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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.

Key words: Index · Corrosion · Scaling potential · Warri and Nigeria

INTRODUCTION

Water quality assessment is one of the most important aspects of water studies [1]. Studies have shown that the quality of water resources is much dependent on their physicochemical properties [2]. 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 [3, 4]. One of the most affected water quality issues globally is scaling [4, 5, 6]. 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. 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 Bangalore and Usha [5], water which tends to dissolve minerals is considered corrosive and that tends to deposit mineral is considered scaling. Mazlomi, *et al*. [8] further pointed out that corrosion tends to release the metal pipe particles into the fluids. 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 odours, 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 [9, 10, 11]. 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 [6]. 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 was used these include; chloride-sulfate mass-ratio (CSMR), Revelle index (RI) and Larson-Skold index (LSI).

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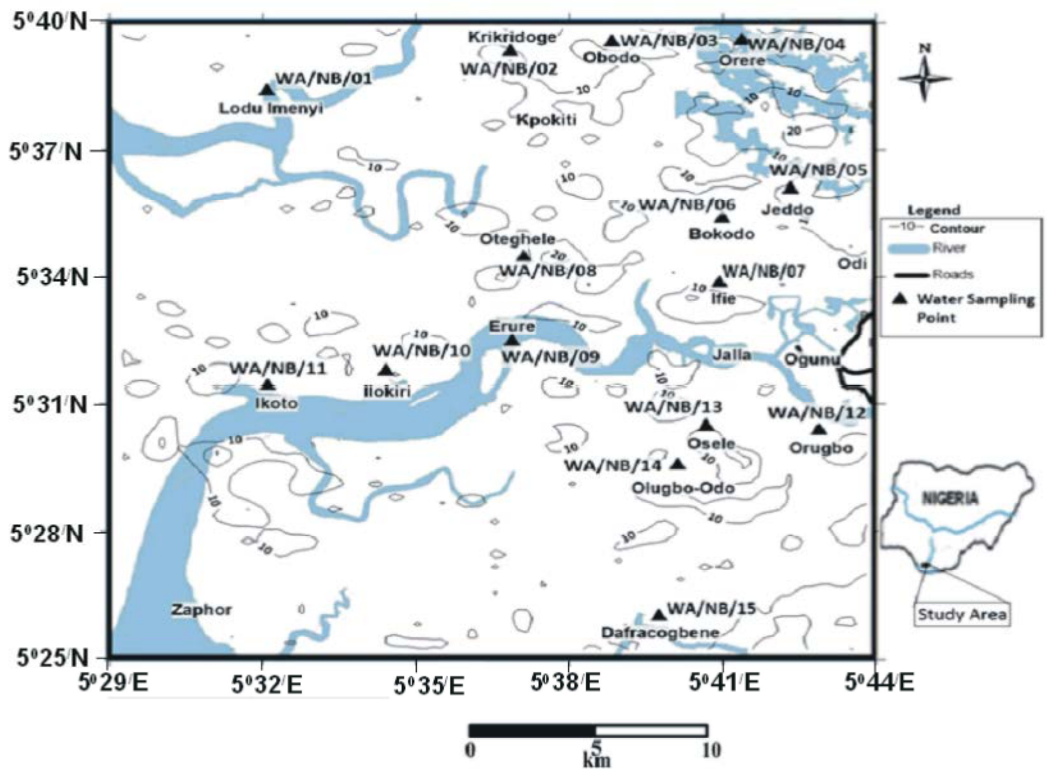

Fig. 1: Location map of the study area showing sample points. (Source: Eyankware, *et al*. [13])

