Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.9, 2015

Corrosion Potentials of Natural Waters in Abakaliki, Ebonyi State, Nigeria

D. C. OZOKO
Department of Geology and Mining, Enugu State University of Science and Technology, P.M.B 01660
E-mail:dan.ozoko@gmail.com

Abstract
Twenty five water samples drawn from boreholes, hand-dug wells and streams from Abakaliki Metroplex of Ebonyi State, southeastern Nigeria were analysed for major element chemistry. Data relevant to the determination of carbonate equilibria was then used to determine the corrosion potential of the waters with respect to the Langelier Saturation Indices (LSI) and Ryznar Stability Indices (RSI). The results showed that the LSI values range from -1.9 to 0.72 while the RSI values are from 7.3 to 11.0. $CaCO_3$ hardness for the waters ranged from 191mg/L to 631mg/L thus indicating very hard water. The LSI values indicated water that is undersaturated with respect to calcite. It also showed that the waters are aggressive. The RSI values showed that the waters are not only aggressive but likely to cause intolerable corrosion. The implication for the study area will be in the area of borehole and plumbing failures in houses and industries. This highly reactive and corrosive water may also attack concrete works.
Keywords: Abakaliki; Langelier Saturation Index; Ryznar Stability index; Corrosive; hardness.

A. INTRODUCTION:

Corrosion is the degradation and destruction of metals, alloys and concrete in the human environment by means of chemical or electrochemical processes. Corrosion is a global phenomenon, affecting all countries. Its impact is negative and affects all infrastructure including buildings, highways, bridges and industrial plants. According to Johnson (1975), the United States loses over $300 billion (USD) annually to corrosion which is about 3.2% of its gross domestic product (GDP). This situation can only be mitigated if there is widespread awareness of the danger of corrosion and by taking measures to prevent or reduce its incidence.

Unfortunately many corrosion problems can be traced directly to groundwater or surface water quality issues. Natural water (i.e. groundwater and surface water) varies compositionally from location to location due to changes in rock or soil chemistry and conditions. When corrosion or encrustation is due to natural water quality problems, the impact will be seen in borehole failures, pump failures, clogging of well screens and also in the damages to pipes used for water distribution in the city. Hence, the proper assessment of the corrosion potentials of natural water in an area might be a predictor of the longevity of boreholes and well head installation. The pioneering works of Langelier (1936), Ryznar (1942), Carrier (1965), Johnson (1975) and Clarke (1980) have led to the widespread application of the equations that they developed in many parts of the world. In Saudi Arabia, Alhameid and Al-Naeem (2014) applied the Langelier equation to the mapping of areas of corrosive groundwater. In Nigeria, Ozoko and Ugwu (2010) applied the Ryznar Stability Index in predicting borehole longevity in the Anambra basin. Obiefuna and Orazaluike (2011) applied Johnsons CEIP (Corrosion Encrustation Index Parameter) to the problem of corrosion in Yola, Adamawa State while Omali et al (2013) applied CEIP to the evaluation of corrosion potentials in Lokoja, Kogi State. Most works on corrosion deal with the corrosion of metals (Mogg, 1972) but Ayers and Westcot (1994) have demonstrated that corrosion can affect not only metals but concrete as well.

In evaluating the corrosion potentials of any natural water, the evaluation of the Langelier Saturation Index is a tool of choice. It is a powerful indicator of the ability of natural water to corrode metal objects or to deposit metal oxides to clog the water pump assembly. According to Roberge (2007) other forms of indices that have been used include Ryznar Stability index, Pulkorius Scaling Index, Larson –Skold index, Oddo – Tomson Index.

