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Research Paper

Assessment of River Water Quality for Irrigation Using Multiple Indices

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ABSTRACT: *The use of a single irrigation water index in the characterization of irrigation water quality may not suffice because of the combined and individual impact of several primary water physiochemical parameters on the overall water quality. Therefore, this study aimed to assess irrigation water quality using multiple indices. Surface water samples were taken from ten locations and analyzed using standard methods. The potential effects of the water quality on soil salinity, sodicity, and permeability hazards were assessed by using derived parameters including sodium adsorption ratio (SAR), soluble sodium percentage (SSP), permeability index (PI), Kelly's ratio, potential salinity (PS) and cation ratio of soil structural stability (CROSS)indices.SAR and CROSS values ranging from 1-1.93 and 0.86-1.36 respectively showed that all ten water samples had no sodicity hazard potential. KR and SSP, with values ranging from 0.66-1.58and 39.82-111.32 respectively, showedfour and eight samples were without sodicity hazard potentials, respectively.PS and Electrical conductivity assessed salinity hazard potential, while permeability hazard potential was assessed by the combinative indices of PI, SAR, and CROSS. Results of the indices showed that all ten river water samples were without permeability hazard potentials. However, with salinity hazards, EC and PS values which ranged between 128-552.38 µS/cm and 0.52-0.84 showed that 90% and 100% of the river samples respectively were suitable for irrigation. Based on the results, using multiple indices is effective, but for sodicity hazard, the combinative use of SSP and KR should be accompanied by soil analysis.*

KEY WORDS: *Water Quality, Sodicity, Salinity, Permeability, Hazard Potential*

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I. INTRODUCTION

In the past, irrigated agriculture was focused mainly on water quantity, but irrigation water quality is as important as quantity in recent times. This is because crop growth and yield depend on soil condition, which is affected by watertotal dissolved salts and specific ion concentrations. A high salinity level in irrigation water creates osmotic pressure, which can be lethal to crops. Even if the salinity is low, high concentrations of some special ions can interfere with the ability of plants to absorb water from the soil. Salts dissolved in water accumulate in soil when the crop uses up the water or soil water is lost through evaporation, and over time thisaffects soil hydraulic properties such as leading a reduction in the water retention capacity and increased saturated hydraulic conductivity of irrigated soils[1]. Soils with distorted hydraulic properties cannot support optimum plant growth and development, affecting crop yield and food security.

Irrigation water sources are primarily groundwater, surface water, and wastewater. Water quality varies greatly with respect to the source.With industrialization and urbanization, most surface water sources are highly susceptible to intermittent contamination, making them unsuitable for several purposes. The suitability of water for any purpose, including irrigation, is determined not only by the total amount of contaminant present but also by the kind of contaminant. With irrigation, contaminants of concern are mainly salts. Various soil and cropping problems develop due toan increase in total salt content and specific ion concentration, among which are salinity and sodicity hazards. Salinity hazard is the effect of the total dissolved ions (cations and anions) in water. It reduces crop yield due to an increase in osmotic force in the direction proportional to the total salt concentration of the soil solution.On the other hand, Sodicity hazard is the effect of a high concentration of sodium ion relative to calcium and magnesium ions in the water. It results in soil dispersion problems that lead to reduced soil infiltration characteristics. A decline in lettuce and cabbage yield was observed with continuous irrigation of saline water of different salinity [2]. In a related work, a 25% reduction in maize yield was observed when river water with a SAR value of 4.5 was used compared to when borehole water with SAR 1.86 was used [3]. After harvest, sodium content in the soil was also analyzed and observed to have increased.

