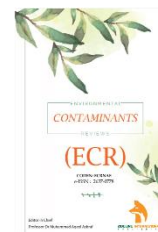


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RESEARCH ARTICLE

STUDIES OF CORROSION AND SCALING POTENTIAL OF GROUNDWATER IN WARRI, NIGER DELTA REGION, NIGERIA

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ABSTRACT

This study was conducted to evaluate the corrosion and scaling potential of groundwater at Warri, Niger Delta region of Nigeria from 15 sample points. Groundwater samples were collected for physicochemical analysis and the measurement was carried out using America Public Health Association standard (APHA) method. The corrosion and scaling tendency of groundwater was determined using chloride-sulfate mass ratio (CSMR), Revelle index (RI) and Larson-Skold index (LSI). Findings revealed that CSMR ranges from 0.00 to 2.84, RI ranges from 0.8 to 3.28 and LSI ranges from 0.81 to 3.28. Based on investigation, CSMR, RI and LSI showed that effect of corrosion potential of groundwater within the study area is low to insubstantial.

KEYWORDS

Index, Corrosion, Scaling potential, Warri and Nigeria.

1. INTRODUCTION

Water quality assessment is one of the most important aspects of water studies (Eyankware, 2019). Studies have shown that the quality of water resources is much dependent on their physicochemical properties (Aghazadeh et al., 2017). The physicochemical properties of water tend to be altered by various processes which include corrosion and scaling. Corrosion is the physicochemical interaction of metal and its environs which is usually electrochemical in nature and can alter the properties of metal (Pirialam et al., 2008; Karegar et al., 2008). One of the most affected water quality issues globally is scaling (Karegar et al., 2008; Banglore and Usha, 2018; Peng et al., 2010). Shankar [7] further pointed out that scale can be formed from a variety of dissolved chemical species, but two reliable indicators are hardness and alkalinity (Shankar, 2014). Calcium carbonate is the most common form of scale deposition attributable to groundwater.

Stability of water is the tendency of water to either dissolve or deposit minerals varying with its chemical makeup. According to a study, water which tends to dissolve minerals is considered corrosive and that tends to deposit mineral is considered scaling (Banglore and Usha, 2018). A group researcher further pointed out that corrosion tends to release the metal pipe particles into the fluids (Mazlomi et al., 2008). If the corrosion occurs quickly, it forms a hole and then perforation of pipes which is considered as a path for water contamination in a state of negative suction; but if the water has a tendency to scaling, the diameter of pipe will reduce over the time due to the formation of sediments layers in the inner part of the pipes which ultimately results to the reduction of flow rate. Corrosive water can react with household plumbing and metal fixtures resulting in the deterioration of the pipes and increased metal content of the water.

Consumption of water with elevated levels of toxic metals, such as lead and copper, has been shown to cause both acute and chronic health problems. In addition, taste and odors, as well as the appearance of delivered water,

are adversely affected. The scale could clog or reduce the flow in pipes, cause build-up in hot water heaters and reduce their efficiency and impart an alkali taste to the water (Demadis, 2004; Demadis et al., 2007; Edwards, 2004). Factors influencing the release of corrosion scale materials derive from a wide variety of issues associated with water chemistry, biological processes, composition of pipe scale and the hydraulic flow characteristics within the pipe. Chemical properties related to corrosion and scale formation of water include pH, alkalinity, dissolved oxygen content and total dissolved solids (TDS). The main physical characteristics are temperature, flow and velocity of water (Peng et al., 2010). In general, two approaches have been used to evaluate the corrosion and scale-forming tendency of water: direct laboratory methods and mathematical indices. For this study, mathematical indices were used these include; chloride-sulfate mass-ratio (CSMR), Revelle index (RI) and Larson-Skold index (LSI)

1.1 Study area, vegetation and climate

The study area is located in Delta State, geographically it lies between latitude 5°25'N – 5°40'N and between longitude 5°29'E – 5°44'E as shown in Figure 1. The study area falls within the tropical region, and it experiences two seasons namely the wet and dry season. The wet season is between April and October while dry season is between November and March. Annual rainfall usually exceeds 3000 mm, temperature sometimes exceeds 28°C with 80% humidity (Iloeje, 1981). The vegetation is typically mangrove swamp forest, though it has been extensively altered by human activities such as farming, lumbering and exploration activities but in many cases, has been replaced by grassland.

