



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

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Authors' contributions

This work was carried out in collaboration between all authors. Author UME designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors IOI and UGI managed the analyses of the study. Author TH managed the literature searches. All authors read and approved the final manuscript.

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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 a 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

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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.

Keywords: Calcium carbonate saturation index; saturation pH; corrosion; borehole waters.

1. 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 [1]. Corrosion attacks the metal substrate and gradually thins the entire metal surface, often causing red-coloured stains in iron or steel plumbing systems or blue-green stains in copper and brass plumbing systems [2,3]. Another type of corrosion attacks are small areas where deep pits can develop and penetrate pipe or tank walls. This type of corrosion may not add significant amounts of iron or copper to the water but can create small holes in a pipe or tank that destroy its usefulness, cause water leaks, and result in major water damage to a home or business [4]. In another case, corrosion may cause oxidation of metals, which involves a conversion of copper or other base metal to an oxidised form in a process similar to the rusting of steel [5,6]. It often results in reduced water flow through supply lines and destruction of water valves and other machined water flow control surfaces, thus resulting in internal and external leaks at valves and faucets.

Corrosion is a complex series of reactions between the water metal surfaces and minerals in which the water is stored or transported. With respect to the corrosion potential of drinking and process water, the primary concerns include potential presence of toxic metals, such as lead and copper, deterioration of and damage to the household plumbing and aesthetic problems such as stained laundry, bitter taste and greenish-blue stains around basins and drains [6,7].

Nearly all metals will corrode to some degree. The rate and extend of the corrosion depends on the degree of physical and chemical characteristics of the media, metal and environment. In soft water, corrosion occurs because of lack of dissolved cations, such as calcium and magnesium in the water [8]. In water that forms scales, a precipitate of calcium or

magnesium carbonate forms on the inside of the piping system [2]. This scale can inhibit the corrosion of the metal substrate, because it acts as a barrier, but can also clog piping system. However, high concentrations of sodium, chloride, or other ions will increase the conductivity of the water and promoting corrosion [7].

Water quality is very critical in influencing the operating efficiency and life of equipment, including pumps, piping systems and wells. Therefore, acidic water with a pH value of less than 6 is a usually corrosive while, alkaline water with pH greater than 8 is less corrosive [9].

Corrosive water can be defined as a condition of water quality which will dissolve metals from the metallic plumbing at an excessive rate. Some of the factors that make water corrosive include, low pH (below 6), a lower alkalinity value (below 35 mg/L CaCO_3), a high specific conductivity as a measure of total dissolved solids (TDS) and high temperature [10].

An indicator of water corrosiveness that is widely in use is calcium carbonate (CaCO_3) saturation index (SI), also referred to as calcium carbonate solubility equilibrium, and is highly important in many phases of water chemistry [11]. It is used to evaluate the scale-forming and scale-dissolving tendencies of water. Langelier saturation index is based on the investigation of the carbonate equilibrium in water, to assess the true pH or true hardness of water [6]. Carbonate equilibrium in water involves gaseous carbon (IV) oxide, aqueous carbon (IV) oxide, carbonic acid (H_2CO_3), bicarbonates, carbonate, solid calcium carbonate or magnesium carbonate [6,12].

Several indices like Ryznar Index, Stiff and Davis Stability Index and Langelier Saturation Index are used to describe the behaviour of calcium carbonate in water, oil, or gas mixtures [8]. In 1936 Wilfred Langelier developed a method for predicting pH at which water is saturated in calcium carbonate, which is called saturation pH (pHs), [13].

Langelier saturation index (LSI) is the difference between the actual system pH and the saturation pH (pH_s). pH is a common measure of water quality that is often related to corrosion of plumbing system components like lead and copper [12]. Lead is a dangerous metal with many health effects, especially in children. Lead usually occurs in drinking water supplies from corrosion of lead solder or lead impurities in plumbing fixtures [11,14].

The assessment of scale-forming and scale-dissolving tendencies of water is useful in corrosion control program and also in preventing calcium carbonate scaling in piping, and equipment such as industrial heat exchangers, boiler feed water heaters and domestic water heaters, including tea kettle [2]. In this consideration, there are three classes of water that can be defined by calcium saturation index namely, waters oversaturated with CaCO₃, which tend to precipitate CaCO₃ scale; waters under saturated with CaCO₃, which tend to dissolve calcium carbonate and waters saturated with CaCO₃, which are in equilibrium with calcium carbonate and have neither CaCO₃ precipitate nor dissolving tendencies [12,15].