Soil salinity and sodicity effectsare manageable challenges with several management options. The selection of management options starts with the assessment of irrigation water suitability.Irrigation water suitabilityis assessed primarily by electrical conductivity (EC) and sodiumadsorption ratio (SAR).While EC is a primary water parameter, SAR is a secondary or derived water hazard potentialindex. It is a ratio of sodium to the combination of magnesium and calcium, and it is the most commonly used index for irrigation quality assessment[4]. However, several secondary water hazard potential indicesare used in irrigation water quality assessment. These include Kelly's ratio (KR), permeability index (PI), soluble sodium percentage (SSP), Magnesium adsorption ratio (MAR), Residual Sodium carbonate (RSC), Potential salinity (PS), and irrigation water quality index (IWQI). These indices are often used independently in the assessment of salinity, sodicity, permeability, and specific ion toxicity hazard potentials [5-13]. Using a single irrigation water index to characterize an irrigation water quality may not suffice because of the several primary water physiochemical properties involved and their individual impact on the overall water quality. Using the RSC and SAR indices, Jha et al [14]observed that though SAR values of the three different groundwater used were within excellent to good range (2.84-14.54), the RSC values for two of the water types used were outside the safe range which was greater than 2.5. Similarly, soil irrigated with water within RSC safe limit gave a higher yield of wheat than soils irrigated with water outside the RSC safe limit. Their work deduced that a single parameter may not suffice in the characterization of irrigation water quality. Similar findings in discrepancy between SAR and sodium percentage (SP) was observed in the work of Batarseh et al., [15]. While 7 samples out of the 145 samples were classified as excellent using SAR, only 1 sample was found to in the good classification while there was none in the excellent classification. of the samples. On the otherhand in the assessment of the effect of season variation on the suitability of groundwater quality in Nalgonda district in India, SAR, RSC, and KR had 100% of the samples under excellent category during the pre-monsoon and post-monsoon seasons while EC and SP values showed 20 and 80% and 25 and 75% respectively for pre-monsoon and post-monsoon seasons [16].Using Pearson's correlation matrix, SAR and SP, ($r = 0.512$) were categorized together while PI and IWQI ($r = 0.170$) were put in another category [17].Obviously, the correlation values were low. Therefore, this study aims to assess irrigation water quality using multiple indices and to categorize.

II. MATERIALS AND METHOD

Water samples were taken from ten rivers in Rivers state, Nigeria. Rivers state is one of the major oil-producing states in the Niger Delta region of Southern Nigeria. The State capital, Port Harcourt, is the commercial hub of the oil and gas industry. The state has an approximate population of 5,198,716 (2006 census) with an average land area of 11077km^2. It is situated at an altitude 32m above sea level with numerous rivers that flow through it hence the name Rivers State. The state comprises twenty-three local government areas with a riverine (coastal) and upland dichotomy. The ten rivers selectedwere in ten different local government areas (LGAs) within the upland region. The major occupation in the rural areas of these LGAs is agriculture (crop production). These LGAs include Etche, Tai, Oyigbo, Gokhanna, Khanna, Omuma, Ikwerre, Emuoha, Ahoada, and Obio Akpor LGAs. The names of the rivers in each of these LGAs are Okehi, Seme, Afam, Bodo, Bori-Zaakpom, Umuelechi, Isiokpo, Rumuji, Ahoada, and Aluu river respectively. These rivers were the major rivers in each LGA. The map of Rivers State indicating these LGAs is as shown in Figure 1.

