

A Study of Potential Corrosivity of Borehole Waters in Eket, Nigeria by Saturation Index Measurement

Keywords : Calcium Carbonate saturation index, saturation p H, corrosion, Borehole waters

Abstract

A study of water chemistry in some boreholes in Eket, Nigeria, was conducted to determine the calcium carbonate saturation index, in order to establish the corrosion tendency of the waters towards metal substrates in piping systems, boilers, heat exchangers and submersible pumps. Calcium carbonate saturation index using Langelier system was determined to be more negative (- 4.16 to - 5.2) below the optimum range of - 0.5 to + 0.5 for water that is in equilibrium with calcium carbonate. The water saturation pH (pHs) determined for the waters sampled in the area had values that ranged from 8.82 to 9.55, with mean value of 9.09. The values were far above the pH values of the waters from all the locations sampled, which ranged from 4.12 to 5.34, with a mean pH of 4.48 . The water chemistry was of same characteristic for all the studied locations, indicating that the waters were drawn from same regional aquifer, have same corrosive tendency and the possibility of metal substrates to be attacked by water used for both industrial and domestic purposes in the study area. The more negative the calcium carbonate saturation index, the greater the possibility of the water in its corrosive action especially in oxygenated waters. Therefore, the waters in Eket are likely to exhibit remarkable corrosive tendency against metal substrates. The implication of this finding is that in the study area, there has to be a strategic corrosion control program in piping systems and industrial equipment such as heat exchangers, boilers, domestic water heaters and submersible pumps in tackling corrosion challenges.

1.0 Introduction

One of the most common problems affecting domestic water supplies is corrosion, a chemical process that slowly dissolves metal, resulting in deterioration and failure of plumbing pipes, fixtures and water-using equipment (Garone et al, 2012). Corrosion attacks the metal substrate and gradually thins the entire metal surface, often causing red-colored stains in iron or steel plumbing systems or blue-green stains in copper and brass plumbing systems (Etesin

31 et al, 2012 ; Oram, 2001). Another type of corrosion attacks are small areas where deep pits
32 can develop and penetrate pipe or tank walls. This type of corrosion may not add significant
33 amounts of iron or copper to the water, but can create small holes in a pipe or tank that
34 destroy its usefulness, cause water leaks, and result in major water damage to a home or
35 business (APHA, AWCF, APWA, 1995). In another case, corrosion may cause oxidation of
36 metals, which involves conversion of copper or other base metal to an oxidized form in a
37 process similar to the rusting of steel (Hermanson, 1991; Galway Water, 2014). It often
38 results in reduced water flow through supply lines and destruction of water valves and other
39 machined water flow control surfaces, thus resulting in internal and external leaks at valves
40 and faucets.

41 Corrosion is a complex series of reactions between the water metal surfaces and minerals in
42 which the water is stored or transported. With respect to the corrosion potential of drinking
43 and process water, the primary concerns include potential presence of toxic metals, such as
44 lead and copper, deterioration of and damage to the household plumbing and aesthetic
45 problems such as stained laundry, bitter taste and greenish-blue stains around basins and
46 drains (Oram, 2001 Galway Waters, 2014).

47 Nearly all metals will corrode to some degree. The rate and extend of the corrosion depends
48 on the degree of physical and chemical characteristics of the media, metal and environment.
49 In soft water, corrosion occurs because of lack of dissolved cations, such as calcium and
50 magnesium in the water. In water that forms scales, a precipitate of calcium or magnesium
51 carbonate forms on the inside of the piping system (Etesin et al, 2012). This scale can inhibit
52 the corrosion of the metal substrate, because it acts as a barrier, but can also clog piping
53 system. However, high concentrations of sodium, chloride, or other ions will increase the
54 conductivity of the water and promoting corrosion (Oram, 2001).

55 Water quality is very critical in influencing the operating efficiency and life of equipment,
56 including pumps, piping systems and wells. Therefore, acidic water with a pH value of less
57 than 6 is usually corrosive while, alkaline water with pH greater than 8 is less corrosive
58 (GWM, USA, 1985).

59 Corrosive water can be defined as a condition of water quality which will dissolve metals
60 from metallic plumbing at an excessive rate. Some of the factors that makes water corrosive
61 include, low pH (below 6), a lower alkalinity value (below 35 mg/l CaCO_3), a high specific

62 conductivity as a measure of total dissolved solid (TDS) and high temperature
63 (Environmental Facts Sheet, 2009).

64 An indicator of water corrosiveness that is widely in use is calcium carbonate (CaCO_3)
65 saturation index (SI), also referred to as calcium carbonate solubility equilibrium, and is
66 highly important in many phases of water chemistry (Bryan, 2009). It is used to evaluate the
67 scale-forming and scale-dissolving tendencies of water. Langelier saturation index is based
68 on the investigation of the carbonate equilibrium in water, to assess the true pH or true
69 hardness of water (Galway Waters, 2014). Carbonate equilibrium in water involves gaseous
70 carbon(IV) oxide, aqueous carbon(IV) oxide, carbonic acid (H_2CO_3), bicarbonates,
71 carbonate, solid calcium carbonate or magnesium carbonate (Galway Waters, 2014; APHA,
72 AWCf, APWA, 2005).

73 Several indices are used to describe the behavior of calcium carbonate in water, oil, or gas
74 mixtures. In 1936 Wilfred Langelier developed a method for predicting pH at which water is
75 saturated in calcium carbonate, which is called saturation pH (pHs), (Egereonu *et al.*, 2012).

