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Evaluation of Corrosion and Encrustation Potentials of Boreholes in Yola Area, Northeastern Nigeria

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ABSTRACT

Corrosion and encrustation potentials of boreholes of Yola area northeastern Nigeria was investigated. The aim of this study was to discuss the results of groundwater quality assessment based on some Corrosion-Encrustation Index Parameters (CEIP) and drinking water standards. The concentration levels of cations were analyzed by spectrophotometric method whereas those of anions were by titrimetric method. The results of CEIP concentration indicate values of 6.5 to 7.8, 0 to 1.80 mg L⁻¹ and 0 mg L⁻¹, respectively for the pH, total iron and manganese ions. Furthermore results of 34 to 121 mg L⁻¹, 0.02 to 2.80 mg L⁻¹ and 10 to 140 mg L⁻¹, respectively were recorded for Total Dissolved Solids (TDS), Dissolved Oxygen (DO) and Total Carbonate Hardness (TCH). Interpretation of these CEIP analytical results based on background values indicate low corrosion and encrustation risk and that borehole deterioration and failure is largely due to poor pump selection as well as use of inferior materials as riser pipes. On the other hand, corrosion and encrustation as a result of relatively high concentration of iron TCH and pH (>7) has been observed in few locations. These could be controlled through oxidation of soluble ferrous ions to insoluble ferric ion. The precipitates formed as a result will subsequently be removed by energetic flocculation, filtration and chlorination. Furthermore, conduction of pumping test prior to pump selection and installation and use of good quality materials as riser pipes is strongly recommended. Finally regular maintenance of boreholes involving air lifting, jetting, acid treatment and chlorination also is recommended.

Key words: Corrosion, encrustation, pH, CEIP, yola area, NE Nigeria

INTRODUCTION

More than 90% of public-private water supplies in Yola area come from groundwater (Ishiaku and Ezeigbo, 2000). The high dependence on groundwater means that there is an urgent need to maintain existing production wells or boreholes.

A good borehole is one that lets water flow into it easily. In other words, it is an efficient access hole which is determined by pumping the hole at different rates and measuring the drawdown. It is thus normal for the efficiency of a borehole to deteriorate with time and there are many varied reasons for this (Amah *et al.*, 2008).

Natural, non-pathogenic bacteria occur in all aquifers and unfortunately can grow as sticky, thick slimes in the pores of a gravel pack and/or in the cracks in the rocks, that let water flow into the hole (Smith, 2005). A similar process takes place in the presence of some minerals in the water.

Thus physic-chemical changes take place when water flows from the aquifer into the hole (Todd, 1995). Unstable minerals such as calcite (lime-scale) and iron and manganese can precipitate and form encrustations and corrosion in the gaps used by the water to enter the hole which is sometimes also encouraged by the growth of bacteria (Appelo and Postma, 2007). But unfortunately many borehole owners and drillers in Yola area are neither conversant with these problems nor affect a regular maintenance of their boreholes.

Previous published works in the study area assessed groundwater quality with emphasis on domestic and agricultural purposes (Ishiaku and Ezeigbo, 2000; Obiefuna and Orazulike, 2010a-c; Obiefuna and Orazulike, 2011) with only one (Ishiaku and Ezeigbo, 2000) highlighting the effects of corrosion and encrustation on boreholes in the study area. Related study in other parts of the world (Shomar *et al.*, 2008; Sundaramanickam *et al.*, 2008; Daghrah, 2009; Hilles and Al-Najar, 2011; Alslaibi *et al.*, 2011).

In this study, an attempt was made at identifying 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 the measurement of the degree of corrosion and encrustation in water wells and pipeline systems (Amah *et al.*, 2008).

MATERIALS AND METHODS

The study area falls within latitudes 9°11'N and 9°24'N and longitudes 12°20'E and 12°34'E and lies about 50 km south of the Hawal Massifs. It is bounded to the east by the Republic of Cameroun and to the west by Ngurore town. The northern boundary is demarcated by Gokra town and the southern boundary by the Mandarare town and occupies approximately 431 km² of the land surface (Fig. 1).