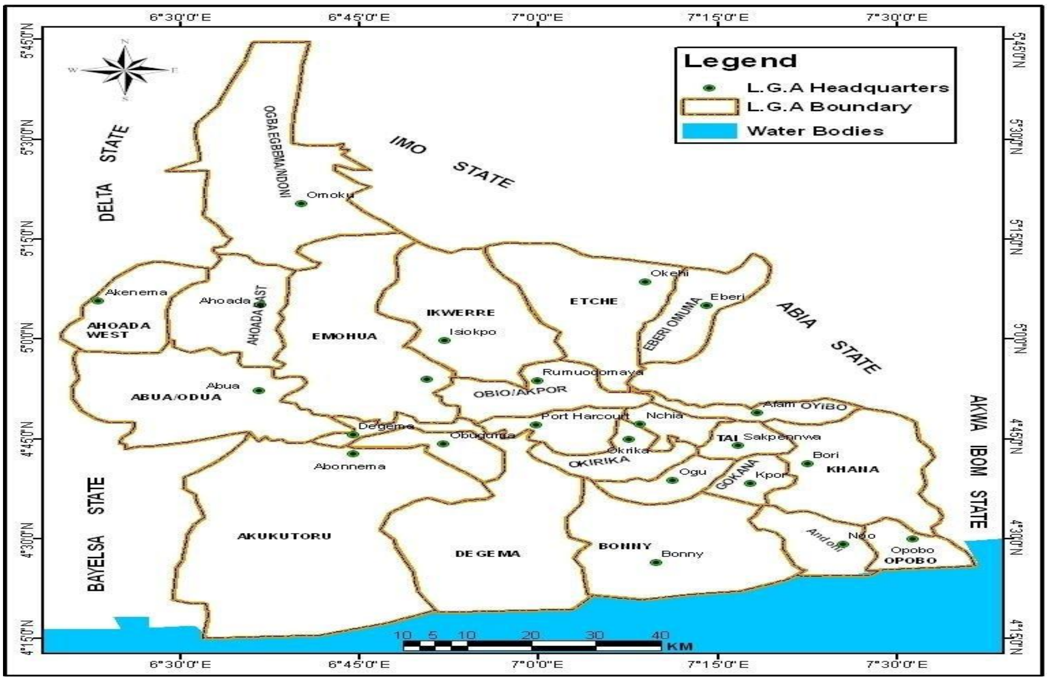

Figure 1: Map of Rivers state with the local government areas [18] (Ndubueze-ogaraku et al., 2017)

Standard field sampling techniques were adopted in the collection of river water samples. W*ater*sampling was done by facing the direction of flow of the river, and samples were taken at a depth of 10cm below the water surface at three different locations, 10m apart, making three replicates for each river. Samples were collected in thoroughly rinsed plastic bottles of 1litre capacity and kept in a cooling box while transported to the chemical/petrochemical engineering laboratory in Rivers State University, Port Harcourt, for analysis. Due to the nature of the rivers, the sampling locations were accessed using a paddling boat.

Water quality analysis:The most important issues related to the deterioration of irrigation water quality are salinity, sodicity, and exposure to specific toxic ions. As a result, this study's primary parameters of concern were major cations and anions such as sodium, calcium, magnesium, potassium, chloride, sulphate, bicarbonate, and nitrate. Other parameters include pH, Total dissolved solids (TDS), Total Hardness, Iron, and Electrical Conductivity (EC).

Standard water quality analysis methods were used to analyze each of the parameters. Concentrations of Sodium (Na^+) and potassium (K^+) ions were analyzed using Flame Photometer, while the UV-VIS spectrophotometer at 420nm wavelength was used to analyze the concentration of sulphate (SO_4^{2-}). Concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}) and total hardness (TH) were analyzed using volumetric acid (0.005mol/l EDTA) titration method. Chloride (Cl^-) and bicarbonate (HCO_3^-) concentrations were determined using the volumetric titration method with silver nitrate (0.1M) and sulphuric acid (0.02N) as titrates, respectively. TDS, EC, and pH were measured using a conductivitimeter (Hannan, Portugal) with a pH probe. Water quality analysis was validated using the charge balance equation (CBE) with acceptable water analyses having CBE less than $\pm 5\%$. The CBE is given as

$$CBE = \frac{\sum catio \rightarrow ns - \sum anions}{\sum cations + \sum anions} \times 100 \rightarrow (1)$$

III. RESULTS AND DISCUSSION

3.1 Primary water parameter validity

Prior to calculating the irrigation water hazard indices, the charge balance error (CBE) was used to validate the analysis of the primary water parameters. It was observed that CBE for the major cations and anions of the river water samples were all negative except for Ahoada and Aluu rivers, as shown in Fig. 2. The negative sign of the CBE indicates the dominance of anions in those river water chemistry while in Ahoada and Aluu river, cations dominated the river water chemistry. The absolute values were all less than 5%, implying that the accuracy of the analyses of the primary water parameters was greater than 95%.