The formular for Langelier Saturation Index (LSI) is given by equation 1

$$LSI = pH - pHs \quad (1)$$

where pH = field pH (i.e. measured in situ) pHs = calculated pH or pH at saturation. The value of the pH at saturation is given by equation 2.

$$pHs = (9.3 + E + F) - (G+H) \quad (2)$$

where $E = \dfrac{(\log_{10}(TDS) - 1)}{10}$

$F = -13.12 \cdot \log_{10}({}^0C+273) + 34.55$

$G = \log_{10}(Ca^{2+} \text{ as } CaCO_3) - 0.4$

$H = \log_{10}(\text{alkalinity as } CaCO_3)$

After determination of equation 2 and plugging its value in equation 1, the value of LSI (Langelier Saturation Index) is then established. Usually if the L S I is a negative value (i.e. < 0), it indicates that the water is aggressive or corrosive. It will tend to dissolve $CaCO_3$ but if the LSI is equal to zero, it indicates a state of equilibrium, i.e. just saturated. It is important to observe that this “state of equilibrium” can shift to corrosion or encrustation if there are any changes in water temperature. Again if the LSI is a positive value (i.e. >0), it is an indication that scaling or $CaCO_3$ precipitation can occur. The purpose of this paper is to evaluate the corrosion potentials of the natural waters of Abakaliki on the basis of the Langelier Saturation Index.

B. THE STUDY AREA

Location

The study area, Abakaliki (see figure 1) is bounded by latitudes 6^0 16’ N and $6^0$21’ N and longitudes 8^0 05’ E and 8^0 10’ E covering an area of about 83 square Kilometres. It is the capital city of Ebonyi State, Southeastern Nigeria. Geomorphologically, it is part of the Cross River Plains. As a state capital, its population has been growing over the years. The only aquifer is made up of fractured and weathered shales that have low yields (Agbo, 1992) and Ozoko (2012).

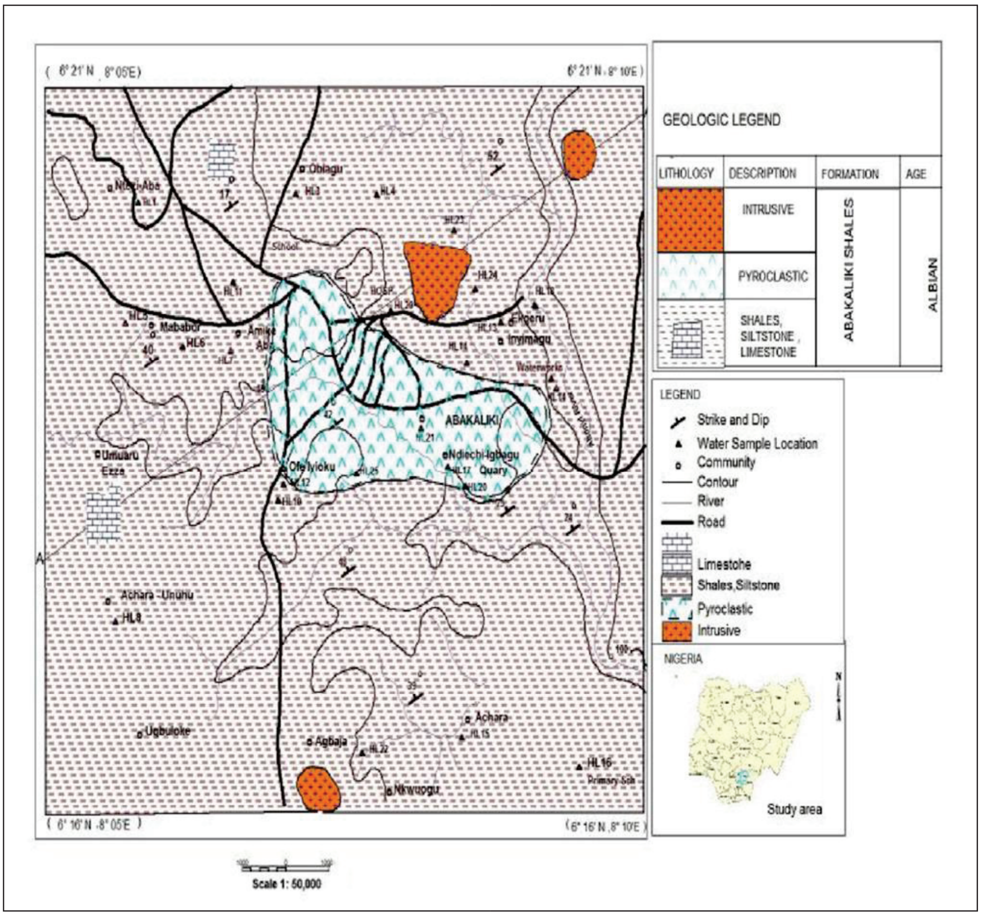

Figure 1. Geologic map of Abakaliki. (Ozoko, 2012)

