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EVALUATION OF CORROSION AND ENCRUSTATION POTENTIALS OF GROUNDWATER WELLS IN CALABAR AREA, SOUTHEASTERN NIGERIA

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ABSTRACT

This article presents results of groundwater quality assessment based on some corrosion-encrustation index parameters (CEIP) and drinking water standards. The CEIP concentration results indicate that the hydrogen ion concentration, pH ranges from 5.4 to 7.6, total iron, Fe varies from 0.02 to 3.0mg/l; Manganese Mn concentration was found to be from 0.01 to 1.0mg/l; the total dissolved solids TDS content of 13.0 to 273.7mg/l; Dissolved oxygen DO of 0.4 to 6.2mg/l; Hydrogen sulphide H_2S of 0.01 to 2.5mg/l; Chloride Cl of 2.6 to 16.2mg/l and bicarbonate HCO_3^- ranged 20.5 to 80.9mg/l while total carbonate hardness TCH ranged from 2.4 to 8.5mg/l. Corrosion is accelerated from a combination of any two factors such as high concentration of H_2S >2.0mg/l; DO >2mg/l; pH <7; Cl^- >500mg/l; TDS >1000mg/l and HCO_3^- >50mg/l. Encrustation is promoted when TCH >100mg/l; pH>7; Mn >0.1 and Fe >0.3mg/l. Interpretation of these CEIP analytical results based on these background values indicate that the groundwater is acidic. Acidic water causes corrosion of pumps, pipes and screens made of iron and steel. On the other hand, encrustation is never a major problem, although it is not completely absent in the area. The high total iron and manganese content greater than the above threshold values are the causes of encrustation in some localities while the high acidity, dissolved oxygen and bicarbonate are the causes of corrosion in Calabar area. Ways of minimizing the problems of corrosion and encrustation in the water industry of Calabar area have been suggested.

KEYWORDS: Corrosion, Encrustation, Index Parameter, Calabar.

INTRODUCTION

The Calabar area of Cross River State is blessed with vast amount of surface and groundwater. But rarely do these water sources meet the standards for either domestic or industrial purposes (Esu and Amah 1999). Over the years, it has been observed that the major causes of borehole deterioration are due to corrosion, encrustation and siltation. But unfortunately, many borehole owners and drillers in the Calabar area are neither conversant with these problems nor effect a regular maintenance of their boreholes.

Corrosion is the gradual deterioration or eating away of metals when exposed for a long time to oxygen and moisture. On the other hand, encrustation is the clogging, cementation or blockage of the well screen openings or voids of water bearing formation by undesirable materials such as precipitation of carbonates of calcium, magnesium, iron, and manganese compounds and deposition of fines on the borehole screens (Johnson, 1975).

In this paper, an attempt is made to identify the presence of inorganic substances tagged "corrosion-encrustation index parameters (CEIP)" known to be responsible for corrosion and encrustation in the water industry. These parameters act as a marker for measurement of degree of corrosion and encrustation in water wells and pipeline systems. A combination of any two factors such as high hydrogen sulphide, H_2S >2mg/l, dissolved oxygen DO >2mg/l; hydrogen ion concentration pH <7; Chloride content Cl^- in excess of 500mg/l, total dissolved solids TDS >1000mg/l and bicarbonate HCO_3^- greater than 50 mg/l will increase the problems of corrosion while total carbonate hardness TCH >100mg/l, pH >7, iron Fe >0.3mg/l and manganese, Mn >0.1mg/l result in encrustation of pipes and screens (Johnson 1975).

In the study area, few of the published works have been on groundwater quality with little or no emphasize on the corrosion encrustation index parameters (CEIP). These include the works of Udom et. al., (1998), Esu and Amah (1999). Other published works were on trace and heavy metals distributions (Ntekim et. al., 1993, Akpan et. al., 2002; and Edet et. al., 2003). This paper examines for the first time the CEIP as the main agents responsible for corrosion and encrustation of water pipes and screens in the Calabar area. The work is also a contribution towards regular maintenance and rehabilitation of boreholes to boost productivity and longevity.