76 Langelier saturation index (LSI) is the difference between the actual system pH and the
77 saturation pH (pHs). pH is a common measure of water quality that is often related to
78 corrosion of plumbing system components like lead and copper (APHA, AWCf,
79 APWA, 2005). Lead is a dangerous metal with many health effects, especially in children.
80 Lead usually occurs in drinking water supplies from corrosion of lead solder or lead
81 impurities in plumbing fixtures (Bryan, 2009; WHO, 2008).

82 The assessment of scale-forming and scale-dissolving tendencies of water is useful in
83 corrosion control program and also in preventing calcium carbonate scaling in piping, and
84 equipment such as industrial heat exchangers, boiler feed water heaters and domestic water
85 heaters, including tea kettle (Etesin *et al.*, 2012). In this consideration, there are three classes
86 of water that can be defined by calcium saturation index namely, waters oversaturated with
87 CaCO_3 , which tend to precipitate CaCO_3 scale; waters under saturated with CaCO_3 , which
88 tend to dissolve calcium carbonate and waters saturated with CaCO_3 , which are in
89 equilibrium with calcium carbonate and have neither CaCO_3 precipitate nor dissolving
90 tendencies (APHA, AWCf, APWA, 1995; WHO, 2011).

91 The aim of this study is to estimate the calcium carbonate saturation index of some borehole
92 waters in Eket and also evaluate the influence of water quality parameters such as calcium,
93 total dissolved solids, alkalinity, pH, temperature and conductivity on the calcium carbonate

94 solubility equilibrium and to establish the corrosion tendency of water in the study area.
95 Companies in the area use water from this source as process and portable water, the local
96 communities also use water from this source for both portable and domestic uses. The huge
97 costs of corrosion control for industrial and domestic equipment in the area lend some
98 impetus to this study.

99 The study will provide adequate data on potable water supply in the study area, whereby such
100 data will be useful in evaluation of the extent of potential corrosivity of water. The data to be
101 generated from the study will help in the future water resources planning development in the
102 study area.

103 The Langelier saturation index (LSI) is a formula developed from studies conducted by Dr.
104 Wilfred Langelier in the early 20th century. The LSI is the basis for water balance and
105 saturation (APHA. AWCF, APWA, 2005)

106 The Langelier saturation index (LSI) is an equilibrium model derived from the theoretical
107 concept of saturation and provides an indication of the degree of saturation of water with
108 respect to calcium carbonate. It can be shown that the Langelier saturation index (LSI)
109 approximates the base 10 logarithm of the calcite saturation level (APHA. AWCF, APWA,
110 2005).

111 The Langelier saturation level approaches the concept of saturation using pH as a main
112 variable. The LSI can be interpreted as the pH change required, bringing water to equilibrium
113 (Kriesi, 2017).

- 114 • If LSI is negative: no potential to scale, the water will dissolve CaCO_3
- 115 • If LSI is positive: scale can be formed and CaCO_3 precipitation will occur
- 116 • If LSI is close to zero: borderline scale potential.

117 The LSI is probably the most widely used indicator of cooling water scale potential. It is
118 purely an equilibrium index and deals only with the thermodynamic driving force for
119 calcium carbonate scale formation and growth (Appendix 1). It provides no indication on
120 how much scale or calcium carbonate will actually precipitate to bring water to equilibrium.
121 It simply indicates the driving force for scale formation and growth in terms of pH as a
122 master variable. In order to calculate the LSI, it is necessary to know the alkalinity (mg/l
123 Ca^{2+} as CaCO_3), total dissolved solids (mg/l TDS), the actual pH, and the temperature of the
124 water ($^{\circ}\text{C}$).

125 LSI is expressed as in equation (i) :

126 $LSI = pH - pH_s$ (i)

127 Where:

- 128 • pH is the measured water pH
- 129 • pH_s is the pH at saturation in calcite or calcium carbonate and is expressed as :

130 $pH_s = (9.3 + A + B) - (C + D)$ (ii)

131 Where:

- 132 • $A = (\log_{10} [TDS] - 1) / 10$ (iii)
- 133 • $B = - 13.12 \log_{10} (^{\circ}C + 273) + 34.55$ (iv)
- 134 • $C = \log_{10} [Ca^{2+} \text{ as } CaCO_3] - 0.4$ (v)
- 135 • $D = \log_{10} [\text{alkalinity as } CaCO_3]$ (vi) (APHA, AWWCF, APWA 2005).

136 The consequences of corrosion are many and varied and the effects of these on the safe,
 137 reliable and efficient operation of equipment or structures are often more serious than the
 138 simple loss of a mass of metal (Corrosion Report, 2001) . Failures of various kinds and the
 139 need for expensive replacements may occur even though the amount of metal destroyed is
 140 quite small.

141 Corrosion is a natural process that occurs when metals are in contact with oxygen and react to
 142 form metal oxides. All water is corrosive to some degree as it contains some amount of
 143 dissolved oxygen. The rate of corrosion depends on a number of factors including acidity or
 144 low pH, electrical conductivity, oxygen concentration and water temperature (Oram, 2001).