The study area is underlain by the upper member of the Bima Sandstone (B3) which is a cretaceous sedimentary unit of the Yola Arm of the Upper Benue Trough (Carter *et al.*, 1963; Abubakar *et al.*, 2006). The surface geologic units of the study area are the fine-medium grained sandstone to the north and south and the coarse grained sandstone to the northeast. The depth to the bedrock varies from 30 m to more than 45 m (Obiefuna and Orazulike, 2010a). Stratigraphically, the Bima Sandstone consist of alternating layers of poorly to moderately consolidated fine to coarse grained sandstones, clay-shales, siltstone and mudstone with an average thickness of more than 250 m as seen from their outcrops in the field.

Two aquifer systems namely the upper unconfined alluvial aquifer and the lower semi-confined to confined aquifer and the lower semi-confined to confined aquifer were identified based on hydrogeological analyses, geological reconnaissance and hydrogeological mapping. The upper alluvial aquifer system occurs at a dept range of 20 to 80 m with an average thickness of about 39 m. The mean hydraulic conductivity is 2.54 m² day⁻¹ with corresponding mean transmissivity value of 237 m² day⁻¹ which indicate moderate to good aquifer. The lower semi-confined to confined aquifer system occur at a depth range of 80 to 250 m with an average thickness of about 14.52 m. The mean hydraulic conductivity is 2.54 m² day⁻¹ with corresponding mean transmissivity value of 103.51 m² day⁻¹ which indicate moderate to good aquifer (Obiefuna and Orazulike, 2010a).

To the northeast a localized recharge area occurred to the west whereas to the southwest it is northeastwards towards the Benue River (Obiefuna and Orazulike, 2010a). They discharge naturally at points or areas where the aquifer with its underlying relatively impermeable alluvial units such as clay-shales and mudstone intercepts the ground surface in river or stream valleys.