Relief and Drainage

Abakaliki has a low – lying undulating topography, generally less than 70m above sea level. The highest point in the area is the Juju Hill which is made up of pyroclastics. The area is drained by the Ebonyi River and its tributaries. Abakaliki belongs to the tropical rain forest zone of Nigeria which is characterised by a rainy season which runs from April to October and a dry season from November to March.

Climate and Vegetation

Average annual rainfall is between 1500 - 1650mm. Dry season temperatures range from 20^0C to 38^0C while rainy season temperature range is from 16^0C to 28^0C. During the dry season, many of the hand – dug wells and intermittent streams dry up. All the hand – dug wells and boreholes receive their greatest recharge during the peak of the rainy season (July – September). Vegetation is typical of tropical rain forest. It consists of evergreen trees and shrubs. Savannah grasses and elephant grasses are also common.

Geology and Hydrogeology

The entire study area (figure 1) is underlain by Abakaliki Shales which form part of the earliest sedimentary rock systems in Nigeria known as Asu River Group (Albian). The Asu River Group regionally consists of poorly bedded sandy shales, fine grained calcareous sandstones, limestones, ironstones and shales. The group has suffered various intrusions and extrusions. The most dominant shale rocks of the group is the Abakaliki Shales which is the formation underlying the study area. Ozoko (2012) described the Abakaliki Formation as dark grey to black shales with mudstones, poorly bedded sandy shales with subordinate limestones and sandstone lenses. Average dips range from 64^0 – 70^0 in the NW direction. The main aquifer horizon in Abakaliki is the shallow, shale – regolith aquifer that is about 8.5-25m thick. Agbo (1992) proposed from vertical electrical sounding results, the existence of deeper aquiferous conditions due to fractures/joints that are up to 400m deep. The average value of hydraulic conductivity (K) for the fractured shale –regolith aquifer is 6.06 x 10^{-3} cm/s. Ozoko (2012) obtained this value on the basis of joints/fracture density calculations.

C. MATERIALS AND METHODS

Field sampling of the natural waters was restricted to groundwater and springs in the shallow regolith aquifer and Ebonyi River. A total of twenty five samples were taken from the area comprising boreholes, hand dug wells and stream locations. Unstable parameters like pH, temperature, and dissolved oxygen were measured in the laboratory. The equipment used for measuring these field parameters was Hanna multiparameter water quality meter (Hach 93130). Tests for cations were done at PRODA Laboratories Enugu (Federal Ministry of Science and Technology) using Atomic Absorption Spectrophotometer while the anions were analysed using normal titrimetric methods of America Public Health Association as described by Clesceri et al (1998). Results from the chemical analysis were then subjected to calculations of Langelier Saturation Indices in order to estimate the corrosion potentials of the natural waters.

D. RESULTS

The results of physico – chemical evaluation of the natural waters are given in Table 1. The pH range of all water samples range from 6.9 to 8.4 which indicate almost neutral to alkaline pH. Temperature readings usually depend on the time of day/season of the year but for this particular data, the range is from 19^0 -24.C because it was taken in the rainy season (July/August).The value of total dissolved solids vary from 827.8mg/L to 1334.2mg/L which indicates significant solute concentrations. Dissolved oxygen (D.O) levels are quite high. They range from 576.8mg/L to 1247.6mg/L which is indicative of high corrosive water. The cation with the highest concentration levels is sodium (Na^+) which ranges from 67.4mg/L to 1178mg/L. Magnesium (Mg^{2+}) varies from 20.3mg/L to 102mg/L while calcium (Ca^{2+}) ranges from 27.3mg/L to 145.8mg/L. Bicarbonates (HCO^-_3) is from 10.4mg/L to 100mg/L while sulphate (SO_4^{2-}) ranges from 39.6mg/L to 387mg/L. Chloride (Cl^-) is from 13.8mg/L to 320mg/L. In other words, the main cation is sodium (Na^+) while the main anions are chloride (Cl^-) and sulphate (SO_4^{2-})