145 In addition to corrosion, dissolution of metals occurs when the water is extremely low in
 146 dissolved salts or in the presence of certain water-borne ions. All materials have a particular
 147 level of solubility and in the case of corroded plumbing; the concentration of the copper or
 148 other plumbing material metal is lower in the water than that material's solubility. As a
 149 result, the plumbing material is gradually dissolved. While this process is usually very slow,
 150 certain water-borne ions can react with and bind the recently dissolved metal allowing more
 151 rapid loss. While corrosion and dissolution are fundamentally different, the end result is
 152 similar and so both are often discussed together under the general term corrosion (Subyami,
 153 2004)

154 Ground water can be acidic or alkaline in pH depending on several factors. Rainfall is
 155 typically acidic because it picks up carbon dioxide as it falls to the earth, forming carbonic
 156 acid. As water percolates through the soil, it also can come in contact with other acid-

forming materials such as decaying organic matter (Obiefuna and Orazulike, 2011). In areas where underground strata contain limestone or dolomite, the acid is neutralized and the water is usually alkaline and hard with pH values between 7 and 8. Where limestone or dolomite is not present underground, the percolating water will retain its acidity and groundwater will typically have pH values between 6 and 7 (Edet and Ekpo, 2008).

Corrosion is more likely and more rapid at higher water temperatures. The rate of corrosion increases by a factor of three to four as water temperature rises from 60°F to 140°F. Above 140°F, the rate of corrosion doubles for every 20°F increase in water temperature (McFarland, *et.al.*, 2012).

2.0 The Study Area

Eket Local Government Area is one of the local government areas in Akwa Ibom State , Nigeria, playing host to a major multinational oil company, Exxon Mobil. Eket is located between latitude 4°31¹ and 4°45¹ North and between longitude 7°52¹ and 8°02¹ East (Figure1). The study area is underlain by sedimentary formation of Late Tertiary and Holocene ages (Magnus et al, 2012) . Deposits of recent alluvium and beach ridge sands occur along the coast and the estuaries of the Imo and Qua Iboe Rivers and also along flood plains of creeks. The study area consists of mainly of coastal plain sands. The sands are mature, coarse and moderately sorted. The coastal plain sands, otherwise known as the Benin formation overlies the Bende-Ameki formation and dips south westward (.Akankpo and Igbokwe, 2011 ; Mbonu and Ebeniro, 1991).. The landscape of Eket comprises of a generally low-lying plain and riverine areas with no portion exceeding 175 metres above mean sea level. The physiography of Eket is that of a beach ridge complex characterized by a succession of sub parallel sand ridges (Figure 1).

The physical relief of Eket Local Government Area is basically flat, though with some marshy river-washed soils around the banks of Qua Iboe River (ALSCON, 1997) . Eket Local Government falls within the tropical zone wherein its dominant vegetation is the green foliage of trees/shrubs and the oil palm tree belt. The Local Government has two seasons: the wet season and the dry season. Eket has abundant deposit of crude oil and clay. Forest resources include timber, palm produce while the area is also noted for seafood production. Farm crops range from yam, cassava, cocoyam, plantain to maize and vegetables (Akankpo and Igbokwe , 2011).

3.0 Materials and Methods

Water samples from boreholes were collected from selected villages within Eket L.G.A : (a) No.12 Ekpeyu street (S1); (b) Ofonmbuk street(S2) ; (c) Hospital road(S3); (d) Ikot Ibiok(S4); (e) Iko Ewak(S5); (f) Liverpool(S6); (g) Iquita street(S7), (h) Etebi street(S8), (i) Nung Uso street(S9) ; (j) Ikot Ebok(S10) . Prior to the collection of water samples, the nozzles of the tap were flamed and sterilized by cleaning with cotton wool soaked in a methylated spirit to avoid contamination. The tap were allowed to run for 5-10 minutes to bring forth the underground water and not the one in the distributing pipeline.

Water samples were collected in a 500ml polyethylene bottles and stored under ice in coolers before being transported to the laboratory for analysis within two hours. Such physico-chemical parameters like pH, conductivity, total dissolved solids (TDS) and temperature were determined at the field using a multimeter (DDJ-303A). Calcium content of the water was determined by Flame Atomic Absorption Spectrometer (Unicam 939/959) using nitrous oxide and acetylene flame, at a wavelength of 422.7nm (Etesin et al, 2012).

The alkalinity of water was determined by titrimetric method, in accordance with the method of APHA. AWCF, APWA (2005). In this study, since all the water samples analyzed had pH below 8.3, only total alkalinity was determined by titration using dilute tetraoxosulphate (VI) acid (APHA. AWCF, APWA ,2005).

The saturation index is a calculated number used to predict the calcium carbonate stability of water from surface or underground bodies like boreholes and wells. In order to estimate the calcium carbonate saturation index, several water quality characteristics must be measured such as alkalinity, total calcium, pH, temperature, conductivity, total dissolved solid, ionic strength etc (APHA, AWCF, APWA, 1995).

Various equations have been proposed for calculating the calcium carbonate saturation index, amongst which, Langelier developed a method for predicting the pH at which water is saturated in calcium carbonate (pH_s), whereby saturation index is expressed as the difference between the actual pH and the saturated pH (APHA. AWCF, APWA, 2005). If the actual pH of water is below the calculated saturated pH, the saturation index is negative and the water a very limited scaling potential. If however, the actual pH exceed pH_s the saturation index is positive and is being super saturated with calcium carbonate, the water has the tendency to form scale. At increasing positive index values, the scaling potential increases (Galway Waters, 2014).

The major task in saturation index estimation is the determination of the saturation pH (pH_s), which is expressed as :

$$pH_s = PK_2 - PK_s + p[Ca^{2+}] + p[HCO_3^-] + 5p_{fm} \quad (vii)$$

Where:

K_2 is second dissociation constant for carbonic acid at the water temperature

K_s is the solubility product constant for $CaCO_3$ at the water temperature

$[Ca^{2+}]$ is the concentration of calcium ion in g-mole per litre

$[HCO_3^-]$ is the concentration of bicarbonate ion in g-mole per litre and

f_m is the activity coefficient for monovalent ionic species.