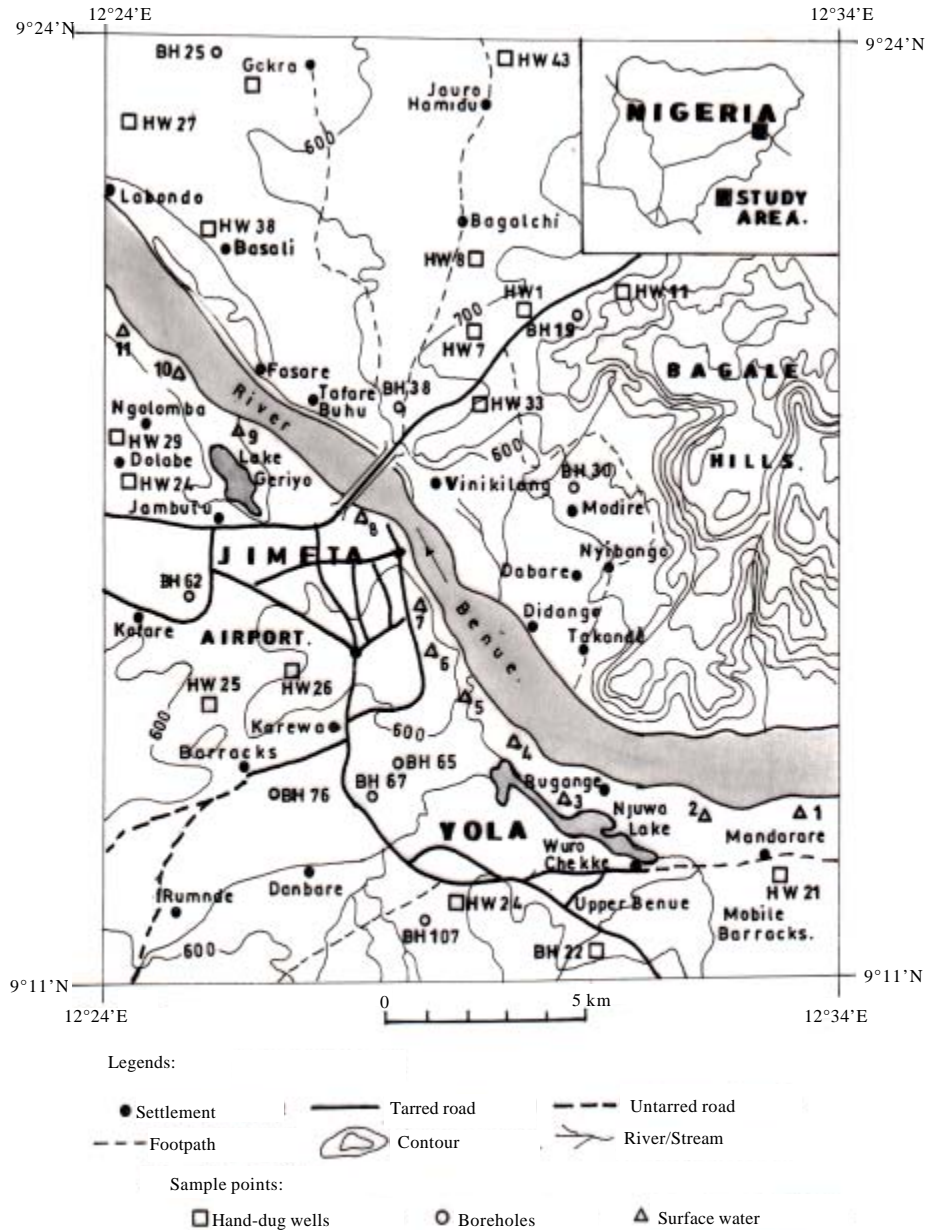


Fig. 1: Map of the study area showing some well locations and sampling points

Groundwater samples were collected from twenty-five locations within the study area. The water samples from boreholes in which pumps are already installed, were collected after about two hours of pumping and the screen interval of the well represents the average sample depth. The samples were bailed, using a stainless steel bailer, from a depth of two meters below the water table which more or less indicates the sample depth. The samples were collected in 1000 mL plastic bottles and field filtration was carried out through filter papers (0.45 μm) to remove suspended solids. They were then carefully sealed, labeled and stored in a refrigerator at 4°C prior to analyses within

24 h of collection. Electrical Conductivity (EC), hydrogen ion concentration (pH), Temperature (°C), Dissolved Oxygen (DO) were determined in the field. The temperature and electrical conductivity were measured with the aid of HACH spectrophotometer equipment model No. DR/2400 temperature and conductivity meter whereas pH and DO were determined with HACH Instruments Incorporated USA spectrophotometer equipment model No DR/2400 pH meter and oxygen meter, respectively. Chemical analyses of other ions were performed in the laboratory employing standard methods, Atomic Absorption Spectrophotometer for cations and conventional titration for anions (by titrimetric method, using the Titro Process Dosimat 665 equipment). Ions were converted from milligram per litre to milliequivalent per litre and anions balanced against cations as a control check of the reliability of the analyses results.

Statistical analysis: Data analyses to check for statistical errors (a reflection of random fluctuations in the analytical procedure) was carried out. It was done (from electrical balance EB calculations since the sum of positive and negative charges in the water should be equal) and expressed mathematically as follows (Appelo and Postma, 2007):

$$\text{Electrical Balance (EB\%)} = \frac{(\text{Sum cations} + \text{Sum anions})}{(\text{Sum cations} - \text{Sum anions})} \times 100 \quad (1)$$

where, cations and anions are expressed as meq L⁻¹ and inserted with their charge sign. The sums are taken over the cations (Na⁺, K⁺, Mg²⁺ and Ca²⁺) and the anions (Cl⁻, HCO³⁻, SO₄²⁻ and NO³⁻) and were found to be within the acceptable range of ±5%.

RESULTS AND DISCUSSION

The results of the chemical analyses are presented in Table 1 whereas Table 2 indicates the range and percentage of Corrosion and Encrustation Index Parameters (CEIP) in sampled borehole water.

Corrosion parameters: The following corrosion index parameters (pH, DO, HCO³, TDS, Cl, H₂S and Temperature) were evaluated and used to assess the corrosion potentials of sampled borehole waters. Table 1 indicate a pH values varying from 6.5 to 7.8 with a mean value of 7.14 revealing 40% acidic water suggesting corrosion and 60% alkaline water suggesting encrustation. These values however fall within the WHO (2006) recommended range of 6.5 to 8.5.

The bicarbonate values ranged from 50 to 207 mg L⁻¹ with 96% of the sampled water having bicarbonate value above 50 mg L⁻¹ (Johnson, 1975) indicating corrosive groundwater. The dissolved oxygen varies from 0.02 to 2.80 mg L⁻¹ with 12% of the sampled water having dissolved oxygen value above 2.00 mg L⁻¹. It thus suggests corrosive groundwater.