Location and Geology of Study Area

The area under investigation lies between latitude 4°50' and 5°06'N and longitude 8°15' and 8°25'E (Fig. 1). It is characterized by a humid tropical climate with high temperatures (annual mean 26°C), high relative humidity (annual mean 85%) and high precipitation (annual mean 3855mm). Over 80% of the rainfall is recorded within the wet season (April to October) while the highest temperature is recorded during the dry season that starts in November and ends in March (Edet et al, 2003). The area is drained by the Calabar River in the west and the Great Kwa River in the east (Fig.1).

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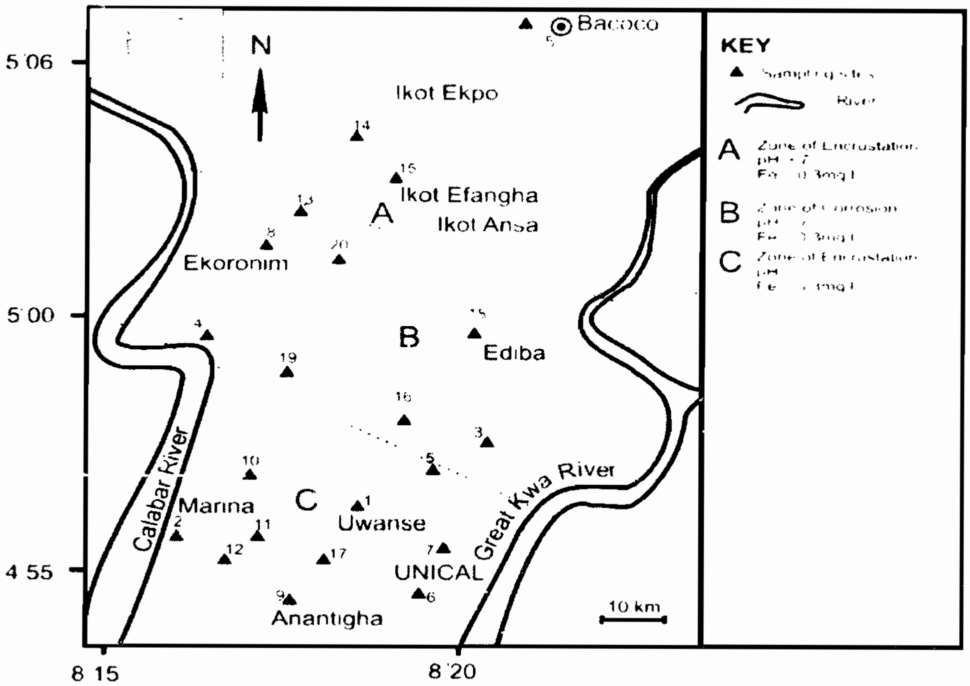

Fig. 1: Map of Calabar showing the study locations (see table 1), Corrosion and Encrustation Zones

Geologically, the area is underlained by Tertiary to Recent Fluviatile sands and clays known as the Coastal Plain Sands or Benin Formation. It consists of alternating sequences of gravel and sand of various sizes, silts, clays, lignite and alluvium. These alternating sequences build up a multi-aquifer system in the area. The materials of this formation are derived from Precambrian Basement and Cretaceous sediments of the Calabar Flank (Fig. 2). The Cretaceous sediments include mostly conglomerate, sandstone, limestone shale, mudstone and marl (Reijers and Petters 1987). The rocks of the Precambrian Oban Massif are the gneisses, schists, granodiorite, granite, pegmatite, tonalite, charnokites and migmatites (Rahman et al, 1981, Ekwueme et. al., 1995). However, the Benin Formation (Coastal Plain Sands) is by far the most prolific aquiferous units in the area and all boreholes are located in this formation (Esu and Amah, 1999). Alluvial deposits aquifer overlies the Benin Formation in the southern parts of the study area. The depth of occurrence of groundwater in the formation varies from one locality to another but becomes progressively shallower coastward (Fig.3).

