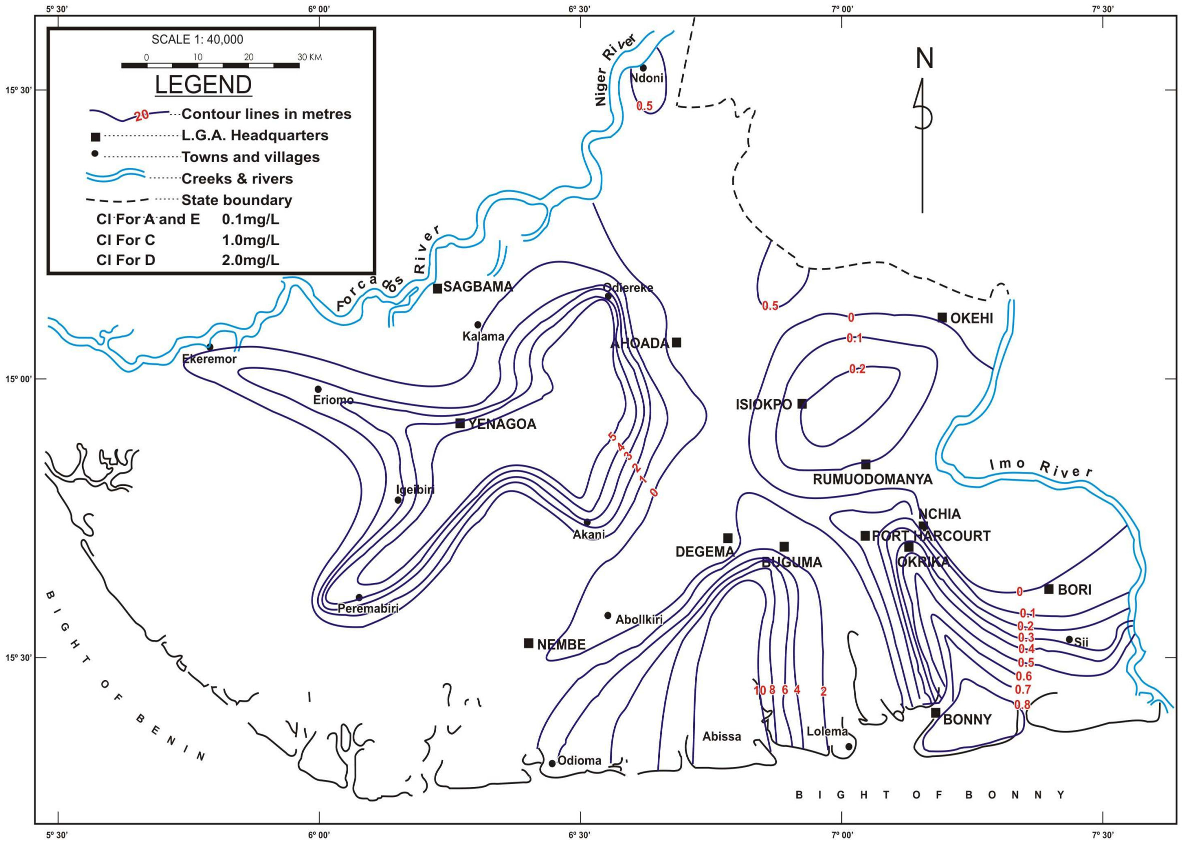
Stratigraphic Control on the Occurrence of Iron

Iron is a major objectionable contaminant in most groundwater samples from the study area. Some successfully completed boreholes are known to have been abandoned due to high iron content. It is therefore intended to examine the vertical distribution of iron concentration in the area with a view to isolating the layer that is iron-contaminated so that boreholes on the area can be designed to exclude the contaminant. In relating groundwater quality to the subsurface stratigraphy, best results are achieved if the aquifers can be separated in space and mapped and its stratigraphy related independently to its water. Because regional correlation of the aquifers is not possible due to sparse data and shallow depths for most of the wells, a close approximation can be obtained by using the borehole depth. Most boreholes are partially penetrating and are screened at the bottom of the borehole. Therefore the total depth of the borehole can be taken as the depth from which the water is extracted hence the concentrations measured for the parameters represent the concentration in the aquifer at that depth, [26].

A close look at the iron concentration shows that there is no definite relationship between the depth of boreholes and iron content. If anything, the relationship is haphazard. For instance, the boreholes with highest concentration of iron in the area of 10mg/l, Idama (saltwater swamp and Umuoji (coastal plain sands) are 100m and 81m deep respectively. Ahoada (coastal plain sands) has 0.04 from a borehole 65m deep.The deep wells at Onne (264m) has iron concentration of 0.06mg/l, Joinkrama (freshwater swamp) has 6.2mg/l from a borehole 176m deep. Toru -Ndoro (freshwater swamp) has 6.2mg/l from 176m-deep borehole while Forupa (freshwater swamp) has 0.3mg/l from a borehole 215m. However, it is curious to note that most of the locations with high iron content are in the freshwater swamp/meander belt region.

The occurrence of iron may rather be related to the geological history and source rocks of the deposits that constitute the aquifers in the Niger delta. The aquifers are predominantly sands with thick brown coloration due to iron oxide coatings and stains.Most of the sands are second and/or third cycle sands with very long transport history [27], [28].

Sediments that originate from northern highlands such as present day Kogi State are usually rich in iron and may have contributed to the sediments that built up the delta. The high rate of deposition associated with the Niger delta may have preserved these iron-rich grains along with other iron minerals such as hematite, limonite and magnetite and incorporates them into geologic records. With slightly acidic and corrosive groundwater, the iron may have been leached from the iron minerals, stains and coatings and liberated into groundwater flow systems. The abundance of pyritic clay interbeds, organic matters and lignite in the area may also have provided sources for the leaching of iron from sedimentary rocks into the groundwater systems.



CONCLUSION

This study revealed that iron contents in 50% of the samples were more than the WHO recommendation for iron concentration in drinking water supplies [25]. Iron therefore is a major chemical issue in groundwater from the area. The high iron concentration appears to be more prevalent in the boreholes drilled in freshwater swamps/backswamp/meander belt region as well as the mangrove swamps and coastal ridges.

An examination of the vertical distribution of iron was made with a view to relating the high occurrence to depth of the borehole. No definite trend or relationship exists between the depth of boreholes and the concentration of iron in the groundwater samples. The iron content appears to be related more to the geologic history of the area.

To make the groundwater in the study area fit for human consumption and domestic use, the water must be treated to remove the iron. Though, there are several treatment options for iron, treatment with alkaline hydrogen peroxide is one surest way of removing dissolved iron from borehole waters. The method is preferable than most conventional methods because it is fast, cost effective, environmentally friendly and does not require external coagulant [1]. It is recommended that further studies be carried out to relate quantitatively the dynamic property of iron (Fe) geochemistry to the groundwater systems. This is because Eh and pH can be used to understand the geochemistry of iron and to predict the environmental changes on the compounds and ions.

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