The aim of this study is to estimate the calcium carbonate saturation index of some borehole waters in Eket and also evaluate the influence of water quality parameters such as calcium, total dissolved solids, alkalinity, pH, temperature and conductivity on the calcium carbonate solubility equilibrium and to establish the corrosion tendency of water in the study area. Companies in the area use water from this source as process and portable water, the local communities also use water from this source for both portable and domestic uses. The huge costs of corrosion control for industrial and domestic equipment in the area lend some impetus to this study.

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

The Langelier saturation index (LSI) is a formula developed from studies conducted by Dr. Wilfred Langelier in the early 20th Century. The LSI is the basis for water balance and saturation [12].

The Langelier saturation index (LSI) is an equilibrium model derived from the theoretical

concept of saturation and provides an indication of the degree of saturation of water with respect to calcium carbonate. It can be shown that the Langelier saturation index (LSI) approximates the base 10 logarithm of the calcite saturation level [12].

The Langelier saturation level approaches the concept of saturation using pH as a main variable. The LSI can be interpreted as the pH change required, bringing water to equilibrium [8].

- If LSI is negative: no potential to scale, the water will dissolve CaCO₃
- If LSI is positive: scale can be formed and CaCO₃ precipitation will occur
- If LSI is close to zero: borderline scale potential.

The LSI is probably the most widely used indicator of cooling water scale potential. It is purely an equilibrium index and deals only with the thermodynamic driving force for calcium carbonate scale formation and growth (Appendix 1). It provides no indication on how much scale or calcium carbonate will actually precipitate to bring water to equilibrium. It simply indicates the driving force for scale formation and growth in terms of pH as a master variable. In order to calculate the LSI, it is necessary to know the alkalinity (mg/l Ca²⁺ as CaCO₃), total dissolved solids (mg/l TDS), the actual pH, and the temperature of the water (°C).

LSI is expressed as in equation (i):

$$LSI = pH - pH_s \quad (i)$$

Where:

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

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

Where:

- $A = (\log_{10} [TDS] - 1) / 10$ (iii)
- $B = - 13.12 \log_{10} (^{\circ}C + 273) + 34.55$ (iv)
- $C = \log_{10} [Ca^{2+} \text{ as } CaCO_3] - 0.4$ (v)
- $D = \log_{10} [\text{alkalinity as } CaCO_3]$ (vi)

[12].

The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than the simple

loss of a mass of metal [16]. Failures of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small.

Corrosion is a natural process that occurs when metals are in contact with oxygen and react to form metal oxides. All water is corrosive to some degree as it contains some amount of dissolved oxygen. The rate of corrosion depends on a number of factors including acidity or low pH, electrical conductivity, oxygen concentration and water temperature [7].

In addition to corrosion, dissolution of metals occurs when the water is extremely low in dissolved salts or in the presence of certain water-borne ions. All materials have a particular level of solubility and in the case of corroded plumbing; the concentration of the copper or other plumbing material metal is lower in the water than that material's solubility. As a result, the plumbing material is gradually dissolved. While this process is usually very slow, certain water-borne ions can react with and bind the recently dissolved metal allowing more rapid loss. While corrosion and dissolution are fundamentally different, the end result is similar and so both are often discussed together under the general term corrosion [17].

Ground water can be acidic or alkaline in pH depending on several factors. Rainfall is typically acidic because it picks up carbon (IV) oxide as it falls to the earth, forming carbonic acid. As water percolates through the soil, it also can come in contact with other acid-forming materials such as decaying organic matter [18]. In areas where underground strata contain limestone or dolomite, the acid is neutralised 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 [19].

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 15.6°C to 60°C. Above 60°C, the rate of corrosion doubles for every 10°C increase in water temperature [20].

2. 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°31' and 4°45' North and between longitude 7°52' and 8°02' East (Fig. 1). The study area is underlain by the sedimentary formation of Late Tertiary and Holocene ages [21]. 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 [22,23]. 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 characterised by a succession of sub parallel sand ridges (Fig. 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 [24]. 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 an 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, and plantain to maize and vegetables [22,25].

3. 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 sterilised by cleaning with cotton wool soaked in a methylated spirit to avoid contamination. The water from the boreholes 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 500 ml polyethylene bottles and stored under ice in coolers before being transported to the laboratory for analysis within two hours.