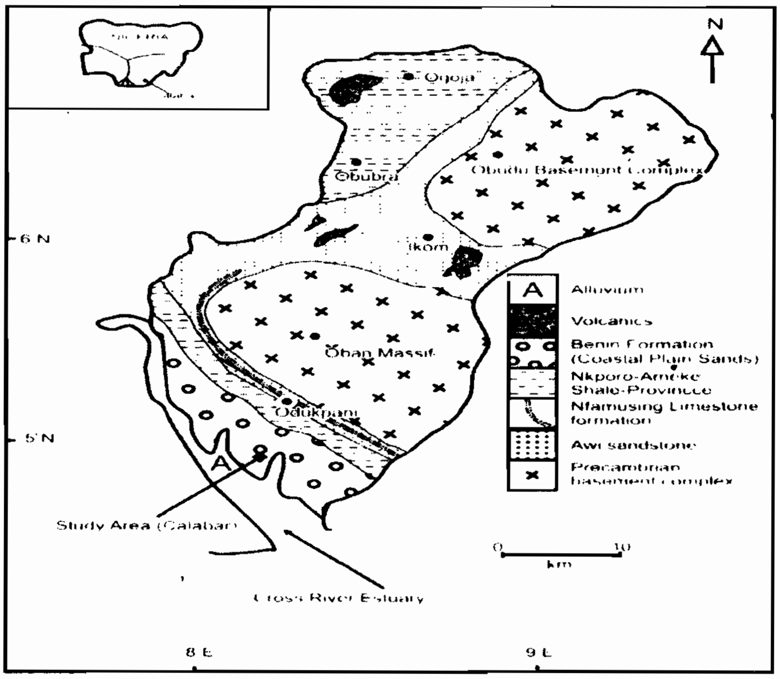

Fig. 2: Generalized geologic map of Cross River State including study area (after Ekwueme et al., 1985)