1.2 Geological setting of the area

Warri and its surrounding area lies within the Tertiary to recent clastic sediment piles of the Niger Delta Basin which consists of the Akata Formation, the Agbada Formation, the Benin Formation from oldest to recent and sometimes, the Somebreiro Warri Deltaic Plain Sands, with

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elevation 30 m above sea level (Figure 2) The Akata Formation rests is the basal unit of the Niger Delta stratigraphic sequence (Allen, 1965; Reymont, 1965; Short and Stauble, 1965). The age of the formation is Paleocene with about 7000 m thick. The overlying Eocene Agbada Formation is the oil reservoir of the Niger Delta basin which consists of an alternating sequence of deltaic sands and shales that is about 3700 m thick.

The Oligocene Benin Formation consists of highly porous sands and gravels with a few intercalations of clay. The uppermost section which is quaternary in age is about 40-150 m thick and comprises of alternating sequences of sand and silt/clay with the later becoming increasingly more prominent towards then coast (Etu-Efeotor and Akpokodje, 1990). The Benin Formation houses the most prolific aquifer in the Niger Delta region with a variable thickness that exceeds 2000 m found especially in the northern part of Warri where it is very shallow. The Somebreiro-Warri Deltaic Plain Sand is Quaternary in age and directly underlies the study area (Wigwe, 1975).

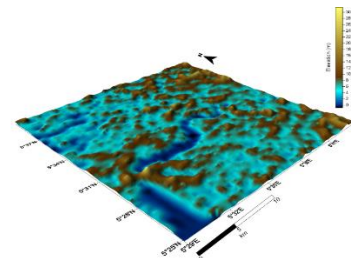


Figure 2: Elevation Map of the Study Area

2. MATERIALS AND METHOD

2.1 Sampling and laboratory analysis

A total of 15 groundwater samples were collected through bore-wells within the study area to ascertain the quality. Systematic approach was employed for the sampling. The analysis was carried out in the R and laboratory of the National Steel Raw Materials Exploration Agency, Kaduna according to APHA procedure as follows: The metallic cations (Mg^{2+} and Ca^{2+}) and the anions (Cl^- and HCO_3^-) were determined using EDTA titrimetric method (APHA, 2012). Nitrate and Sulphate ions were determined using Ion-selective electrode (Orion 4 star) and turbidimetric method (UV-Vis spectrometer) respectively. The alkali earths (K^+ and Na^+) were determined by Jenway flame clinical photometer (PFP7 model). Total dissolved solids (TDS) and the electrical conductivity (Ec) were measured with TDS meter (model HQ14D53000000, USA) and HACH conductivity meter respectively. The degree of acidity and alkalinity of the groundwater samples was assessed in the field using the pH meter Hach sensION + PH1 portable pH meter and Hach sensION + 5050 T Portable Combination pH Electrode

$$\text{Chloride-sulfate mass-ratio (CSMR)} = \frac{Cl^-}{SO_4^{2-}}$$

$$\text{Revelle index (RI)} = \frac{Cl^-}{HCO_3^-}$$

$$\text{Larson-Skold index (LSI)} = \frac{Cl^- + SO_4^{2-}}{HCO_3^-}$$

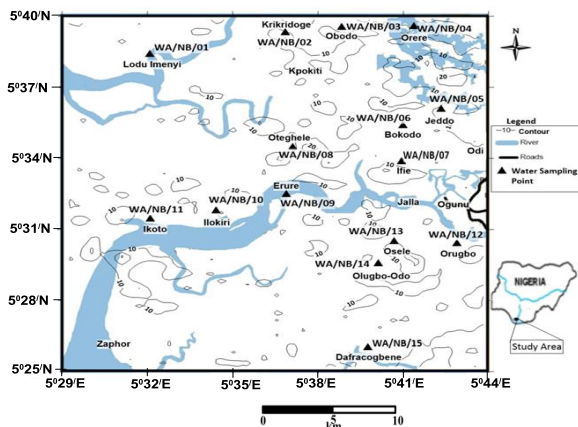


Figure 1: Location map of the study area showing sample points (Eyankware et al., 2020).

3. RESULTS AND DISCUSSION

Table 1. Physical and chemical characteristics of water quality of distribution networks of Warri (Eyankware et al., 2020). Where BDL is below detection limit