The relatively high concentrations of HCO₃ and DO in the sampled water tend to lower the pH of the water, increase its acidity and cause corrosion of metallic objects used in borehole construction. Groundwater in the study area is generally shallow and thus contains relatively high concentrations of dissolved oxygen in places (Schwartz and Zhang, 2003). Furthermore high concentration of bicarbonate in the sampled water may be due to increase in dissolved carbon dioxide generated in the soil zone when water comes in contact with calcite and limestone as well as from fossil fuel combustion released into the atmosphere. The shallow groundwater will

Table 1: Physicochemical characteristics of groundwater samples for yola area on the bases of Corrosion-Encrustation Index Parameters (CEIP)

Location	pH	Temperature (°C)	EC conductivity (dS m ⁻¹)	Hardness (mg L ⁻¹)	TDS (mg L ⁻¹)	Total Fe (mg L ⁻¹)	Mn (mg L ⁻¹)	DO (mg L ⁻¹)	Cl (mg L ⁻¹)	H ₂ S (mg L ⁻¹)	HCO ₃ (mg L ⁻¹)	Borehole No.
Gire	6.60	32	0.100	58.60	67	0.32	0.00	0.17	77.00	0.03	153.30	BH7
Fut, Yola	6.80	30	0.096	92.50	62	0.15	0.00	0.19	42.00	0.03	207.00	BH10
Bagalchi	6.90	30	0.065	52.80	44	0.12	0.00	1.20	67.00	0.001	159.50	BH17
Bajabure phase I	6.60	30	0.050	24.50	34	0.28	0.00	1.60	56.70	0.05	88.50	BH20
Bajabure phase II	7.20	30	0.058	45.50	39	0.09	0.00	2.50	0.00	0.18	93.20	BH21
Damare	6.90	30	0.066	86.50	44	0.07	0.00	2.25	57.00	0.06	95.70	BH24
Gokra	6.50	30	0.102	140.00	68	1.80	0.00	1.20	0.003	0.02	65.00	BH25
Jambutu	7.10	30	0.075	22.30	50	0.09	0.00	0.02	116.00	0.13	93.00	BH36
Karewa gra	6.70	30	0.120	26.50	80	0.22	0.00	0.07	24.00	0.18	70.16	BH51
Lake geriyo	7.70	30	0.118	42.60	79	0.04	0.00	1.50	56.30	0.19	109.00	BH57
Rumde	7.10	30	0.104	72.50	69	0.04	0.00	0.92	56.40	0.03	62.00	BH60
Dougirei	7.20	30	0.097	74.50	65	0.01	0.00	0.14	114.00	0.02	78.50	BH66
Army Barracks	7.40	30	0.090	37.00	60	0.08	0.00	1.50	11.02	0.00	101.00	BH75
Road Jimeta												
Damilu	7.50	30	0.115	54.00	77	0.07	0.00	0.05	159.40	0.08	94.90	BH81
Jimeta	7.80	30	0.180	92.00	121	0.007	0.00	1.35	65.90	20.02	99.60	BH84
Demsawo	7.50	30	0.050	55.60	34	0.002	0.00	1.80	0.004	0.09	109.00	BH87
Distance	7.60	30	0.084	10.00	56	0.00	0.00	0.08	0.03	0.00	50.00	BH91
Learning Yola												
Wuro Dole	6.90	30	0.073	16.00	49	0.01	0.00	0.03	0.10	0.00	70.40	BH92
Mbamba	7.60	30	0.066	10.90	44	0.25	0.00	0.11	0.006	0.00	53.00	BH98
Sebore	6.80	30	0.110	29.80	74	0.42	0.00	1.40	55.80	0.01	100.20	BH100
Wuro Hausa	7.20	30	0.099	27.90	66	0.09	0.00	1.00	0.009	0.09	101.70	BH110
Njibboli	7.40	30	0.130	32.30	87	0.25	0.00	1.20	66.90	0.01	103.50	BH117
Modire	7.10	30	0.057	22.50	38	0.07	0.00	1.10	0.01	0.01	110.30	BH120
Lainde	7.40	30	0.093	41.50	62	0.82	0.00	2.80	132.90	0.01	102.00	BH123
Njobbore	6.90	30	0.063	26.40	42	0.24	0.00	0.95	0.001	0.02	89.40	BH124

subsequently become rich in carbonic acid. In addition, the interaction between the liberated carbon dioxide and the atmospheric precipitation results in the formation of carbonic acid as follows (Schwartz and Zhang, 2003):



Thus this antecedent acidic rain water subsequently infiltrates into the groundwater system to lower the pH of the groundwater and increase acidity. Hence about 4% of the sampled groundwater has hydrogen sulphide concentration above 2 mg L⁻¹. However, the relatively low level of chloride (<160 mg L⁻¹) and TDS values (<122 mg L⁻¹) are generally less than 500 mg L⁻¹ for chloride and less than 1000 mg L⁻¹ for TDS based on Johnson(1975) suggest that these parameters contributes negligibly to corrosion of boreholes in the study area.