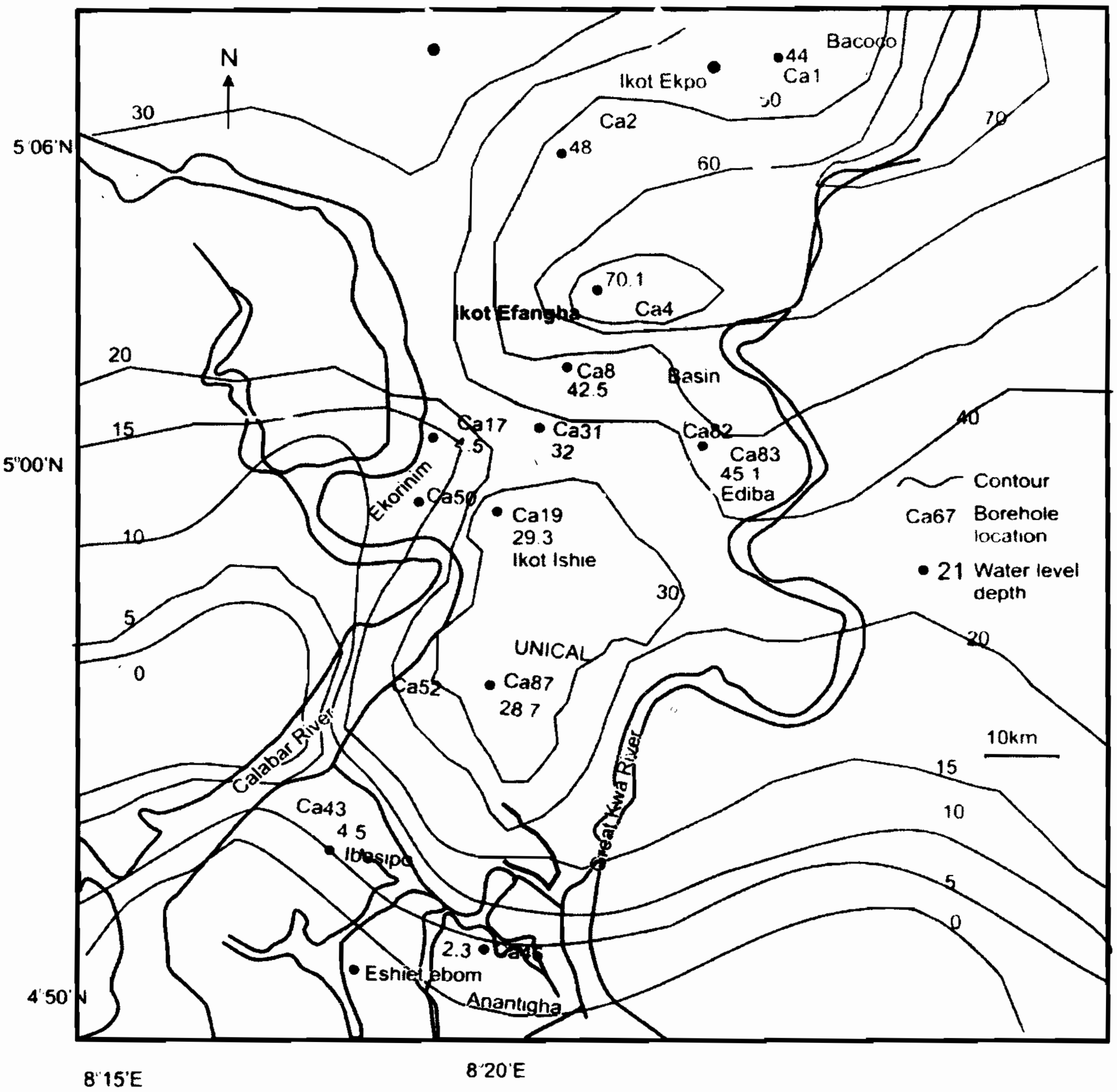

Fig. 3: Depth to water levels with respect to ground surface

Methodology

Groundwater samples were collected from twenty (20) locations within the study area (Fig.1). The water samples were collected in clean 200ml polyethylene plastic bottles and stored in a refrigerator at 4^0C prior to analysis within 24 hours of collection. Electrical conductivity (EC), hydrogen ion concentration (pH), temperature (T^0C), dissolved oxygen (DO), were determined in the field. The temperature and electrical conductivity were measured with the aids of WTW LF 91 temperature and conductivity meter. pH and DO were determined with WTW pH 90 meter and WTW OXI oxygen meter respectively. Analyses of Chloride, hardness, iron, manganese and total dissolved solids were done by employing a palin test spectrophotometer 5000 series while hydrogen sulphide was determined by converting from mg/l sulphide to mg/l hydrogen sulphide (APHA; 1975).

RESULTS AND DISCUSSION

The results of the chemical analyses are presented in Table 1 while Table 2 shows the range and percentage of corrosion encrustation index parameters (CEIP) in sampled borehole water.

Corrosion Parameters

The following corrosion index parameters were evaluated: pH, DO, HCO^-_3, TDS, Cl^-, H_2S and temperature (Johnson 1975). From the data, the hydrogen ion concentration, pH varied from 5.4 to 7.6 with a mean of 6.3 (Table 1). While Table 2 reveals that 80% of the sampled locality have pH values within the acidity range of pH<7.0. Waters with a pH of 7.0 are classified as neutral. Those with a pH less than 7.0 are acidic while pH greater than 7.0 are termed alkaline. The highest desirable level of pH in drinking water is not less than 6.5 (WHO 1993). Water with low pH<7 tend to be aggressive to certain metals such as iron and steel (Esu and Amah 1999; Johnson, 1975). This explains why the boreholes in the Calabar area are frequently in the

Table 1: Physico-chemical characteristics of Groundwater samples for Calabar Area on the basis of Corrosion-Encrustation Index Parameters (CEIP).