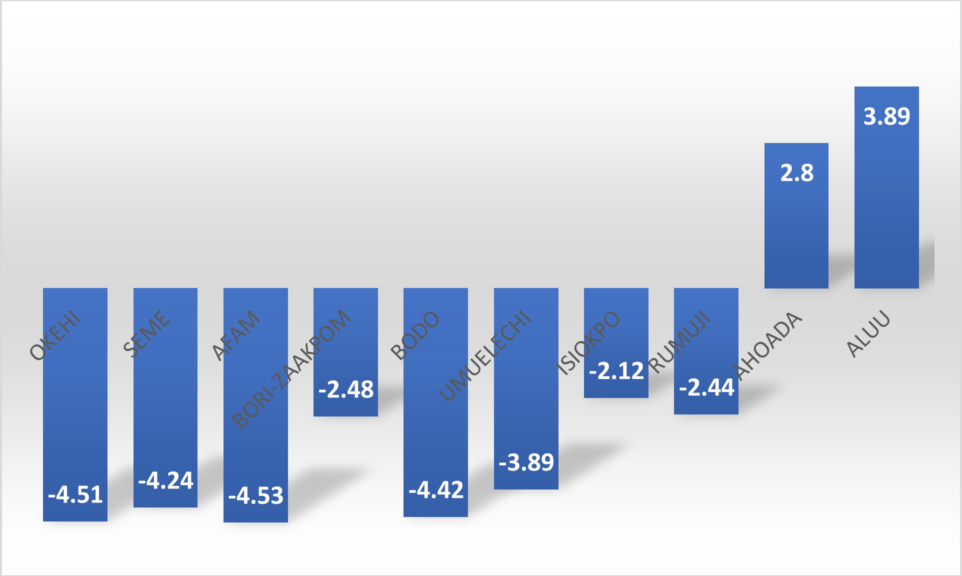

Figure 2: Charge balance error percentage of river water chemistry

3.2 Evaluation of Irrigation Water Quality Hazard Potential Indices

The effect of irrigation water quality on soil and crop yield is often a complicated challenge because of the several water parameters. This study considered only regulated derived parameters with tendencies to affect soil salinity, sodicity, and permeability. Table 1 showed the primary water parameters and their permissible limits set up by the World Health Organisation (WHO).

Table1:Primary River water parameters

Parameters	units	Okehi	Seme	Afam	Bodo	Bori-Zaakpom	Umuelechi	Isiokpo	Rumuji	Ahoada	Aluu	WHO
pH		6.18	6.93	7.3	7.07	6.60	6.68	6.70	6.28	6.23	6.54	6.5-8.5
Electrical conductivity	µS/cm	147.2	146.011	552.379	186.763	169.126	143.489	154.526	147.163	141	128	750
Sodium	mg/l	17.279	15.484	21.095	24.032	23.821	17.916	22.679	20.132	19.463	19.863	20
Calcium	mg/l	11.621	10.695	9.432	11.832	11.747	8.8	9.979	7.916	9.879	16.137	200
Magnesium	mg/l	6.795	4.521	4.505	4.926	5.037	2.353	1.547	2.142	4.926	7.337	250
Potassium	mg/l	0.048	5.111	4.263	3.397	5.163	3.126	3.158	3.101	2.238	4.337	10
Iron	mg/l	0.647	0.179	0.156	0.516	0.422	0.41	0.433	0.288	0.309	0.651	1.0
Chloride	mg/l	15.716	12.842	11.479	20.211	13.732	10.768	11.369	9.589	11.532	18.268	250
Sulphate	mg/l	28.447	16.765	22.447	25.672	29.674	20.579	35	41.962	20.16	24.67	200
Bicarbonate	mg/l	65	70.25	55.83	57.3	60.83	54.94	45	28.65	58.13	73	NA
Nitrate	mg/l	0.609	0.714	0.597	0.61	0.31	0.316	0.243	0.397	1.713	0.642	45

3.3Sodicity hazard

Water with high sodium ion concentration results in sodium ion adsorption on soil cation exchange sites causing the breakdown of soil aggregate particles. This effect is referred to as sodicity hazard. Sodicity hazard is commonly assessed by sodium adsorption ratio (SAR), Kelly's ratio, and soluble sodium percentage (SSP), as shown in equations 2-4.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad \rightarrow (2)$$

$$KR = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \qquad \rightarrow (3)$$

$$SSP = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100 \rightarrow (4)$$