In aqueous systems, different isomorphs of calcium carbonate can form like calcite, aragonite and valerite, with different solubility properties. Depending on the isomorph of calcium carbonate in the aqueous system, values of PK_2 , PK_s and p_{fm} required to solve equation are available in literature (APHA, AWCf, APWA, 1995). Alkalinity in water or waste water is as the result of the presence of hydroxide, carbonate and bicarbonate ions. The alkalinity of water is a measure of its capacity to neutralize acids. However, bicarbonate is the major contributor to alkalinity and it arises from the action of carbon dioxide in percolating water on basic minerals in soil and rocks (APHA, AWCf, APWA, 2005; Etesin et al, 2012).

4.0 Results and Discussion

The results of the analyses of the borehole waters from the study area and calculations are presented in Tables 1, 2, and 3, while Figures 2, 3, 3, 4 and 5 are plots of the variations in the physicochemical properties of the waters and the calcium carbonate saturation index of the waters from different locations.

The temperature of the waters ranged from 21.5°C to 27.2°C with a mean of 25.05°C $\pm$ 1.17°C. The pH of waters had a range of 4.12 to 4.72, with a mean of 4.48 $\pm$ 0.37. For all the waters the pH indicated acidic range (Table 1). The pH values were outside the limits of the World Health Organization guidelines of 6.5 to 8.5 for potable water (WHO, 2011).

The calcium concentration of the waters ranged from 3.61 mg/litre to 20.02 mg/litre, with a mean of 11.55 mg/litre $\pm$ 1.55 mg/litre (Table 1). The conductivity of the waters had a range of 51.43 μ S/cm to 170.8 μ S/cm, with a mean of 117.58 μ S/cm. The high conductivity recorded at some stations could be attributed to salt water intrusion as the stations are close to the

coastal line, whereby water with high levels of sodium, chloride or other ions will increase the conductivity of the water and promoting corrosion (Oram, 2001).

The total dissolved solid (TDS) of the waters had a range of 26.1 mg/litre to 85.2 mg/litre, with a mean of 59.09 ± 4.09 mg/litre. The range of alkalinity recorded for the waters was 49.98 mg/litre to 75.1 mg/litre, with a mean alkalinity of $58.72 \text{ mg/litre} \pm 2.57 \text{ mg/litre}$ (Table 1). The range of the total dissolved solids (TDS) obtained for waters in the study area were far below the maximum 1000 mg/l TDS limit of the World Health Organisation (WHO, 2006), indicating that the waters are fresh (Obiefuna and Orazulike, 2011).

The range of saturation pH (pHs), at which water is saturated with calcium carbonate determined for the waters was 8.82 to 9.55, with a mean of 9.09 ± 0.23 (Table 2). The saturation index calculated for all the waters studied from the area had values that ranged from -5.2 to -4.16 , with mean value of -4.62 ± 0.37 (Table 3), compared to the optimum Langelier saturation index of -0.5 to $+0.5$ (APHA, AWCF, APHA, 2005). The mean saturation index for the waters was out of the optimum range of the Langelier saturation index, indicating that all the waters studied in the study area are calcium carbonate dissolving and under saturated with calcium carbonate, thereby have corrosivity potential on metal substrates (Pisigan, 1984; Etesin et al, 2012).

The negative values of calcium carbonate saturation index determined for the waters in this study, indicated that calcium carbonate will not precipitate in the waters from the study area, hence there may be a possibility of corrosion of metal substrates in contact with the waters, especially if dissolved oxygen is high (MTI, 1995). The relationship between the saturation pH (pHs) and Langelier saturation index is illustrated in Fig. 4.

The Langelier saturation index mean value obtained in this study is -4.62 ± 0.37 , which is lower than the value of -2.89 reported for waters in Ikot Abasi and the mean saturation pH (pHs) obtained in this study is 9.09 ± 0.23 , which is higher than the value of 8.93 reported for waters from Ikot Abasi (Etesin et al, 2012).

In a similar study reported on the geochemical studies of groundwater systems of semiarid Yola area, Northeast, Nigeria (Obiefuna and Orazulike, 2011), the saturation index of the waters were less than unity, as also obtained in this study, which indicated waters under-saturated with respect to calcite, dolomite and gypsum (Etesin et al, 2012; APHA, AWCF, APWA, 2005). The unsaturation of calcite, dolomite and gypsum in the waters suggests that their soluble ions Calcium, magnesium, sulphate and carbonate components are limited by

mineral equilibrium, and the water has the potential to be corrosive , mostly to metal substrates (Environmental Fact Sheet, 2009). Mineral dissolution in groundwater is affected by the presence of carbon dioxide and temperature of the underground water (Freeze and Cherry, 1979). In the study area, the temperature of the waters ranged from 21.5°C to 27.2°C with a mean of 25.05°C $\pm$ 1.17°C, while alkalinity of the waters ranged from 49.98 mg/l to 75.10 mg/l , with the mean of 58.72 mg/l , which is less than the limits set by the WHO (2006). The low alkalinity in the water of the study area , may likely impact on the quality of the water in terms of being corrosive.

From the results of the analyses, the low alkalinity of the water (Table 1) correlate with the calcium carbonate saturation index values (Table 3) . Equilibrium calculations help to determine the saturation state of groundwater with respect to various minerals and gases of interest, and more so, are useful in predicting the presence of reactive minerals in the groundwater system and estimating mineral reactivity (Deutsch, 1997 ; Obiefuna and Orazulike, 2011).