S/N	PARAMETERS/ LOCATION	pH	Temperature °C	Conductivity µs/cm	Hardness mg/l	Total Dissolved Solid Mg/l	Iron Fe mg/l	Manganese Mn, mg/l	Dissolved Oxygen DO mg/l	Chloride Cl^- mg/l	Hydrogen sulphide H_2S mg/l	Bicar-bonate HCO_3 mg/l
1	Uwanse	5.8	26	186	8.0	130.2	0.21	0.26	2.4	6.6	1.5	45.0
2	Marina	7.0	27.5	355	8.5	248.5	2.04	0.1	6.2	12.9	1.2	58.5
3	Atimbo	7.2	26.5	390	4.2	273.7	3.0	0.24	5.8	12.6	2.5	55.0
4	Essien town	6.3	26.0	163	3.2	76.3	0.22	0.01	1.0	8.2	0.01	60.0
5	Edim Otop	5.8	26.3	35.0	2.5	15.0	0.60	0.15	5.0	4.0	0.05	75.0
6	Uncial Qtrs	6.2	27.0	25.0	3.0	15.0	1.3	0.05	2.5	10.5	0.10	40.5
7	Unical Girls	6.3	27.3	36.0	2.4	20.5	0.1	0.15	1.5	4.5	0.50	30.5
8	Ekorinum	7.2	26.1	136.0	3.1	71.4	0.03	0.04	0.5	16.2	2.0	40.5
9	Anantigha	5.6	27.0	60.0	5.2	40.0	1.1	0.03	3.8	12.0	3.0	60.4
10	Edgerley	7.2	27.2	299	4.6	143.5	1.33	0.36	0.4	2.6	1.0	25.2
11	Idang	5.4	26.8	55	7.5	35	0.5	0.20	2.8	10.4	1.5	30.1
12	Ibesikpo	6.0	27.4	27.4	8.1	43.5	1.4	0.06	2.0	15.5	2.0	65.0
13	Federal Housing	6.8	25.0	30.0	2.35	13.0	0.35	0.04	2.5	11.5	1.1	56.2
14	Ikot Omin	7.0	25.4	36.0	4.25	20.1	0.6	0.01	5.1	12.0	0.05	90.4
15	Ikot Effanga	7.0	26.3	25.0	4.6	11.0	0.11	0.01	3.2	10.4	0.45	60.3
16	Otu Ansa	6.8	27.0	26.5	3.2	15.0	0.3	0.10	1.1	7.8	0.10	20.5
17	Yellow Duke	6.4	27.2	40.2	2.9	19.0	0.01	0.11	2.9	6.2	2.11	80.9
18	Ediba	6.2	25.9	41.3	3.4	25.0	0.04	0.01	3.4	11.5	1.0	51.2
19	State Housing Est	7.6	26.5	35.2	3.2	30.4	0.03	1.0	2.5	4.5	0.05	50.0
20	Ikot Uduak	6.8	27.0	65.1	4.5	50.5	0.06	0.06	2.1	6.2	0.01	52.1

Table 2: Summary of range and percentage CEIP (Johnson, 1975) and (WHO, 1993) standards in drinking water

Parameters	Range of CEIP	Mean	Johnson (1975)	WHO (1993)	%CEIP	REMARKS
pH	5.4-7.6	6.30	Corrosive pH<7, Encrusting pH>7	Acidic pH<7 Alkaline pH>7	80	Corrosive
Temp °C	25.0-27.5	26.6	Corrosive Temp. >27°C	-	50	Corrosive
TDS mg/l	13.0-273.7	64.8	Corrosive TDS >1000	<1000	0	-
Fe mg/l	0.01-3.0	0.70	Encrusting Fe >0.3	<0.3	70	Encrusting
Mn mg/l	0.01-1.0	0.15	Encrusting Mn >0.1	<0.05	50	Encrusting
DO mg/l	0.4-6.2	2.84	Corrosive DO >2.0		75	Corrosive
H_2S mg/l	0.01-2.5	0.91	Corrosive H_2S >2.0		30	
Cl^- mg/l	2.6-16.2	9.45	Corrosive Cl^- >500	200	0	
HCO_3 mg/l	20.5-80.9	53.86	Corrosive HCO_3 >50		70	Corrosive
TCH mg/l	2.35-8.5	4.5	Encrusting TCH >100	100	0	

danger of severe corrosion of its pipes, pumps and screens made of iron.