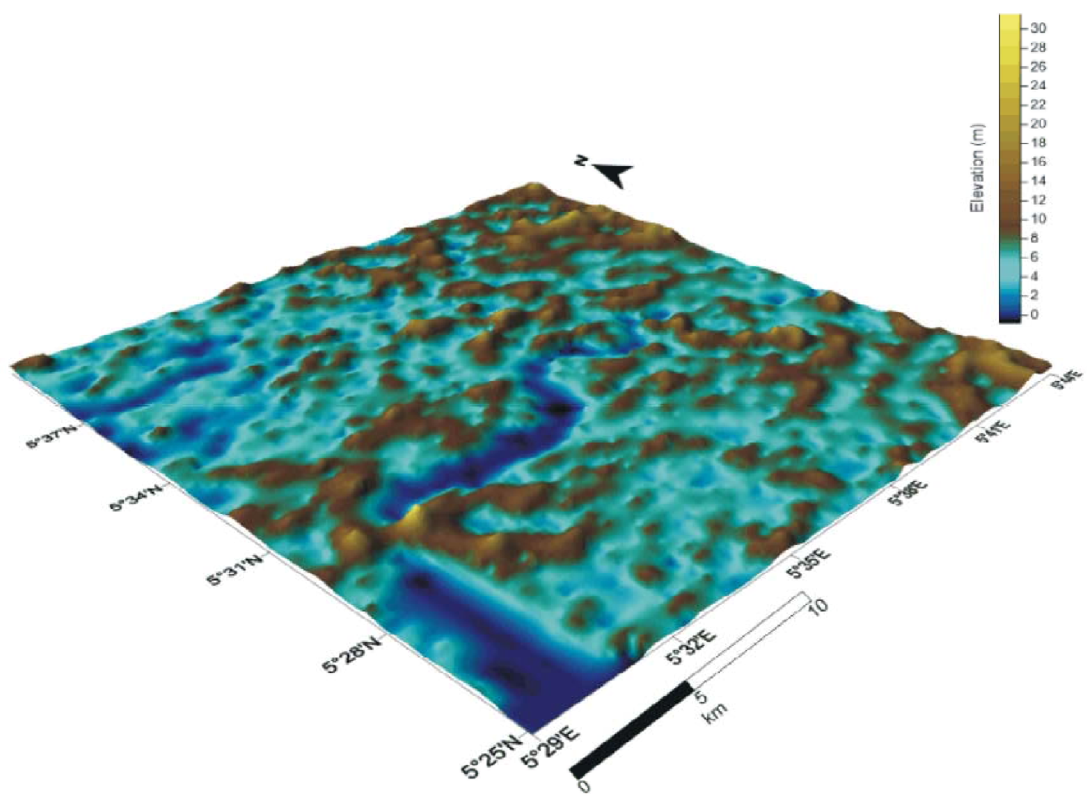

Fig. 2: Elevation Map of the Study Area

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 Fig. 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 [12]. 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.

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 [14, 15, 16], with elevation 30 m above sea level (Fig. 2). The Akata Formation rests is the basal unit of the Niger Delta stratigraphic sequence. 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 [17]. The Benin Formation houses the most proliferous 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 [18].

MATERIALS AND METHOD

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 [19] procedure as follows: The metallic cations (Mg^{2+} and Ca^{2+}) and the anions (Cl^- and HCO_3^-) were determined using EDTA titrimetric method. 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.

$$Chloride-sulfate\ mass-ratio\ \left(CSMR\right)=\frac{Cl^-}{SO4^{2-}}$$

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

$$Larson-Skold\ index\ \left(LSI\right)=\frac{Cl^-+SO4^{2-}}{HCO_3^-}$$

RESULTS AND DISCUSSION

Water Stability Index

Chloride-Sulfate Mass Ratio (CSMR): According to Mahmood, *et al*. [20]; Omid, *et al*. [21] CSMR >0.5 it signifies that water facilities are considered to promote galvanic corrosion of leaded connections in water distribution channel. 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 Fig. 3a). This is due to the sea water intrusion via streams and industrial waste.

Revelle Index (RI): Akoteyon, [22] stated that when RI values < 0.5 it indicate 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. The RI values for this study ranged from 0.81 to 3.28 with a mean value of 1.96 (Table 2 and Fig. 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 [23, 24]. The high chloride concentration in groundwater could be linked to salt intrusion from sea via streams and creeks [25, 26].