5.0 Conclusion and Recommendation

5.1 Conclusion

Calcium carbonate saturation index had been determined for waters from boreholes in Eket , as calculated by Langelier saturation index. The results indicated more negative values below the optimum range of water that is in equilibrium with calcium carbonate, which is calcium carbonate dissolving without scale formation.

The water saturation pH (pHs) were far above the pH values of the waters from all the locations sampled. The water chemistry were of same characteristics indicating that the waters were drawn from similar aquifer, have same corrosive tendency and the possibility of metal substrate to be corroded by water used for both industrial and domestic purposes in the study area. The more negative the calcium carbonate saturation index, the more notorious the water is in its corrosive action (Larson and Budswell, 1943; Larson and Skold, 1958).

Therefore, the waters in Eket are likely to exhibit some corrosive tendencies against metal substrates. The implication of this finding is that there has to be a strategic corrosion control program.

As indicated, corrosion is a major problem that impacts every industry (Radian, 2004). In the study area, just as in other environments, attention to corrosion in the materials selection, construction, operation and maintenance of facilities employing corrosion - able metals will

save billions of dollars in repair/maintenance and replacement costs. To save the huge cost of corrosion, every attempt must ensure the breaking of the linkage in the triangles of corrosion namely anode, cathode and electrolyte. And one of such preventive and controlling measures will be coating the surface of the metal with nonconductive organic coatings like paint and primers.

5.2 Recommendation

For the boreholes in the study area, as low cost is a significant part of the decision process, one major consideration will be the addition of a layer of calcite (sanitary calcium carbonate) to the bottom of the well, that will dissolve slowly neutralizing the water's corrosiveness. On the other hand for high technology approach, it is advisable to add a dilute solution of sodium carbonate or bicarbonate to the water treatment system as to raise the pH and alkalinity in order to combat corrosiveness of the water.

For further study on the water quality of the area, it is suggested that heavy metal contents of water and the ground water dynamic using geochemical modeling be undertaken.

References

- Aluminium Smelter Company of Nigeria (1997). Socio-economic Transformation of a Nigerian Economy. ALSCON Limited, Ikot Abasi, Nigeria. 73-78.
- AWWA Research Foundation Research Report (1985). Internal Corrosion of Water Distribution System.
- APHA, AWCF, APHA (1995). Standard Methods for the Examination of Water and waste water . American Public Health Association. 19th Edition. New York.
- APHA, AWCF, APHA (2005) .Standard Methods for the Examination of water and waste water. American Water Works Association.21st Edition. New York.
- Akankpo A.O and Igbokwe M.U (2011). Monitoring Ground-water contamination using surface electrical resistivity and geochemical methods. *Journals of water resources prof.* 3(5); 318 - 324.
- Bryan R. Swistock, M. S., Stephanie Clemens, M.S. and William. (2009) Quality of Water in Rural Pennsylvania and the Effect of Management Practices. Center for Rural Pennsylvania. 200 North Third St., Suite 600,Harrisburg, PA 17101 . Center for Environmental Quality. Wilkes-Barre, PA.

346 Edet, A and Ekpo, B. (2008). Hydrogeochemistry of a fractured aquifer in the Ogoja/Obudu
347 Area of SE , Nigeria. In : Adelana , S.M.A and MacDonald , A. M. Applied
348 Groundwater Studies in Africa . IAH Selected Papers on Hydrogeology. Vol.13. CRS
349 Press/Balkema Leiden , The Netherlands.

350 Egereonu, U.U; Anuo A.U. and Egereonu J.C. (2012). Comparative Analysis of the degree of
351 pollution of Okitatankwo River along Border Communities: Mbaitoli, Ikeduru,
352 Emekuku and Uratta of Imo state, Nigeria. *Analytical science journal*. Vol.1 No 1, 7-
353 16.

354 Environmental Facts Sheet. (2009). Corrosivity of water supplies. Environmental Services,
355 New Hampshire.(603), 271-3503

356 Etesin, U. M; Ogbonna, I. and Harry, T. (2012) . Potential Corrosivity of Underground
357 waters to Piping Systems in Ikot Abasi, Nigeria. *Tropical Journal of Environmental*
358 *Research. Calabar*. 11, 604 – 612

359 European Union (2018). European Union Drinking Water directive .
360 Galway Water (2014). Colmanstonn Co. Galway, Ireland.

361 Garone, A; Barbierri, M; Parisse, B.(2012). Groundwater Dynamic in a coastal Aquifer using
362 statastical analysis and Geochemical Modelling. Geophysical Research Abstracts.Vol.
363 **14**.EGU 2012- 2412, 2012 EGU General Assembly.

364 Ground Water Manual. (1985) A Water Resources Technical Publication. US Government
365 Printing Office, Denver.

366 Hermanson, R.E. 1991. Corrosion from Domestic Water. EB1581. Washington State
367 University. Pullman,WA.

368 Kriesi (2017). Pure Planet Science and Technology, Inc, Kriesi.

369 Magnus, U. I ; Efurumibe, E. L. and Akaninyene, O. A. (2012). Determination of Aquifer
370 Characteristics in Eket, Akwa Ibom State, Nigeria, using the Vertical Electrical
371 Sounding Method. *International journal of water resources and engineering*. 4(1), 1 –
372 7

373 Mark L. McFarland, Tony L. Provin, Diane E. Boellstorff. (2012). Drinking Water Problems.
374 *Agri life extension*

375 Material Testing Institute (MTI)-USA. Publication No. 43(1995). Material of construction for
376 once-Through Waters.