High concentration of dissolved oxygen, (DO) and bicarbonate, (HCO_3) have been reported for most of the water samples in the area. The DO ranged from 0.4 to 6.2 mg/l with 75% of the sample locality having DO above 2.0mg/l. On the other hand, HCO_3^- varied from 20.5 to 80.9mg/l with 80% of them having HCO_3 >50mg/l. Johnson, (1975), stipulates that water may be corrosive, if DO >2.00mg/l, pH<7 and HCO_3^- >50.0mg/l. The combined effects of HCO_3^- and DO in water is to lower the pH of the water, increase its acidity and corrosive effects on metals. Groundwater from shallow aquifers, all over the world usually contains a lot of dissolved gases such as dissolved oxygen and carbon dioxide (Cisse et al, 2000; Ugbaja and Edet, 2004). Thus, the high DO in particular is due to the shallow water level in aquifers in the study area (Fig.3). Furthermore, the increasing acidity and HCO_3 along the groundwater flow paths may be due to increasing dissolved carbon dioxide CO_2 generated at the soil zone, when water comes in contact with calcite and limestone. The groundwater will consequently become rich in carbonic acid (H_2CO_3). Additional sources may include the combustion of fossil fuel from gas flaring; power stations, factories and vehicles (Udom and Amah, 2006). These industrial activities, liberate carbon dioxide which reacts with atmospheric precipitation to form carbonic acid (acid rain) as follows

$$CO_2 + H_2O \rightarrow H_2CO_3$$

This acid infiltrates underground into the groundwater system to reduce the pH of the water and increase acidity. However, 6 out of 20 boreholes (30%) have the concentration of hydrogen sulphide H_2S >2.0mg/l. On the other hand, Chloride concentration ranges from 2.6 to 16.2mg/l while TDS varied from 13.0 to 273mg/l. The level of Chloride (generally below 20mg/l) shows absence of saltwater encroachment into the aquifers in the area. According to Tremblay et al (1979), chloride contents of 40mg/l and above in water is indicative of saltwater encroachment. Chloride in excess of 500mg/l and TDS>1000mg/l contribute to corrosion of metals in water (Johnson 1975, Table 2). High TDS and chlorides Cl^- increase the electrical conductivity of water which promote corrosion. Thus the contributions of Cl^- and TDS to corrosion in the Calabar area are negligible (Table 2).

The higher the temperature of groundwater the more aggressive the environment and consequently the tendency towards corrosion of borehole installations as found in boreholes drilled in the Chad Basin of Borno State of Nigeria with surface temperature of not less than 28°C (Ogomigo, 1985). Temperature in Calabar area ranged from 25.0-27.5°C and may encourage corrosion of borehole installations. The high acidity (or low pH), dissolved oxygen DO, bicarbonate HCO_3^- and Temperature (Fig.4a) are therefore the major causes of corrosion in Calabar area (Table 2).