Table 1: Physical and chemical characteristics of water quality of distribution networks of Warri. (Data Source: Eyankware, *et al*. [13])

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)	C^{l-}(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

where BDL is below detection limit

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

	Index		
Sample Code	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)	$\frac{Cl^-}{SO4^{2-}}$	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)	$\frac{Cl^- + SO4^{2-}}{HCO_3^-}$	LSI<0.8	Chlorides and sulfate unlikely to interfere with natural formation film
		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

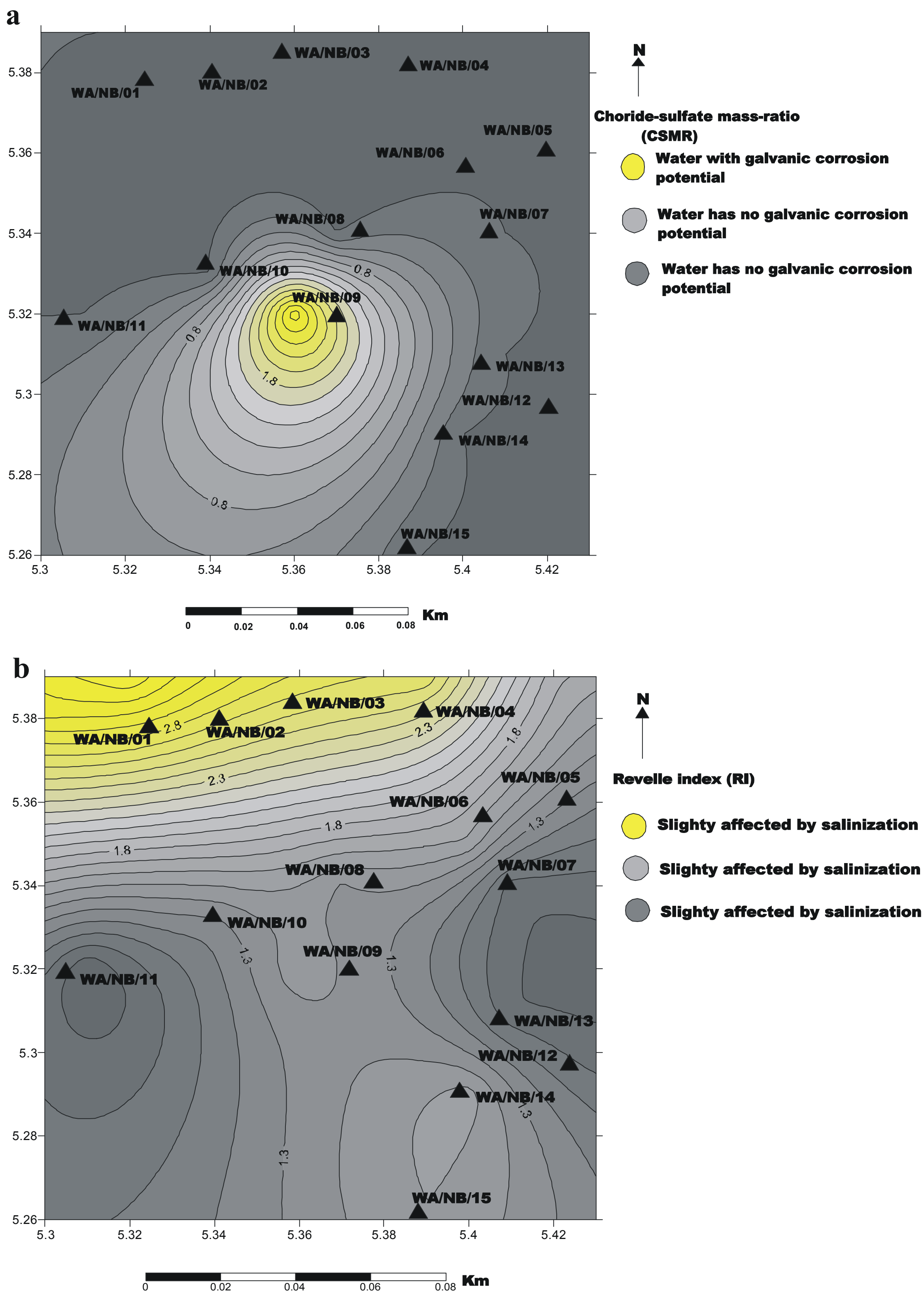

Fig. 3: Continued