The higher the temperature of groundwater the more aggressive the environment and consequently the tendency towards corrosion of borehole installation as found in boreholes drilled in the Chad Basin with surface temperatures of not less than 28°C (Amah *et al.*, 2008).

Furthermore, temperatures ranging from 25 to 27.5°C recorded for boreholes in Calabar area have been suggested as one of the causes of corrosion of wells in the area. Accordingly the relatively high acidity (or low pH) and bicarbonate (HCO₃) and temperature (Fig. 2a) are likely one of the contributing factors to corrosion of some boreholes in the study area (Table 2).

Table 2: Summary of range and percentage CEIP (Johnson, 1975; WHO, 2006) standards in drinking water

Parameters	Range of CEIP	Mean	Johnson (1975)	WHO (2006)	% CEIP	Remarks
pH	6.5-7.8	7.14	Corrosive pH<7	Acidic pH<7	40	Corrosive
			Encrusting pH>7	Alkaline pH>7	60	Encrusting
Temperature°C	30-32	30.08	Corrosive Temp>27°C	-	100	Corrosive
TDS (mg L ⁻¹)	34-121	60.44	Corrosive TDS>1000	<1000	0	-
Fe mg (L ⁻¹)	0-1.80	0.22	Encrusting Fe>0.3	<0.3	16	Encrusting
Mn mg (L ⁻¹)	0-0	0.00	Encrusting Mn>0.1	<0.05	0	-
DO mg (L ⁻¹)	0.02-2.80	1.01	Corrosive DO>2.0	-	12	Corrosive
H ₂ S mg (L ⁻¹)	0-20.02	0.85	Corrosive H ₂ S>2.0	-	4	Corrosive
Cl-mg (L ⁻¹)	0-159	46.34	Corrosive Cl>500	200	0	-
HCO ₃ (mg L ⁻¹)	50-207	98.39	Corrosive HCO ₃ >50	-	96	Corrosive
TCH (mg L ⁻¹)	10-140	47.79	TCH>100 Encrusting	100	4	Encrusting

High bicarbonate concentrations in groundwater arising from the presence of unstable minerals such as calcite in aquifer zone can result in CaCO₃ clogs and reduce well performance. Calcite deposition is often observed in wells where methane is present which is subsequently oxidized to CO₂ by microbial oxidation. These usually take the form of a calcified slime which looks like white spots in rock or casing surfaces. About 5% loss in specific capacity of wells arising from high concentrations of dissolved oxygen, total alkalinity and low pH has been reported in New York by the United States Geological Survey (Johnson, 1975).

Encrustation parameters: The degree of encrustation taking place in the well screen openings and water bearing formations can be evaluated employing the following encrustation index parameters such as Iron (Fe), Manganese (Mn), hydrogen iron concentration (pH) and Total Carbonate Hardness (TCH). The concentrations of Iron (Fe) and Manganese (Mn) in the sampled water ranged from 0 to 1.80 mg L⁻¹ and 0 to 0 mg L⁻¹, respectively. These results indicate that 16 and 0% of the 25 boreholes sampled have Fe and Mn contents greater than 0.3 mg L⁻¹ for Fe and 0.1 mg L⁻¹ for Mn respective requirements for the occurrence of chemical encrustation on well screen and aquifer to take place (Table 2). The results thus indicate that only few samples will stain laundry and plumbing fixtures but encrustation from precipitation of iron and manganese compounds on well screens, pipes and aquifers are quite uncommon. However, the high concentration of iron in few of the samples in the study area is due to corrosion of well structure and piping materials in contact with acidic groundwater, especially if the borehole was shut down for some time or not flushed out before pumping (Amah *et al.*, 2008).

Encrustation may also occur when suspension of fine particles of clay and silt are carried unto the screen probably due to improper development of the borehole or wrong choice of screen slot size or screening a portion of the hole containing an abnormal amount of these materials (Amah *et al.*, 2008).