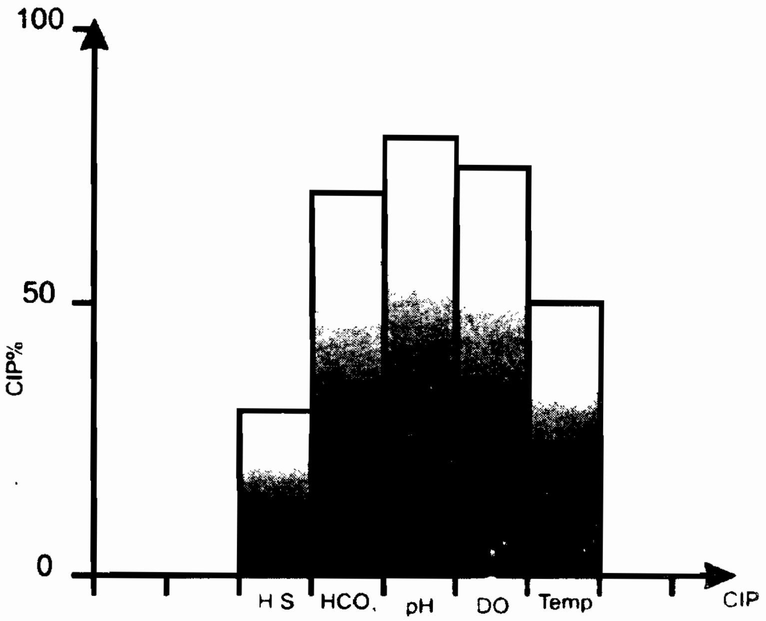

Fig. 4a: Histogram of percent Corrosion Index parameters (CIP

Encrustation Parameters

According to Johnson (1975), the degree of encrustation taking place in the well screen openings and water bearing formation can be evaluated with the aids of encrustation index parameters such as iron Fe, manganese Mn, Hydrogen ion concentration pH and total carbonate hardness TCH. The level of concentrations of iron Fe and Manganese Mn ranged from 0.01 to 3.0mg/l and 0.01 to 1.0mg/l respectively. These results indicate that 70% and 50% of the 20 borehole sampled, have Fe and Mn contents greater than 0.3mg/l and 0.1mg/l respective requirements for the occurrence of chemical encrustation on well screen and aquifer to take place (Table 2). The interpretation of this data indicates that Calabar area has high contents of Fe and Mn (Table 2). Thus the water will not only stain laundry and plumbing fixtures but incrustation from precipitation of iron and manganese compounds on well screens, pipes and aquifers are quite common. The high concentration of iron in groundwater from Calabar area is due to corrosion of well structure and piping materials in contact with acidic water, especially if the borehole was shut down for some time or not flushed out before pumping. It may possibly be due to iron fixing bacteria particularly, crenothrix. Iron bacteria associated with sedimentary environment and decaying matter, play an important role in the encrustation process, especially in water containing low, but detectable dissolved oxygen concentrations and high dissolved iron-concentrations as found in the Calabar area. Iron bacteria live in groundwater of appreciable iron content. It is believed that they feed on carbon compounds including the bi-carbonates and carbon dioxide. The production of slime is a result of the life cycle of the organisms and iron is changed into insoluble oxides. The slime may entrap particles of other insoluble mineral salts thus leading to encrustation around the well screen.

Encrustation may also result from fine particles of clay and silt being carried unto the screen in suspension. When this occurs, it is probably due to improper development of the borehole, wrong choice of screen slot size or screening a portion of the hole containing an abnormal amount of these materials. Encrustation from precipitation of carbonates of calcium and magnesium or their sulphates to form a scale is not common in the study area. The carbonate hardness recorded ranged from 2.35 to 8.5mg/l. Water with high concentration of total carbonate hardness exceeding 100mg/l leads to the formation of scales in boilers, encrustation of screens pipes and will not form lather with soap (WHO, 1993). According to Durfor and Becker (1964) hardness values of 0 to 60mg/l is an indication of soft water. Thus the groundwater is soft and its contributions to encrustation of water wells in the area is minimal. Encrustation of groundwater wells in the study area is therefore mainly due to high total Fe and Mn contents of the water (Fig.4b).