377 Mineral Saturation Index.” (2018). *A Dictionary of Earth Sciences*.

378 Neff, C. H. (1984). Assessment of Corrosion Monitoring Procedures for Potable Water
379 Systems. Pro. NACE Corrosion 84, paper no. 155

380 Obiefuna, G. I and Orazulike, D. M . (2011). Geochemical Studies of Groundwater Systems
381 of Semiarid Yola Area, Northeast. *Global Journal of Geological Sciences*. Vol.9. 1:
382 33 - 53

383 Oram, B. (2009) Corrosion, Saturation Index, Balanced Water in Drinking Water Systems..
384 Wilkes University

385 Oram, B.(2001). Corrosion, saturationindex, Balanced water in drinkin g water systems-
386 impact and potential Health concerns with corrosive water B.F.Environmental
387 consultants Inc.(unpublished).

388 Pisigan, R.A. and singley, J.E.(1984). Evaluation of Water corrosivity Using the Langelier
389 Index and Relative corrosion Rate Models. A paper presented at the meeting of the
390 National Association of corrosion Engineers. New Orleans. L.A.

391 Radian Annand (2004).Examination of the Corrosion Mechanism and Corrosion Conteol of
392 Ms in saltwater Environments. Department of Chemical, Universwity of Toronto
393 (unpublished).

394 Subyami, Ali M.(2004). Hydrochemical Identification and Salinity problem of
395 Groundwaterin WadYalamBasin, westernSaudi Arabia. *Journal of Arid*
396 *Environments*.60 (2005) 53-66. Elsevier.

397 Swistock, B.R.,W.E. Sharpe, and P.D. Robillard.(2001). Corrosive Water Problems. F 137,
398 Penn State

399 USEPA Report EPA/600/9-85/007 (1985) Plumbing Material and Drinking Water Quality:
400 proceedings of a Seminar.

401 World Health Organisation (2008). Guidelines for Drinking Water Quality Incorporating 1st
402 and 2nd addenda.

403 World Health Organisation (2011). Giudelines for Drinking Water Quality. Fourth Edition.

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409 **Table1: Results of physicochemical analyses of borehole waters from Eket, Nigeria**

Sampling Borehole	DO (mg/l)	pH	Redox potential (mv)	Ca (mg/l)	Conductivity (µs/cm)	TDS (mg/l)	Alkalinity (mg/l)	Temperature (° C)
12 Ekpeyu street (S1)	4.11	4.69	160	16.8	154	80.3	49.98	21.5
Ofonmbuk street (S2)	3.32	4.42	196	15.4	167	83.2	55.1	26
Hospital Road (S3)	4.23	4.58	153	15.4	130	65.1	75.1	24.4
Ikot Ibiok (S4)	4.42	4.23	113	8.1	51.43	26.1	50.01	27.2
Iko Ewak(S5)	3.06	5.34	40	3.61	62.7	30.1	49.98	26.5
Liverpool(S6)	3.60	4.12	113	8.06	102.7	52.0	70.01	26.3
Iquita street(S7)	3.45	4.14	110	4.12	63.1	31.6	72.01	26.3
Etebi street(S8)	5.43	4.32	165	10.4	170.8	85.2	50.01	24.0
Nung Uso street(S9)	4.58	4.72	75.2	20.02	150.6	75.3	50.03	24.3
Ikot Ebok(S10)	4.80	4.25	162	13.6	123.5	62	64.98	24
Mean	4.1	4.48	128.72	11.55	117.58	59.09	58.72	25.05
Standard deviation	1.06	0.37	47.26	5.55	45.29	22.99	10.57	1.72

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Table2: Calculated pHs values of the sampled waters

Sampling Borehole	A	B	C	D	pHs
12 Ekpeyu street (S1)	0.090	2.156	0.825	1.699	9.02
Ofonmbuk street (S2)	0.092	2.069	0.788	1.741	8.93
Hospital Road(S3)	0.081	2.099	0.788	1.876	8.82
Ikot Ibiok(S4)	0.042	2.046	0.508	1.699	9.18
Iko Ewak(S5)	0.048	2.059	0.158	1.699	9.55
Liverpool(S6)	0.072	2.063	0.506	1.845	9.08
Iquita street(S7)	0.049	2.063	0.215	1.858	9.34
Etebi street(S8)	0.093	2.107	0.617	1.699	9.18
Nung Uso street(S9)	0.088	2.102	0.901	1.699	8.88
Ikot Ebok(S10)	0.079	2.107	0.734	1.813	8.94
Mean	0.073	2.087	0.604	1.763	9.09
Standard deviation	0.02	0.03	0.26	0.08	0.23

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428 **Table3: Calculated LSI values of Eket underground waters**

Sampling borehole	p H	PHs	LSI (saturation index)
12 Ekpeyu street(S1)	4.69	9.02	- 4.33
Ofonmbuk street (S2)	4.42	8.93	- 4.51
Hospital Road(S3)	4.58	8.82	- 4.28
Ikot Ibiok(S4)	4.23	9.18	- 4.95
Iko Ewak(S5)	5.34	9.55	- 4.21
Liverpool(S6)	4.12	9.08	- 4.96
Iquita street(S7)	4.14	9.34	- 5.2
Etebi street(S8)	4.32	9.18	- 4.86
Nung Uso street(S9)	4.72	8.88	- 4.16
Ikot Ebok(S10)	4.25	8.94	- 4.69
Mean	4.48	9.09	- 4.62
Standard deviation	0.37	0.23	0.37