The carbonate hardness recorded ranged from 10 to 140 mg L⁻¹ with a mean value of 47.79 mg L⁻¹ with only 4% of the sampled groundwater exceeding 100 mg L⁻¹ revealing low risk level in most of the sampled groundwater (Johnson, 1975; Amah *et al.*, 2008). Furthermore, according to Durfor and Becker (1964) classification 76% of the sampled groundwater are soft whereas 24% are moderately hard to hard indicating minimal contribution to encrustation. Thus encrustation of groundwater wells in few of the wells is mainly due to high total iron, high pH (alkalinity) and high TCH contents of the water (Fig. 2b). Oxidation of organics in leachates found

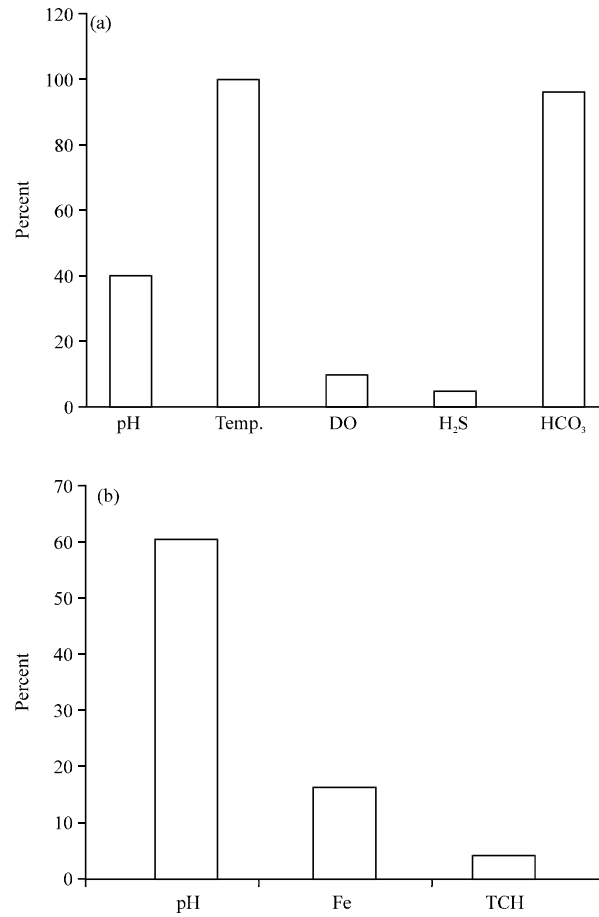


Fig. 2 (a-b): Plot of histogram of percent (a) Corrosion Index Parameters (CIP) and (b) Encrustation Index Parameters (EIP) against water quality parameters

in the study area (which is high in organic carbon) raises the pH of groundwater and precipitates CaCO₃ especially if carbonate is near saturation. These cause CaCO₃ clogging which reduces well performance as mineral build up in the intake zone reduces effective hydraulic conductivity of the system.

Prevention of borehole deterioration: This study indicate that the study area generally has low corrosion and encrustation risk and borehole failures may be largely due to poor pump selection, use of inferior materials as riser pipes and poor pump installation and operation. These lead to burning of pumps and/or collapsing and falling into boreholes (Ishiaku and Ezeigbo, 2000). Borehole corrosion and encrustation risk observed in few locations could be minimized if appropriate materials are used in well construction and completion by borehole designers and drillers. These include the use of corrosion resistant casings and well screens made of non-ferrous metal alloys (stainless steel) as well as PVC pipes and coating of borehole installation materials with galvanized zinc and tar.

Encrustation due to high concentration of iron in the sampled groundwater may be controlled through oxidation of soluble ferrous ions to insoluble ferric ion. The precipitates formed as a result is subsequently removed by energetic flocculation, filtration

and chlorination. Furthermore, conduction of pumping test prior to pump selection and installation and use of good quality materials as riser pipes is strongly recommended. In addition regular maintenance of boreholes involving air lifting, jetting, acid treatment and chlorination is recommended.

CONCLUSION

The assessment and interpretation of CEIP indicate low risk level to corrosion and encrustation for majority of boreholes in the study area. These suggest that high rate of borehole failures in the area could be due to poor pump selection and operation, use of inferior materials as riser pipes and lack of regular maintenance of boreholes. Hence, conduction of pumping test prior to pump selection and installation and regular maintenance of boreholes involving air lifting, jetting, acid treatment and chlorination is recommended.

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