The description of the values of these indices is presented in Table 2, while the calculated values of these indices are as displayed in Figs 3 and 4. SAR values for all water samples were less than 3 (Fig. 3), indicating the suitability of all river water for irrigation. On the other hand, only four out of the ten rivers were suitable with KR values < 1 while the remaining six rivers, including Afam, Bor-zaakpom, Bodo, Umuelechi, Isiokpo, and Rumuji rivers, were not suitable for irrigation having KR values > 1 (Fig.4). This is similar to the work of Shrivastav and Dubey (2012) in terms of the variation between SAR and RSC categorization of irrigation water quality. The SSP values of the samples ranged between 39.82-111.32% (Fig. 5). Seven out of the ten rivers were in the permissible category, while Okehi river with an SSP value of 39.82 was categorized as good.Again Rumuji and Isiokpo rivers were classified as poor with SSP>80%. Sodicity was further evaluated using a recent index known as cation ratio of soil structural stability (CROSS). CROSS was developed by Rengasamy and Marchuk [19]. In addition to Na, Ca, and Mg ions, CROSS introduced K ion and special coefficients in its formula (Eqn 5) with the concentrations of the ions measured in mmol/l as against meq/l as it applies to SAR, KR, and SSP.

$$CROSS = \frac{(Na + 0.56K)}{\sqrt{\frac{Ca+0.6Mg}{2}}} \rightarrow (5)$$

CROSS values in this study were between 0.86 and 1.36, indicating that all water samples were excellent for irrigation with respect to sodicity, similar to SAR value categorization. However, the values of SAR were higher than CROSS, as shown in Fig. 3.

Table 2: Sodicity hazard classification based on SAR, KR, and CROSS

SAR		KR		CROSS	
Limiting values	category	Limiting values	Category	Limiting values	Category
<3	Excellent; no problems	<1.0	Suitable	<3	Excellent; no problems
3-6	Good; moderate problems	>1.0	Unsuitable	3-6	Good; moderate problems
>6	Not suitable; severe problem			>6	Not suitable; severe problem