Sample Location	EC	pH	TDS	Temp (°C)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	NO ³⁻ (mg/L)	HCO ³⁻ (mg/L)	K ⁺ (mg/L)	SO ₄ ²⁻ (mg/L)	Cl ⁻ (mg/L)
WA/NB/01	827	7.01	613	27	1.20	1.58	5.05	BDL	1.83	0.39	BDL	6.02
WA/NB/02	1013	6.34	527	28	1.18	1.21	4.99	0.62	1.92	0.39	BDL	5.76
WA/NB/03	809	6.72	549	30	1.60	0.36	5.51	BDL	3.05	0.78	BDL	8.15
WA/NB/04	1018	7.18	698	26	2.80	1.58	7.35	BL	3.66	0.39	BDL	6.38
WA/NB/05	897	6.23	730	29	1.20	1.33	4.59	0.62	5.49	1.17	BDL	6.73
WA/NB/06	909	6.96	843	29	1.20	1.21	3.67	BDL	4.27	1.56	BDL	6.73
WA/NB/07	787	6.21	604	26	1.18	1.33	5.01	BDL	3.66	1.95	BDL	3.54
WA/NB/08	601	6.68	583	25	2.20	1.69	1.72	BDL	3.05	0.78	BDL	4.25
WA/NB/09	618	7.31	663	27	3.40	1.69	2.29	BDL	1.92	1.56	0.96	2.83
WA/NB/10	549	6.82	587	28	2.60	0.39	1.83	BDL	3.66	0.78	BDL	4.60
WA/NB/11	492	6.37	529	25	2.80	0.12	1.14	BDL	3.05	2.34	BDL	2.48
WA/NB/12	568	6.54	583	29	4.80	0.42	0.91	BDL	3.66	BDL	BDL	3.54
WA/NB/13	536	6.17	499	27	3.60	0.97	0.45	0.62	1.92	0.39	BDL	1.77
WA/NB/14	438	6.90	501	28	5.81	1.33	0.38	BDL	1.83	0.78	BDL	2.83
WA/NB/15	391	6.31	408	30	6.61	0.58	0.22	BDL	3.05	0.39	BDL	4.60
Minimum	536	6.17	499	27	3.6	0.97	0.45	0.62	1.92	1.83	0.96	1.77
Maximum	438	6.9	501	28	5.81	1.33	0.38	0.62	1.83	5.49	0.96	8.15
Average	391	6.31	408	30	6.61	0.58	0.22		3.05	3.13		4.71

Table 2: Results of Water stability indices calculations samples obtained from Warri

Sample Code	Index CSMR	RI	LSI
WA/NB/01	0.00	3.28	3.28
WA/NB/02	0.00	3.00	3.00
WA/NB/03	0.00	2.67	2.67
WA/NB/04	0.00	1.74	1.74
WA/NB/05	0.00	1.22	1.22
WA/NB/06	0.00	1.57	1.57
WA/NB/07	0.00	0.96	0.96
WA/NB/08	0.00	1.39	1.39
WA/NB/09	2.94	1.47	1.97
WA/NB/10	0.00	1.25	1.25
WA/NB/11	0.00	0.81	0.81
WA/NB/12	0.00	0.94	0.94
WA/NB/13	0.00	0.92	0.92
WA/NB/14	0.00	1.54	1.54
WA/NB/15	0.00	1.50	1.50
Minimum	0.00	0.81	0.81
Maximum	2.94	3.28	3.28
Average	0.34	1.66	1.69

Table 3: Indexes criteria with the interpretation of the water status

Index	Equation	Index value	Status
Chloride-sulfate mass-ratio (CSMR)	$\frac{Cl^-}{SO_4^{2-}}$	CSMR < 0.5	Water has no galvanic corrosion potential
		CSMR > 0.5	Water with galvanic corrosion potential
Revelle index (RI)	$\frac{Cl^-}{HCO_3^-}$	RI < 0.5	Unaffected by salinization
		0.5-6.6	Slightly affected by salinization
		> 6.6	Strongly affected by salinization
Larson-Skold index (LSI)	$\frac{Cl^- + SO_4^{2-}}{HCO_3^-}$	LSI < 0.8	Chlorides and sulfate unlikely to interfere with natural film formation
		0.8 < LSI < 1.2	Chlorides and sulfates may interfere with natural film formation
		LSI > 1.2	High local corrosion tendency expected as the index increases

3.1 Water stability Index

3.1.1 Chloride-sulfate mass ratio (CSMR)

According to some study, CSMR > 0.5 it signifies that water facilities are considered to promote galvanic corrosion of leaded connections in water distribution channel (Mahmood et al., 2018; Omid et al., 2019). The value of CSMR ranges from 0.00 to 2.94 with an average value of 0.34 Table 2. In this study, the 99 % of groundwater fell below 0.5 which implies groundwater within the study area has no galvanic corrosion potential, except for sample WA/NB/09 with value of 2.94 which indicate that groundwater showed galvanic corrosion potential (Tables 2, 3 and Figure 3a). This is due to the sea water intrusion via streams and industrial waste.