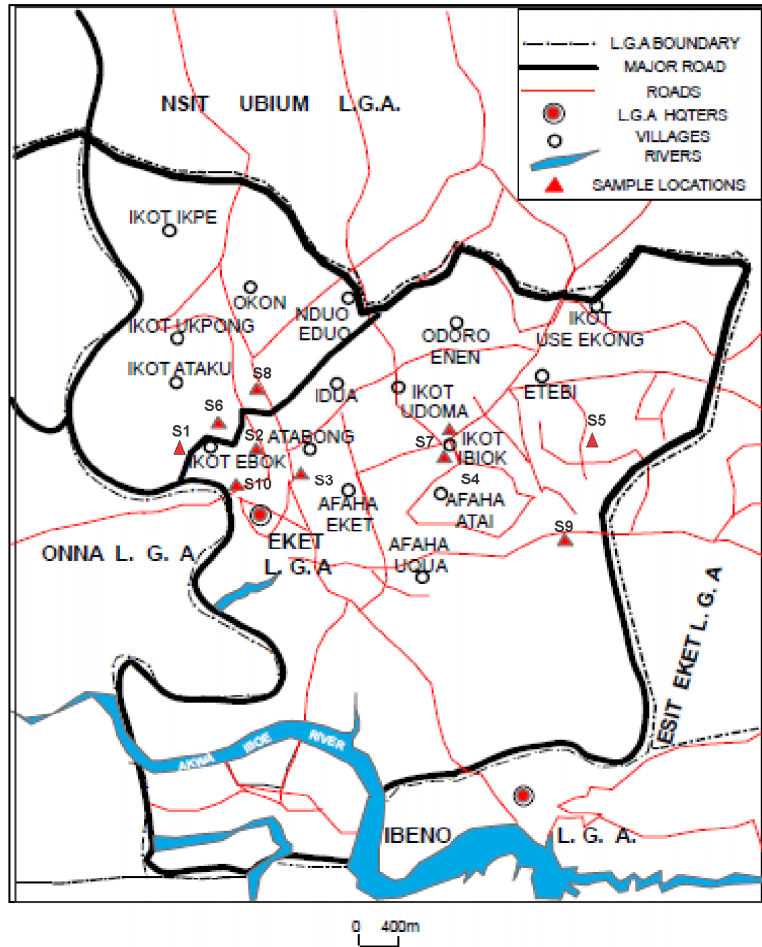


Fig. 1. Map showing the studies locations in Eket LGA

pH Total dissolved solid (TDS), Dissolved oxygen (DO) and Conductivity

Such physico-chemical parameters like pH, conductivity, dissolved oxygen (DO) total dissolved solids (TDS) and temperature were determined at the field using a multimeter (DDJ-303A).

Calcium content

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 422.7 nm [2,12].

Total Alkalinity

Total alkalinity was determined by titrimetric method, according to method No.2320 B of

APHA, AWWA.WEF. [12]. In this study, since all the water samples analyzed had pH below 8.3, only total alkalinity was determined by titration as stated.

Total Hardness

Total hardness content of the waters was determined by disodium ethylenediaminetetraacetic acid (EDTA) titration according to method No.2340 C of APHA, AWWA.WEF. [12].

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 and total dissolved solid [12].

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 [12]. 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 [8].

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

$$pH_S = pK_2 - pK_S + p[Ca^{2+}] + p[HCO_3^-] + 5 pfm \quad (vii)$$

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/L

$[HCO_3^-]$ is the concentration of bicarbonate ion in g-mole/L

fm 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 pfm required to solve equations are available in literature [4]. 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 neutralise 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 [2,12].

Statistical Analyses

The mean and standard deviation of the parameters determined were computed for each station in which water was sampled. The Pearson's correlation coefficient (R) was calculated to establish the correlation pattern

between some water parameters. Analysis of variance (ANOVA) was also ran to establish the variation of water parameters between sampling stations, at a significance level of $P < 0.05$.

4. 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 Figs. 2, 3 and 4 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 ± 1.17°C. The pH of waters had a range of 4.12 to 4.72, with a mean of 4.48 ± 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 [15].

The calcium concentration of the waters ranged from 3.61 mg/L to 20.02 mg/L, with a mean of 11.55 mg/L ± 1.55 mg/L (Table 1). The conductivity of the waters had a range of 51.43 µS/cm to 170.8 µS/cm, with a mean of 117.58 µS/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 [7].

