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

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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. CaCO₃ 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 formula for Langelier Saturation Index (LSI) is given by equation 1

\[ \text{LSI} = \text{pH} - \text{pHs} \]  \hspace{1cm} (1)

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

\[ \text{pHs} = (9.3 + E + F) - (G+H) \] \hspace{1cm} (2)

where \( E = \log_{10}(\text{TDS}) - 1 \)
\( F = -13.12 \cdot \log_{10}(\text{Ca}^{2+}+273) + 34.55 \)
\( G = \log_{10}(\text{Ca}^{2+} \text{ as CaCO}_3) - 0.4 \)
\( H = \log_{10}(\text{alkalinity as CaCO}_3) \)

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 LSI is a negative value (i.e. \(< 0\)), it indicates that the water is aggressive or corrosive. It will tend to dissolve CaCO₃ 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° 16’ N and 6° 21’ N and longitudes 8° 05’ E and 8° 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).

![Geologic map of Abakaliki](image)

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°C to 38°C while rainy season temperature range is from 16°C to 28°C. 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° – 70° 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

D. 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.

C. 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° to 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

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

<table>
<thead>
<tr>
<th>S/ N</th>
<th>Location</th>
<th>Water Sample No</th>
<th>pH</th>
<th>Temp (°C)</th>
<th>TDS (mg/l)</th>
<th>Dissolved Oxygen (mg/l)</th>
<th>Na+ (mg/l)</th>
<th>Mg2+ (mg/l)</th>
<th>Ca2+ (mg/l)</th>
<th>HCO3- (mg/l)</th>
<th>SO42- (mg/l)</th>
<th>Cl- (mg/l)</th>
<th>Fe (Total mg/l)</th>
<th>NO3- (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ntezi Abu</td>
<td>HL1</td>
<td>7.4</td>
<td>21</td>
<td>985.7</td>
<td>1072</td>
<td>217</td>
<td>36</td>
<td>42</td>
<td>20</td>
<td>80</td>
<td>70.4</td>
<td>0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>Prison Hospital</td>
<td>HL2</td>
<td>7.5</td>
<td>20</td>
<td>911.5</td>
<td>996.4</td>
<td>204</td>
<td>54.3</td>
<td>37</td>
<td>25</td>
<td>88</td>
<td>265</td>
<td>BDL</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>Obiahu West</td>
<td>HL3</td>
<td>7.0</td>
<td>24</td>
<td>1102</td>
<td>600</td>
<td>147.2</td>
<td>70.1</td>
<td>32</td>
<td>24.3</td>
<td>90.4</td>
<td>287</td>
<td>3.20</td>
<td>2.4</td>
</tr>
<tr>
<td>4</td>
<td>Obiahu Central</td>
<td>HL4</td>
<td>7.4</td>
<td>20</td>
<td>1004.7</td>
<td>673.8</td>
<td>132.6</td>
<td>65</td>
<td>29.6</td>
<td>19.8</td>
<td>46.7</td>
<td>320</td>
<td>4.5</td>
<td>2.8</td>
</tr>
<tr>
<td>5</td>
<td>Igbaku</td>
<td>HL5</td>
<td>7.4</td>
<td>22</td>
<td>827.8</td>
<td>1102</td>
<td>125</td>
<td>32</td>
<td>27.3</td>
<td>40.2</td>
<td>62</td>
<td>110.7</td>
<td>BDL</td>
<td>BDL</td>
</tr>
<tr>
<td>6</td>
<td>Abakaliki (BH)</td>
<td>HL6</td>
<td>7.3</td>
<td>19</td>
<td>902.3</td>
<td>1048</td>
<td>142</td>
<td>27</td>
<td>52.4</td>
<td>17.5</td>
<td>57.3</td>
<td>63</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>Ebonyi River</td>
<td>HL7</td>
<td>7.3</td>
<td>20</td>
<td>1209</td>
<td>576.8</td>
<td>184.3</td>
<td>84</td>
<td>72.1</td>
<td>82</td>
<td>102</td>
<td>38.6</td>
<td>4.8</td>
<td>3.7</td>
</tr>
<tr>
<td>8</td>
<td>Ugbuloke</td>
<td>HL8</td>
<td>7.4</td>
<td>21</td>
<td>1001.2</td>
<td>1148.2</td>
<td>89</td>
<td>102</td>
<td>85</td>
<td>75</td>
<td>153</td>
<td>77</td>
<td>0.2</td>
<td>2.5</td>
</tr>
<tr>
<td>9</td>
<td>Mgbabor</td>
<td>HL9</td>
<td>7.6</td>
<td>22</td>
<td>877.6</td>
<td>1204.3</td>
<td>67.4</td>
<td>94</td>
<td>66.4</td>
<td>33.2</td>
<td>387</td>
<td>92.3</td>
<td>0.1</td>
<td>3.7</td>
</tr>
<tr>
<td>10</td>
<td>Ndiachi Igbagu</td>
<td>HL10</td>
<td>7.1</td>
<td>22</td>
<td>1324</td>
<td>753.4</td>
<td>120</td>
<td>25</td>
<td>57.2</td>
<td>16.4</td>
<td>104</td>
<td>98.4</td>
<td>7.3</td>
<td>4.3</td>
</tr>
</tbody>
</table>

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110
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