Table 1. Chemical characteristics of hand dug wells, ponds and streams in Abakaliki. (mg/l)(after Ozoko, 2012)

S/N	Location	Water Sample No	pH	Temp (^{0}C)	TDS	Dissolved Oxygen (O_2)	Na^+	Mg^{2+}	Ca^{2+}	HCO_3^-	SO42-	Cl^-	Fe (Total)	NO3-
1	Ntezi Abu	HL1	7.4	21	985.7	1072	217	36	42	20	80	70.4	0.3	1.2
2	Prison/ Hospital	HL2	7.1	20	911.5	996.4	204	54.3	37	25	88	265	BDL	0.2
3	Obiagu West	HL3	7.5	24	1102	600	147.2	70.1	32	24.3	90.4	287	3.20	2.4
4	Obiagu Central	HL4	7.4	20	1004.7	673.8	132.6	65	29.6	19.8	46.7	320	4.5	2.8
5	Igbagu	HL5	7.8	22	827.8	1102	125	32	27.3	40.2	62	110.7	BDL	BDL
6	Abakaliki (BH)	HL6	7.3	19	902.3	1048	142	27	52.4	17.5	57.3	63	0.7	0.3
7	Ebonyi River	HL7	7.3	20	1209	576.8	184.3	84	72.1	82	102	38.6	4.8	3.7
8	Ugbuloke	HL8	7.4	21	1001.2	1148.2	89	102	85	75	153	77	0.2	2.5
9	Mgbabor	HL9	6.9	22	877.6	1204.3	67.4	94	66.4	33.2	387	92.3	0.1	3.7
10	Ndiachi Igbagu	HL10	7.1	22	1324	753.4	120	25	57.2	16.4	104	98.4	7.3	4.3

11	Rice Farm Well	HL11	7.2	20	1159.8	709.8	135.3	32	60.8	33	107	84.7	6.9	5.7
12	Ofeiyi Oku	HL12	7.3	22	956.7	1126.4	102	41.2	90	36	120	52.6	0.4	BDL
13	Akaeru-Iyimagu	HL13	6.9	22	904.8	1014.7	98.6	29	75	38	95.8	123	0.3	0.3
14	Waterworks Area	HL14	7.1	20	845.6	1247.6	1178	33	101.7	18.7	110	13.8	BDL	BDL
15	Achara near Govt. Admin Estate Pond	HL15	6.8	24	1227.4	803.4	202.4	45	48	22	119.6	96.2	7.9	2.7
16	School (primary well)	HL16	7.1	22	975.6	997.7	101.3	42	63	18.7	74.2	205	0.5	0.5
17	Pond near Quarry, Abakaliki	HL17	7.6	20	1198.7	923.4	75.2	22.7	85	44	39.6	306.4	0.8	3.4
18	Pond near Quarry, Abakaliki	HL18	7.9	19	1334.2	720.3	83.7	31.4	69.3	82.6	43.2	250	3.75	5.8
19	Abia Stream (intermittent)	HL19	7.4	19	1206	850	94.2	32.2	38	25	50	210	3.6	4.6
20	Intermittent Stream Near Quarry, Abakaliki	HL20	7.1	22	1118.6	794	96.8	29.7	47.3	18.3	39.6	115.3	4.7	4.9
21	Limestone Quarry Abakaliki	HL21	8.4	20	1001	1008	68.7	21.8	145.8	100	58.4	70.2	BDL	BDL
22	Intermittent Stream Abia	HL22	7.0	22	997.8	1211.3	88.6	30	43.6	20.2	65.6	35.7	BDL	0.2
23	Near Juju Hill	HL23	7.4	24	1294	620	152.3	32.2	55.8	26.3	121.2	82	5.8	4.4
24	Achi-Stream	HL24	7.6	20	1206.4	680.4	104.8	20.3	67.2	30	86	94.2	5.2	3.9
25	Iyi-Okwu	HL25	7.7	20	1108.7	750.2	97.6	23.6	71.2	32.4	77.8	98.3	3.4	3.5