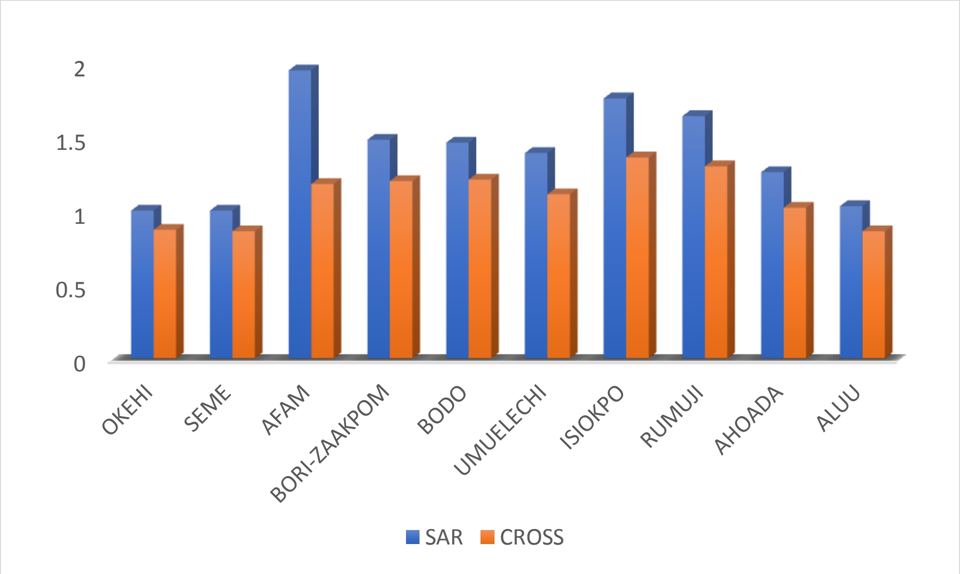

Fig. 3: SAR and CROSS values of riversamples

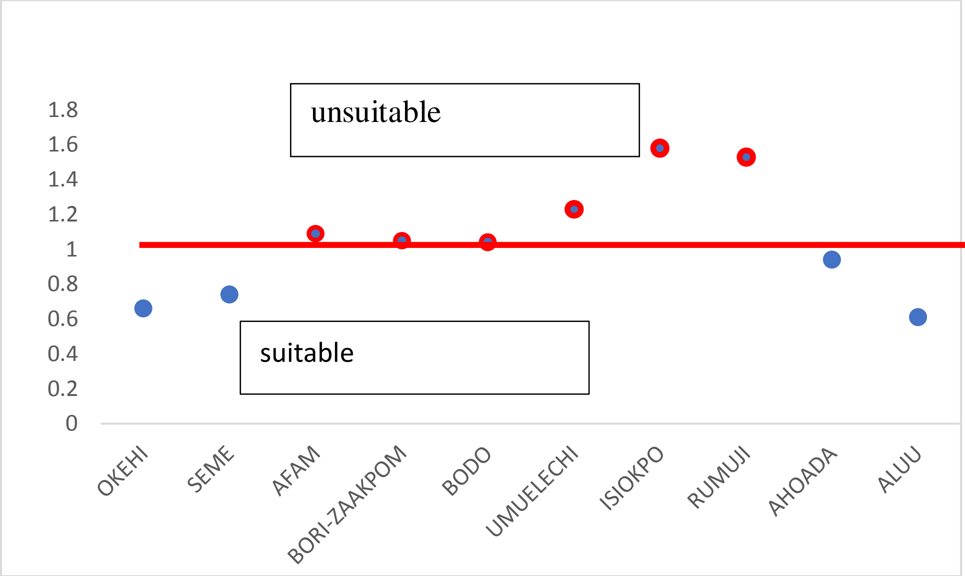

Fig. 4: KR values of river samples

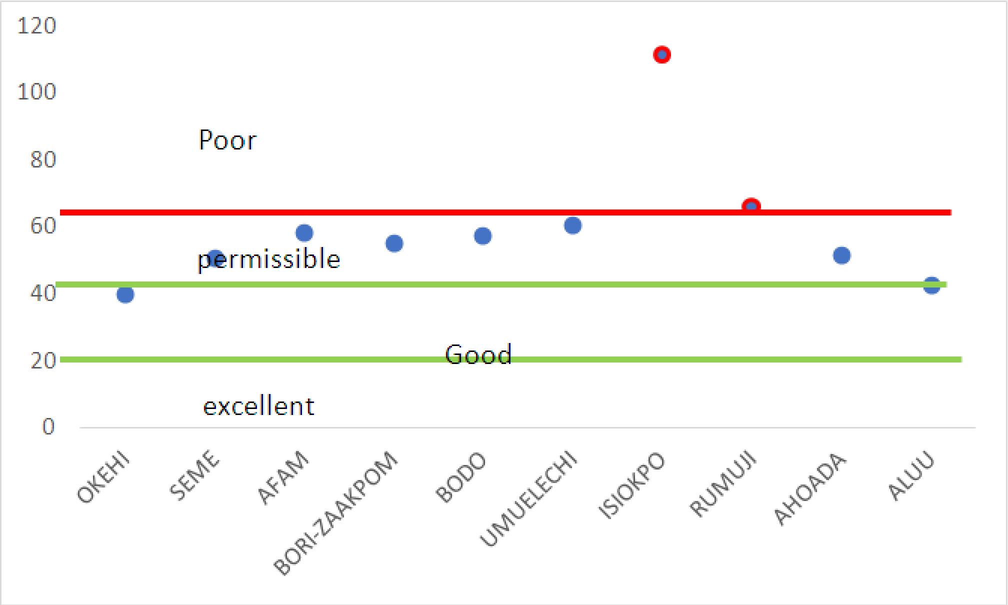

Fig. 5: SSP values of river samples

Pearson's correlation between these indices showed a linear correlation between SAR and KR, SAR and CROSS, KR and CROSS, and KR and SSP (Table 3). The Strongest correlation occurred between CROSS and KR at$r = 0.926$, while the least correlation was seen between SAR and KR ($r = 0.793$). The correlation between SAR and CROSS was at $r = 0.886$, while the correlation between KR and SSP$was\ r = 0.83$. The strong correlations (r>0.7) suggest that these indices can assess sodicity hazard in the following pairs SAR and CROSS and/or KR and SSP.

Table 3: Correlation of irrigation water quality hazard indices

	SAR	*KR*	*PS*	*PI*	*CROSS*	*EC*	*SSP*	*MAR*
SAR	1							
KR	**0.793515**	1						
PS	-0.05394	-0.04468	1					
PI	0.424337	0.65667	-0.66297	1				
CROSS	**0.886236**	**0.926416**	0.142643	0.450676	1			

EC	0.632932	0.078313	-0.25632	0.069975	0.221646	1		
SSP	0.639723	**0.82789**	-0.01295	0.565491	**0.760394**	0.004031	1	
MAR	-0.49349	**-0.84979**	0.029197	-0.66203	-0.68759	0.213033	**-0.88848**	1