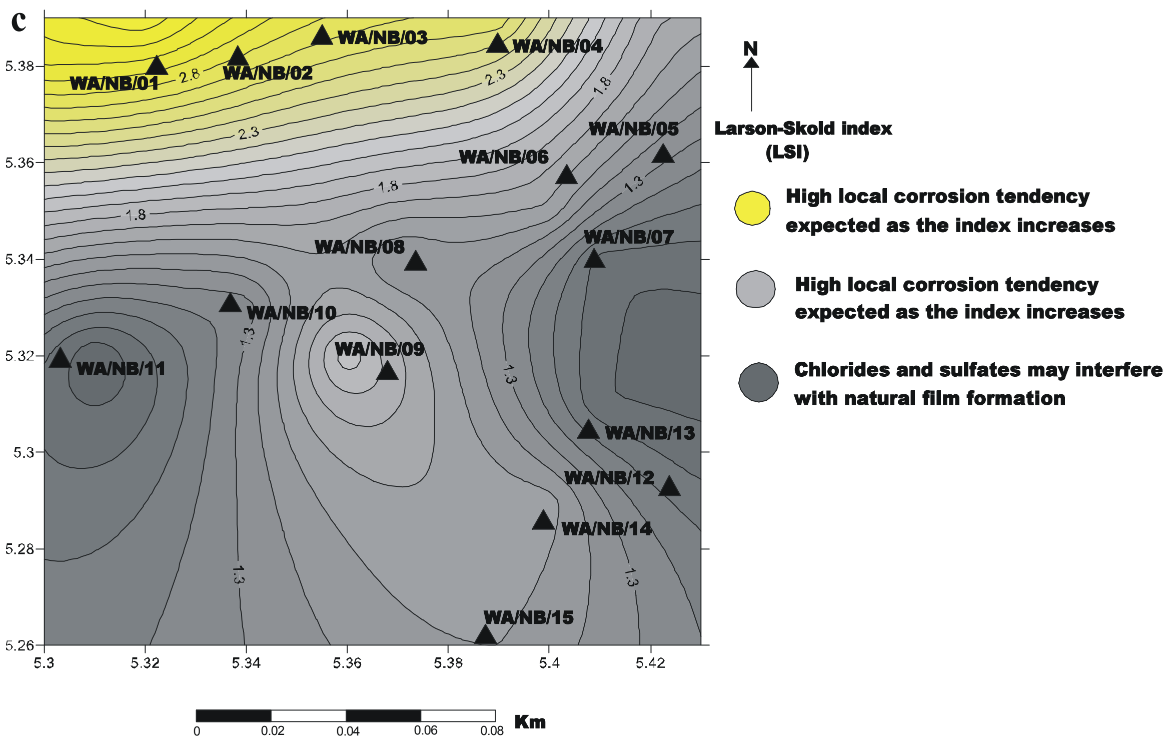

Fig. 3: a, b and c showing spatial distribution of chloride-sulfate mass-ratio (CSMR), Revelle index (RI) and Larson-Skold index (LSI) across the Study area respectively

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 [27, 28]. In this study, the LSI results varied from 0.81 to 3.28, with an average value of 1.66. From Fig. 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 [29]. In the same vein, the presence of sulfate in water may speedy corrosion activities [30, 31, 32, 33].

CONCLUSION

From study carried out within the study area, the increasing industrialization taking place in with in 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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