E. LANGELIER SATURATION INDEX (LSI) AND CORROSION POTENTIAL

Values of LSI were obtained for the study area by applying equations 1 and 2 to the data in Table 1. Results of the LSI calculations are given in Table 2. According to table 2, the values of LSI for the area range from – 1.9 to 0.72. Over 99.9% of all the samples have negative LSI values which indicate very aggressive water that is likely very corrosive. Only the hand-dug well located at the limestone Quarry in Abakaliki had a positive value of 0.72. This value is indicative of slight encrustation potential or non- corrosive water.

Table 2: Values of Langelier Saturation Indices (LSI) calculated for the Study area

S/N	Location	Sample No	pH	pHs	L. S. I	Remarks
1	Ntezi Abu	HL1	7.4	8.9	-1.5	Serious Corrosion
2	Prison/ Hospital	HL2	7.1	8.8	-1.7	Serious Corrosion
3	Obiagu West	HL3	7.5	8.9	-1.4	Serious Corrosion

4	Obiagu Central	HL4	7.4	9.1	-1.7	Serious Corrosion
5	Igbagu	HL5	7.8	8.7	-0.93	Serious Corrosion
6	Abakaliki (BH)	HL6	7.3	8.9	-1.6	Serious Corrosion
7	Ebonyi River	HL7	7.3	8.1	-0.8	Serious Corrosion
8	Ugbuloke	HL8	7.4	8.0	-0.61	Serious Corrosion
9	Mgbabor	HL9	6.9	8.4	-1.5	Serious Corrosion
10	Ndiachi Igbagu	HL10	7.1	8.9	-1.8	Serious Corrosion
11	Rice Farm Well	HL11	7.2	8.6	-1.4	Serious Corrosion
12	Ofeiyi Oku	HL12	7.3	8.8	-1.5	Serious Corrosion
13	Akaeru-Iyimagu	HL13	6.9	8.3	-1.4	Serious Corrosion
14	Waterworks Area	HL14	7.1	8.5	-1.4	Serious Corrosion
15	Achara near Govt. Admin Estate Pond	HL15	6.8	8.8	-2.0	Serious Corrosion
16	School (primary well)	HL16	7.1	8.7	-1.6	Serious Corrosion
17	Pond near Quarry, Abakaliki	HL17	7.6	8.3	-0.69	Serious Corrosion
18	Pond near Quarry, Abakaliki	HL18	7.9	8.1	-0.25	Serious Corrosion
19	Abia Stream (intermittent)	HL19	7.4	8.9	-1.5	Slight Corrosion
20	Intermittent Stream Near Quarry, Abakaliki	HL20	7.1	8.9	-1.8	Serious Corrosion
21	Limestone Quarry Abakaliki	HL21	8.4	7.7	0.72	Might lead to Scaling or encrustation
22	Intermittent Stream Abia	HL22	7.0	8.9	-1.9	Serious Corrosion
23	Near Juju Hill	HL23	7.4	8.6	-1.2	Serious Corrosion
24	Achi-Stream	HL24	7.6	8.6	-0.96	Serious Corrosion
25	Iyi-Okwu	HL25	7.7	8.5	-0.79	Serious Corrosion

F. DISCUSSION

The study shows that all natural waters (i.e. both ground water and surface water) in Abakaliki have negative LSI values which indicate that they are corrosive and aggressive. In other words they are likely to dissolve $CaCO_3$ or other minerals as they come in contact with them. In order to further investigate the situation, the $CaCO_3$ hardness of the water and the Ryznar Stability Index for the waters were also calculated to compare it with LSI results. Table 3 shows the results for $CaCO_3$ hardness and the Ryznar Stability Index for the area. The $CaCO_3$ - hardness for Abakaliki ranges from 199mg/L to 631mg/L which means very hard water. The Ryznar Stability Index (RSI) ranges from 7.3 to 11 which is indicative of very aggressive water with potentials for intolerable corrosion.