The dissolved oxygen determined for the waters had a range of 3.06 mg/L to 5.47 mg/L, with a mean of 4.10 ± 1.06 mg/L. The mean dissolved oxygen was lower than the WHO limit of 5 mg/L (Appendix 3) for portable waters, with most stations sampled having values that were far below the limit of 5 mg/L. The redox potential determined for the waters had a range of 40 mV to 196 mV, with the mean of 128.7 ± 47.26 mV. The redox potential values indicated an oxidising environment that aids corrosion of metal substrates.

The total dissolved solid (TDS) of the waters had a range of 26.1 mg/L to 85.2 mg/L, with a mean of 59.09 ± 4.09 mg/L. The range of alkalinity recorded for the waters was 49.98 mg/L to 75.1 mg/L, with a mean alkalinity of 58.72 mg/L ± 2.57 mg/L (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 Organization [26], indicating that the waters are fresh [18].

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 $+0.5$ [12]. 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 [2,27].

Table 1. Results of physicochemical analyses of borehole waters from Eket, Nigeria

Sampling borehole	DO (mg/L)	pH	Redox potential (mV)	Ca (mg/L)	Conductivity ($\mu\text{S}/\text{cm}$)	TDS (mg/L)	Alkalinity (mg/L)	Temperature ($^{\circ}\text{C}$)
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