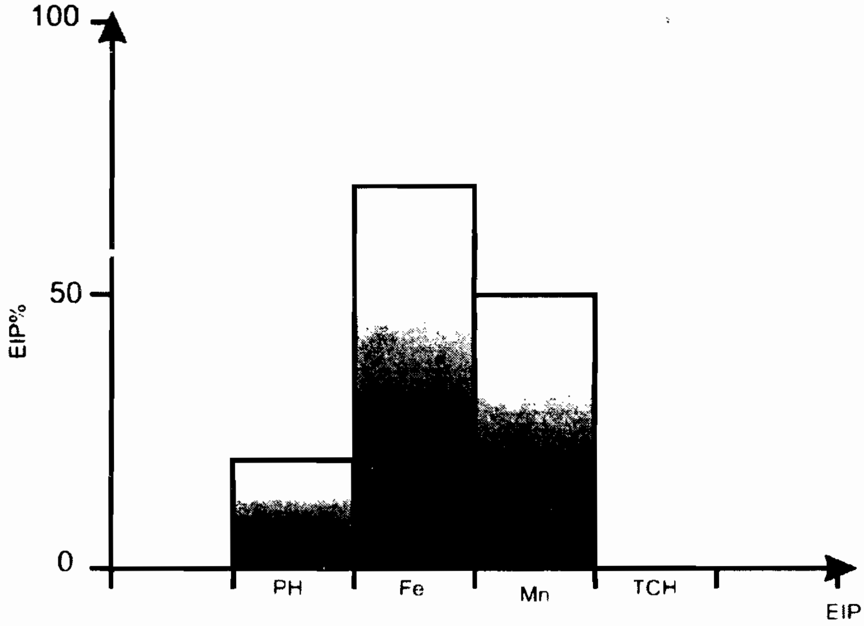

Fig. 4b: Histogram of percent Encrustation Index Parameters (EIP)

In general, the study area can be divided on the basis of CEIP into three zones A, B and C. Zone A is characterized by water of pH>7, Fe≤0.3mg/l (Fig. 1) as found in the area, north of Calabar. Zone B and C are peculiar to the central and southern area of Calabar. The water in Zone B is acidic with pH<7, Fe≤0.3mg/l while Zone C has a high encrusting index parameters (pH>7, Fe>0.3mg/l).

Prevention of Borehole Deterioration

Borehole deterioration is noticed when little water or none at all coming out of the riser pipes or the borehole discharging muddy water, sand and silt. Borehole deterioration is therefore associated with the problems of

i) Corrosion of pipes and pumps
ii) Encrustation of well screens
iii) Siltation
iv) and no maintenance of boreholes.

Corrosion can be minimized by borehole designers, drillers and owners in the area if appropriate materials for well construction or completion are used. Such materials include the use of corrosion resistant casings and well screens made of non-ferrous metal alloys (Stainless steel), PVC pipes and coating of borehole installations with zinc galvanizing and tar

Encrustation of borehole installation cannot be completely eliminated. Excessive concentration of Fe and Mn may be controlled through the oxidation of soluble ferrous ions or manganous bicarbonates to insoluble ferric ion and manganese hydroxides respectively. The precipitates are then removed by energetic flocculation followed by filtration and chlorination. Also periodic (regular) maintenance of boreholes should be carried out at least once in every six months or once a year. The procedure include air lifting, jetting, acid treatment and chlorination on a regular basis whether or not troubleshooting is noticed.

CONCLUSION

- Groundwater from shallow aquifers in Calabar area is slightly acidic, corrosive to pumps pipes and screens made up of iron and base metal alloys. The corrosive effects are due to the groundwater having the following characteristic index parameters above their corrosion threshold values in most localities, viz: pH (5.4-7.6); DO (0.4-6.7)mg/l; and HCO_3 (20.5-80.9)mg/l.
- Encrustation of water pipes and well screens are not ruled out but due to the presence of iron Fe^{3+} (0.01-30)mg/l. Manganese Mn^{3+} (0.01-1.0)mg/l and probably iron fixing bacteria in high concentrations in few localities.
- Boreholes designers, drillers and owners should make use of PVC materials for borehole construction to minimize corrosion of pipes.
- Borehole maintenance and rehabilitation at regular intervals will increase its specific capacity and longevity.

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