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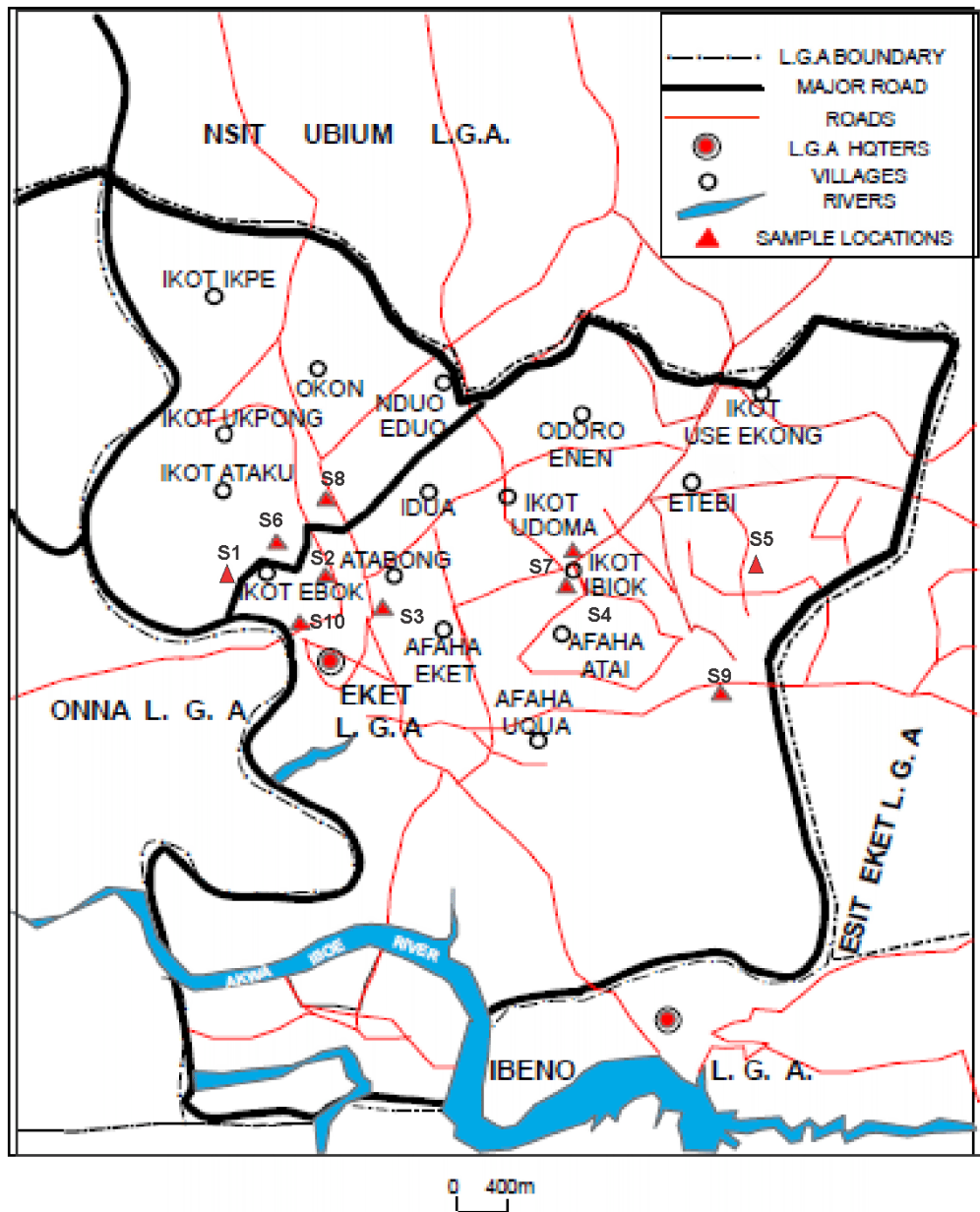
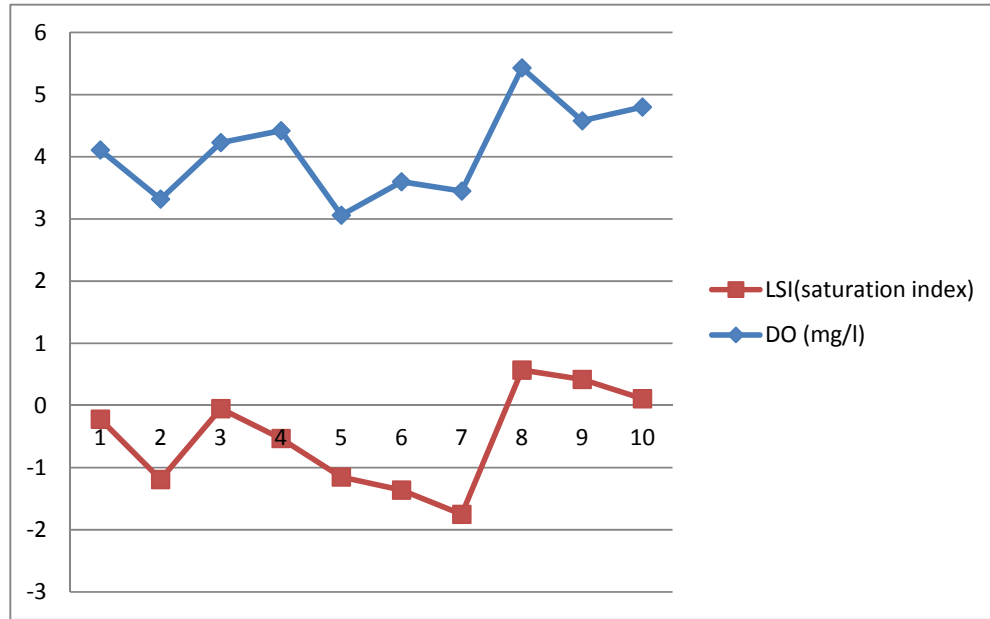