Table 2. 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

Table 3. 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

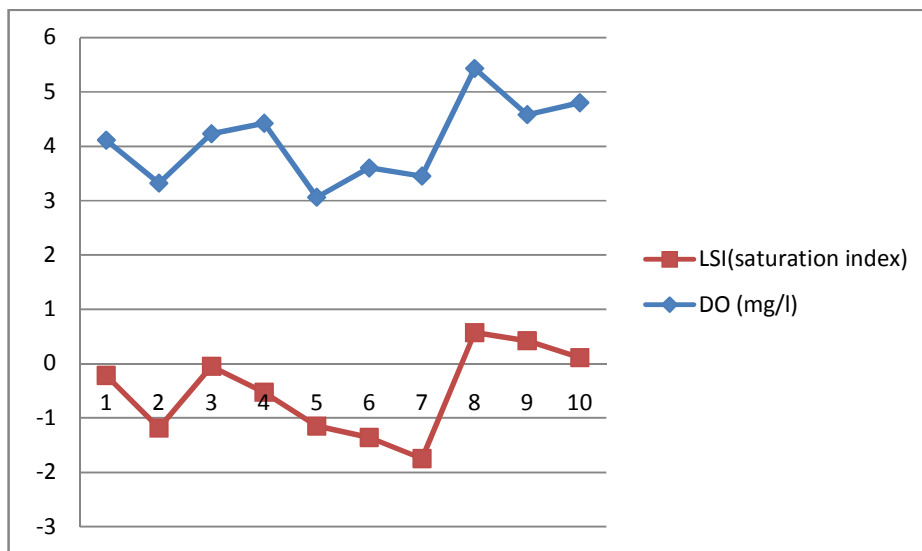


Fig. 2. DO, LSI from study area

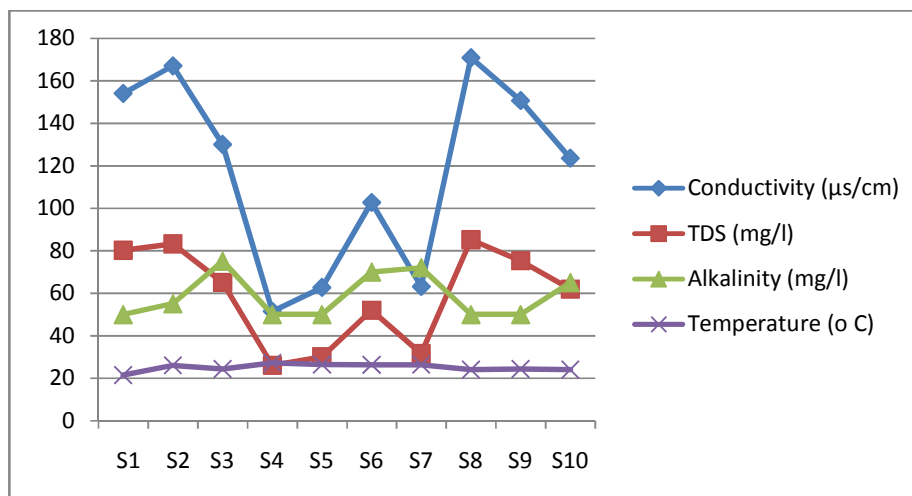


Fig. 3. Cond, TDS, alkalinity and temp. of waters from study area

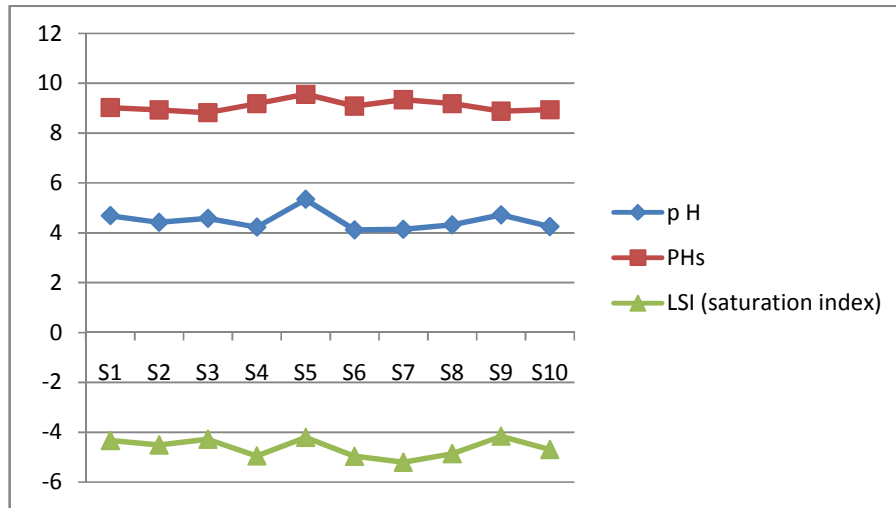


Fig. 4. p H, p Hs, and calculated LSI of waters from the study area

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 [7]. 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 [2] and elsewhere [28].

In a similar study reported on the geochemical studies of groundwater systems of semiarid Yola area, Northeast, Nigeria [18], 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 [2,12]. 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 [10]. Mineral dissolution in groundwater is affected by the presence of carbon dioxide and the temperature of the underground water [29]. In the study area, the temperature of the waters ranged from 21.5°C to 27.2°C with a mean of $25.05^{\circ}\text{C} \pm 1.17^{\circ}\text{C}$, 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 World Health Organisation [26].

The total alkalinity in the waters of the study area show moderate negative correlation ($R = -0.62$) with LSI, and also showed no significant negative correlation with water saturation pH ($R = -0.22$). The implication of the low total alkalinity of the waters will likely aggravate the corrosive tendency of the water. 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 [18,30].

The ANOVA analyses ($P < 0.05$) of the water parameters between sampling stations show no significant variation, thereby corroborating the fact that the waters from the boreholes are from the same aquifer [21].

5. 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. 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. 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.

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 neutralising 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.

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 non-conductive organic coatings like paint and primers.

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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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

APPENDIX 2

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

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

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

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

$$D = \log_{10} [Alkalinity], \quad \text{All the concentration are in mg/L.}$$

APPENDIX 3

WHO Permissible Limits for Potable Water

S/N	Parameter	Unit	WHO Limits
1	p H		6.5 - 8.5
2	Temp (°C)	°C	< 40
3	Cond (uS/cm)	u S/cm	< 2000
4	OH Alkalinity	mg CaCO ₃ /l	< 500
5	Dissolved oxygen	mg/l	> 5.00
6	Salinity	%	0
7	TDS	mg/l	< 500
8	Redox Potential	m V	
9	Total Hardness	mg CaCO ₃ /l	80 - 100
10	Calcium	mg CaCO ₃ /l	< 200
11	Magnesium	mg CaCO ₃ /l	< 150
12	Bicarbonate Alkalinity	mg CaCO ₃ /l	< 500
13	Acidity	mg CaCO ₃ /l	
14	Carbonate Alkalinity	mg CaCO ₃ /l	< 500
15	Chloride	mg/l	< 250
16	Iron	mg/l	< 0.3
17	Sulphide	mg/l	
18	Sulphate	mg/l	< 250
19	Phosphate	mg/l	
20	Nitrate	mg/l	< 10.0
21	Free CO ₂	mg/l	
22	Total CO ₂	mg/l	
23	BOD ₅	mg/l	6
24	COD	mg/l	10

Source : WHO, 2011

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