Table 3: Values of $CaCO_3$-hardness and Ryznar Stability Indices in the Study Area

S/N	Location	Sample No	$CaCO_3$-hardness/ Interpretation mg/L	Ryznar Stability Index/ Interpretation
1	Ntezi Abu	HL1	253 – Very hard water	10 – Very aggressive water, intolerable corrosion
2	Prison/ Hospital	HL2	315 – Very hard water	11 – Very aggressive water, intolerable corrosion

3	Obiagu West	HL3	367 – Very hard water	10 – Very aggressive water, intolerable corrosion
4	Obiagu Central	HL4	341 – Very hard water	11 – Very aggressive water, intolerable corrosion
5	Igbagu	HL5	199 – Very hard water	9.7 – Very aggressive water, intolerable corrosion
6	Abakaliki (BH)	HL6	242 – Very hard water	10 – Very aggressive water, intolerable corrosion
7	Ebonyi River	HL7	525 – Very hard water	8.9 – Heavy Corrosion
8	Ugbuloke	HL8	631 – Very hard water	8.6 – Heavy Corrosion
9	Mgbabor	HL9	551 – Very hard water	10 – intolerable corrosion
10	Ndiachi Igbagu	HL10	246 – Very hard water	9.9 – Very aggressive water, intolerable corrosion
11	Rice Farm Well	HL11	283 – Very hard water	11 – Very aggressive water, intolerable corrosion
12	Ofeiyi Oku	HL12	394 – Very hard water	9.3 – Very aggressive water, intolerable corrosion
13	Akaeru-Iyimagu	HL13	306 – Very hard water	9.8 – Very aggressive water, intolerable corrosion
14	Waterworks Area	HL14	390 – Very hard water	10 – Very aggressive water, intolerable corrosion
15	Achara near Govt. Admin Estate Pond	HL15	305 – Very hard water	7.3 – Significant Corrosion
16	School (primary well)	HL16	330 – Very hard water	10 – Very aggressive water, intolerable corrosion
17	Pond near Quarry, Abakaliki	HL17	306 – Very hard water	9.0 – Heavy Corrosion
18	Pond near Quarry, Abakaliki	HL18	302 – Very hard water	8.4 – Heavy Corrosion
19	Abia Stream (intermittent)	HL19	227 – Very hard water	10 – Very aggressive water, intolerable corrosion
20	Intermittent Stream Near Quarry, Abakaliki	HL20	240 – Very hard water	11 – Very aggressive water, intolerable corrosion
21	Limestone Quarry Abakaliki	HL21	454 – Very hard water	7.0 – Little Scale formation or slight corrosion
22	Intermittent Stream Abia	HL22	232 – Very hard water	11 – Very aggressive water, intolerable corrosion
23	Near Juju Hill	HL23	272 – Very hard water	9.9 – Very aggressive water, intolerable corrosion
24	Achi-Stream	HL24	251 – Very hard water	8.8 – Heavy Corrosion
25	Iyi-Okwu	HL25	275 – Very hard water	9.3 – Very aggressive water, intolerable corrosion

Notes on $CaCO_3$ Hardness
0 – 60 mg/L – Soft water
60 – 120 mg/L – Moderately soft water
120 – 180 mg/L – Hard water
>180 mg/L – Very hard water

Table 4 shows the original scale used by Ryznar(1944) to define the corrosiveness of water while and the modifications proposed by Carrier (1965). Though the Ryznar Stability Index like the Langelier Saturation Index (LSI) is also based on the concept of saturation pH, it provides another way of estimating the corrosiveness of water. It is based on the equation given in equation 3.

Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.9, 2015

$RSI = 2 \times pHs - pH$ ....(3)

where RSI = Ryznar Stability Index pHs = Saturation pH which is obtained by equation 2.
pH = Measured pH

Table 4: Original scale of Ryznar (1942) and the modified scale of Carrier (1965)

Ryznar (1944)

RSI	Interpretation
< 5.5	Heavy Scaling
5.5 – 6.2	Scale will form
6.2 – 6.8	Water will neither corrode metal or deposit scales
6.8 – 8.5	Water is aggressive
8.5	Water is very aggressive

b. Carrier (1965)

RSI	Interpretation
4.0 – 5.0	Heavy Scale will be deposited
5.0 – 6.0	Light Scale
6.0 – 7.0	Little scale or mild Corrosion
7.0 – 7.5	Significant Corrosion will take place
7.5 – 9.0	Heavy Corrosion
9.0	Intolerable Corrosion

From the foregoing it is obvious that with the RSI range of the study area from to 7.3 – 11.00, this translates from "aggressive to very aggressive in the old Ryznar scale" and from "significant corrosion to intolerable corrosion" in the Carrier (1965) scale. The implications for the study area will range from high rates of borehole failures to frequent plumbing failures in households and industries. The economic implications for the state will be great. It is even possible that the natural waters will attack concrete according to Ayers and Westcot (1994). Another implication of corrosive water is its high reactivity with minerals. The more reactive a water is, the more easily it will react with rock minerals and promote rapid chemical erosion.

G. CONCLUSION

Twenty five water samples drawn from boreholes, hand – dug wells and streams in Abakaliki were analysed for major elements and checked for corrosion potentials. LSI and RSI calculations showed that nearly all the samples are very aggressive chemically and have serious potentials for causing intolerable corrosion of metals, alloys and concrete.

References:

Agbo, J. U. 992. Origin of dissolved solids in groundwaters of the Southeast Ebonyi River basin, Lower Benue Trough. Water Resources- Journal of the Nigerian Association of Hydrogeologist, vol. 31(1&2) pp. 31-46.

Alhameid, A.H., and Al-Naeem, A.A., 2014, Spatial Patterns of groundwater quality and its impact on pipes and wells equipment in Al-Hassa, Oasis Kingdom of Saudi Arabia. Trends in Applied Science Research, vol.9 (No9) pp.545-556.

Ayers, R.S. and Westcot, D. W., 1994. Water Quality for Agriculture (FAO Irrigation and Drainage paper).

Carrier Air Conditioning Company, 1965. Handbook of Air Conditioning System Design, Mc Graw Hill. New York.

Clark, F.E., 1980. Corrosion and Encrustation in Water wells. A field guide for Assessment, Prediction and Control (FAO Irrigation and Drainage Paper).

Clesceri, L. S., Greenberg, A. E., Eaton, A. D. (eds). 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association Washington, DC.

Johnson, E.E., 1975. Groundwater and wells. Johnson Division UOP Inc. pp. 317-344.

Langelier, W. F., 1936. The analytical control of anti-corrosion water treatment. Journal of American Water Works Association. Vol. 28, Nos. 10, pp. 1500-1521.

Mogg, J.L., 1972. Practical Corrosion and Incrustation Guidelines for water wells. Groundwater vol. 10, issue 2, pp.6-11.

Obietuna, G.I. and Orazuluike, D.M., 2011 Evaluation of Corrosion and Encrustation potentials of bore holes in Yola area, Northeastern Nigeria. Trends in Applied Science Research, vol. 6 (No.10).pp.1197-1200.

Onah, A. O.,Egboka, B. C.E. and Ishaku, J. M., 2013. Determination of Corrosion and Encrustration potentials of groundwater wells in Lokoja area, Central Nigeria. Research Journal in Engineering and Applied Science. vol. 2 (No4).pp.236-242.

Ozoko, D. C. and Ugwu, I. M., 2010. Prediction of Bore- hole failure in Anambra Basin on the basis of Corrosion and Encrustation Studies. Journal of Environmental Research and Policies vol. 5, (Nos. 4) pp.52-60.

Ozoko, D. C., 2012. Hydrogeochemical and microbial characteristics of Abakaliki shales, Journal of Environmental Hydrology, Vol.20, Paper 5, 1-9.

Roberge, P.R., 2007. Corrosion Inspection and Monitoring John Wiley and Sons, New York. 373pp

Ryznar, J.N.,1944. A new index for determining amount of calcium carbonate scale formed by a water. Journal of American water works Association. vol. 36, p472