FIG. 1: Map showing the studied locations in Eket LGA

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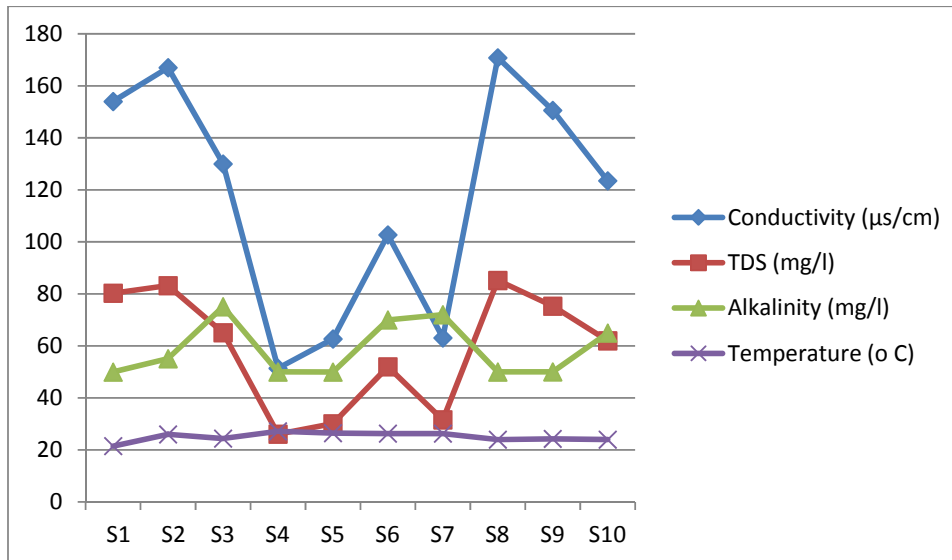


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Fig. 2 : DO , LSI from Study Area

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Fig. 3 : Cond, TDS , Alkalinity and Temp. of Waters from Study Area

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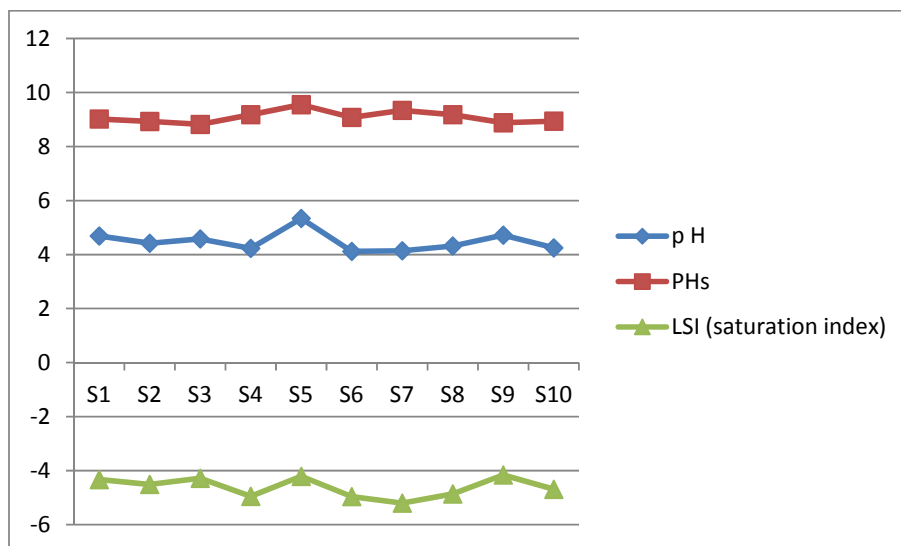


Fig. 4 : p H, p Hs, and Calculated LSI of Waters from the Study Area.

Appendix 1

LSI Values and the Effect of Corrosion Potential or Scaling Potential

LSI	Description	General Recommendation	Risk
-5	Severe corrosion	Treat water	Plumbing annihilation
-4	Severe corrosion	Treat water	Plumbing annihilation
-3	Moderate corrosion	Treatment recommended	Long term pipe death
-2	Moderate corrosion	Treatment recommended	Long term pipe death
-1	Milder corrosion	Treatment may be needed	The long finger
-0.5	Milder corrosion	Treatment may not be required	Hope all is well
-0.3	Milder corrosion	Treatment may not be required	Looking good
0	Near balanced	No treatment	Just right
0.3	Some faint coating	No treatment	Looking good
0.5	Mild coating	No treatment	Hope all goes well

1	Mild scale coating	Treatment may be needed	Long finger
2	Moderate scaling	Treatment needed	Possible trouble
3	Moderate scaling	Treatment advised	Long term pipe death
4	High scale coating	Treatment advisable	Plumbing annihilation

Source : Galway Waters, 2014

Appendix 2

$$PHs = (9.3 + A + B) - (C + D),$$

$$A = (\log_{10} [TDS] - 1)/10$$

$$B = - 13.12 \log_{10} (T^{\circ}C + 273) + 34.55,$$

$$C = \log_{10} [Ca] - 0.40,$$

$$D = \log_{10} [Alkalinity], \quad \text{All the concentration are in milligram per litre.}$$