<table>
<thead>
<tr>
<th>S/N</th>
<th>Location</th>
<th>Sample No</th>
<th>pH</th>
<th>pHs</th>
<th>L. S. I</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ntezi Abu</td>
<td>HL1</td>
<td>7.4</td>
<td>8.9</td>
<td>-1.5</td>
<td>Serious Corrosion</td>
</tr>
<tr>
<td>2</td>
<td>Prison/Hospital</td>
<td>HL2</td>
<td>7.1</td>
<td>8.8</td>
<td>-1.7</td>
<td>Serious Corrosion</td>
</tr>
<tr>
<td>3</td>
<td>Obiagu West</td>
<td>HL3</td>
<td>7.5</td>
<td>8.9</td>
<td>-1.4</td>
<td>Serious Corrosion</td>
</tr>
<tr>
<td>S/N</td>
<td>Location</td>
<td>Sample No</td>
<td>CaCO₃-hardness/ Interpretation mg/L</td>
<td>Ryznar Stability Index/ Interpretation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------</td>
<td>-----------</td>
<td>-------------------------------------</td>
<td>----------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Ntezi Abu</td>
<td>HL1</td>
<td>253 – Very hard water</td>
<td>10 – Very aggressive water, intolerable corrosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Prison/ Hospital</td>
<td>HL2</td>
<td>315 – Very hard water</td>
<td>11 – Very aggressive water, intolerable corrosion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 CaCO₃ or other minerals as they come in contact with them. In order to further investigate the situation, the CaCO₃ 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 CaCO₃ hardness and the Ryznar Stability Index for the area. The CaCO₃ - 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.
Obiagu West  
HL3  
367 – Very hard water  
10 – Very aggressive water, intolerable corrosion  

Obiagu Central  
HL4  
341 – Very hard water  
11 – Very aggressive water, intolerable corrosion  

Igbagu  
HL5  
199 – Very hard water  
9.7 – Very aggressive water, intolerable corrosion  

Abakaliki (BH)  
HL6  
242 – Very hard water  
10 – Very aggressive water, intolerable corrosion  

Ebenyi River  
HL7  
525 – Very hard water  
8.9 – Heavy Corrosion  

Ugbuloke  
HL8  
631 – Very hard water  
8.6 – Heavy Corrosion  

Mgbabor  
HL9  
551 – Very hard water  
10 – Intolerable corrosion  

Ndiachi Igbagu  
HL10  
246 – Very hard water  
9.9 – Very aggressive water, intolerable corrosion  

Rice Farm Well  
HL11  
283 – Very hard water  
11 – Very aggressive water, intolerable corrosion  

Ofei Otu  
HL12  
394 – Very hard water  
9.3 – Very aggressive water, intolerable corrosion  

Akpa – Iyimagu  
HL13  
306 – Very hard water  
9.8 – Very aggressive water, intolerable corrosion  

Waterworks Area  
HL14  
390 – Very hard water  
10 – Very aggressive water, intolerable corrosion  

Achara near Govt. Admin Estate Pond  
HL15  
305 – Very hard water  
7.3 – Significant Corrosion  

School (primary well)  
HL16  
330 – Very hard water  
10 – Very aggressive water, intolerable corrosion  

Pond near Quarry, Abakaliki  
HL17  
306 – Very hard water  
9.0 – Heavy Corrosion  

Pond near Quarry, Abakaliki  
HL18  
302 – Very hard water  
8.4 – Heavy Corrosion  

Abia Stream (intermittent)  
HL19  
277 – Very hard water  
10 – Very aggressive water, intolerable corrosion  

Intermittent Stream Near Quarry, Abakaliki  
HL20  
240 – Very hard water  
11 – Very aggressive water, intolerable corrosion  

Limestone Quarry Abakaliki  
HL21  
454 – Very hard water  
7.0 – Little Scale formation or slight corrosion  

Intermittent Stream Abia  
HL22  
232 – Very hard water  
11 – Very aggressive water, intolerable corrosion  

Near Juju Hill  
HL23  
272 – Very hard water  
9.9 – Very aggressive water, intolerable corrosion  

Achi-Stream  
HL24  
251 – Very hard water  
8.8 – Heavy Corrosion  

Iyi-Owu  
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.
RSI = 2 * 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)

<table>
<thead>
<tr>
<th>Ryznar (1944)</th>
<th>Interpretation</th>
<th>b. Carrier (1965)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5.5</td>
<td>Heavy Scaling</td>
<td>4.0 – 5.0</td>
<td>Heavy Scale will be deposited</td>
</tr>
<tr>
<td>5.5 – 6.2</td>
<td>Scale will form</td>
<td>5.0 – 6.0</td>
<td>Light Scale</td>
</tr>
<tr>
<td>6.2 – 6.8</td>
<td>Water will neither corrode metal or deposit scales</td>
<td>6.0 – 7.0</td>
<td>Little scale or mild Corrosion</td>
</tr>
<tr>
<td>6.8 – 8.5</td>
<td>Water is aggressive</td>
<td>7.0 – 7.5</td>
<td>Significant Corrosion will take place</td>
</tr>
<tr>
<td>8.5</td>
<td>Water is very aggressive</td>
<td>7.5 – 9.0</td>
<td>Heavy Corrosion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.0</td>
<td>Intolerable Corrosion</td>
</tr>
</tbody>
</table>

From the foregoing it is obvious that with the RSI range of the study area from 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.

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