3.1.2 Revelle index (RI)

Akoteyon, [22] stated that when RI values < 0.5 it indicates that the water chemistry and the corrosion and scaling tendencies are not affected by salinization. In the same vein, the samples were subjected to RI evaluation to depict the possible impact of salinization on the water chemistry and the corrosivity and scaling potentials (Akoteyon, 2013). The RI values for this study ranged from 0.81 to 3.28 with a mean value of 1.96 Table 2 and Figure 3b. The RI values in this study further indicate that the origin of chloride in the water resources is not attributed to halite (rock salt) dissolution (Akoteyon et al., 2018; Mgbenu and Egbueri, 2019). The high chloride concentration in groundwater could be linked to salt intrusion from sea via streams and creeks (Offodile, 1992; Olobaniyi and Owoyemi, 2004).

3.1.3 Larson-Skold index (LSI)

The LSI index has been used to study the relationship between weak acidic anions (HCO_3^-) and strong acidic anions (Cl^- and SO_4^{2-}) in water (Sajil, 2019; Shams et al., 2012). In this study, the LSI results varied from 0.81 to 3.28, with an average value of 1.66. From Figure 3c, it was observed that area around Lodu Imenyi, Krikrdoge, Obodo and Kpokiti showed high LSI value, high local corrosion tendency expected as the index increases. When compared to other part of the study. Studies have shown that HCO_3^- influences the acidity of water, which in turn makes it corrosive (Mukate et al., 2019). In the same vein, the presence of sulfate in water may speedily corrosion activities (Atasoy and Yesilnacar, 2010; Ismail and El-Shamy, 2009; Kaur et al., 2009; Sahinkaya et al., 2007).

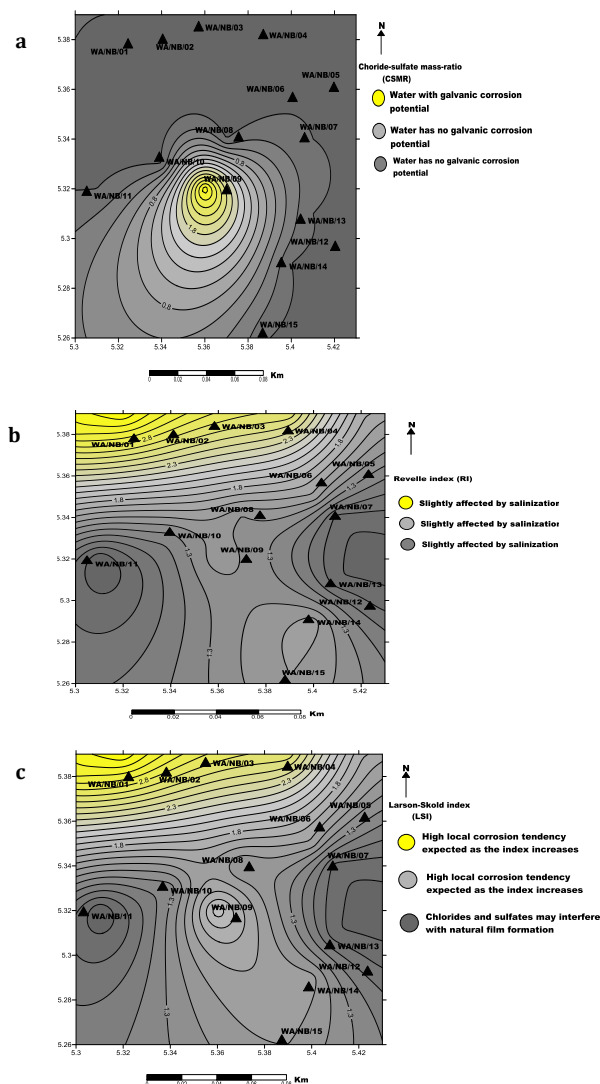


Figure 3: a, b and c showing spatial distribution of chloride-sulfate mass-ratio (CSMR), Revelle index (RI) and Larson-Skold index (LSI) across the Study area respectively.

4. CONCLUSION

From study carried out within the study area, the increasing industrialization taking place within the oil producing region of Niger delta, corrosivity and scaling features of the available groundwater were assessed using the CSMR, RI and LSI index. Findings revealed that values obtained from CSMR showed that groundwater within the study area has no galvanic corrosion potential except at location WA/NB/09 at Erure were groundwater showed galvanic corrosion potential. The values obtained from RI showed that groundwater is slightly affected by salinization, values from LSI revealed that if index increase there is possibility of high local corrosion tendency in groundwater within the study area. Generally, the study area has is slightly affected by low corrosion potential from chloride concentration within the study area. This research is believed to help in protection, treatment and sustainability of the groundwater in the study area. Moreover, water pipelines should be preserved with several modes of corrosion inhibition.

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