3.4 Salinity Hazard

Soil salinity hazard was evaluated based on EC and potential salinity (PS) values. For EC values of the river water samples, all water samples expect Afam river could be used without any threat to salinity hazard since their EC values were less than 250mS/cm. Afam river water with EC 550 mS/cm could be used with well-managed leaching practices. When assessing the water samples' salinity hazard using PS(Eqn. 5), water sampleswere classified as excellent because the PS values ranged between 0.52 and 0.84meq/l (Fig. 6 and Table 4). However, Pearson's correlation test between EC and PS showed a non-linear relation, with $r = -0.20$. The non-linear correlation between EC and PS could be attributed to the absence of cations in the PS formula, as the salinity of the water is affected by both cations and anions. The low correlation values between PS and SAR (-0.054), PS and KR (-0.045), as well as PS and CROSS (0.143), corroborate this fact. The formula of these indices all includes the three major cations that affect water salinity and hardness.

$$PS = Cl^{-} + 0.5SO_4^{2-} \rightarrow 6$$

Table 4: Salinity c hazard classification based on SAR, KR, and CROSS

Salinity hazard			
EC		PS	
Limiting values (µS/cm)	category	Limiting values	category
<250	Low	<5	Excellent to good
250-750	Medium	5-10	Good to Injurious
750-2250	High	>15	Injurious to unsatisfactory
>2250	Very high		

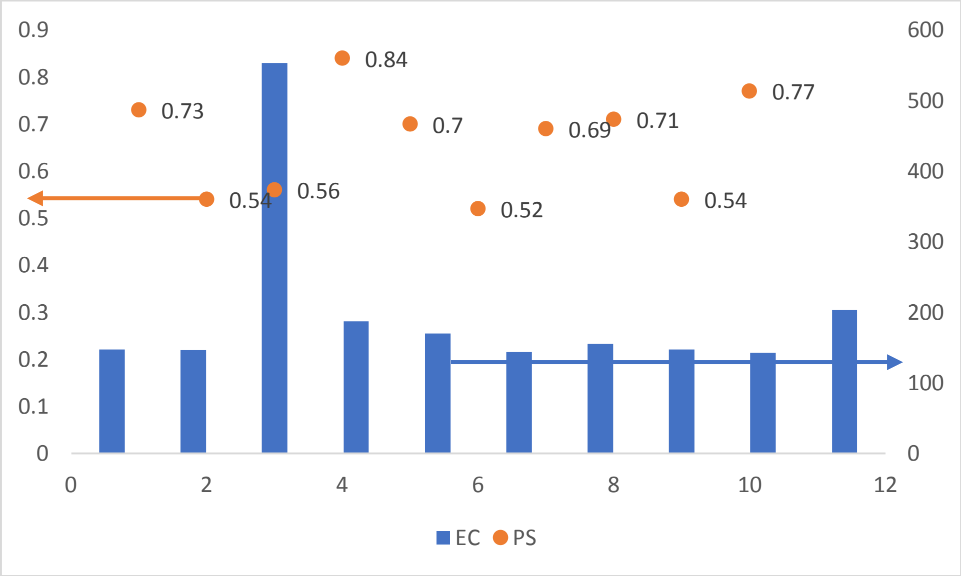

Fig. 6: EC and PS values of river samples

3.5 Permeability hazard

SAR is often used with EC in assessing permeability hazards, but the effects of EC and SAR on soil permeability are dissimilar. While SAR is inversely related to soil permeability, EC is directly related to soil permeability [9]. However, the permeability hazard in this work was assessed using the permeability index (PI) and SAR. The PI values were calculated using equation 6, and the interpretations are as displayed in Table 5.

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \rightarrow (6)$$

Table 5: PI values of river water and classificationc

RIVER	PI	Classification	PERMEABILITY INDEX	
OKEHI	94.34	Excellent	Limiting values	Category
SEME	110.59		>75%	Excellent
AFAM	106.55			
BORI-ZAAKPON	98.69			
BODO	99.89		25-75%	Good
UMUELECHI	122.39			
ISIOKPO	114.49			
RUMUJI	107.87		<25%	Unsuitable
AHOADA	104.45			
ALUU	86.13			

From Table 5, all river water in this study was classified as excellent as PI values of river water were greater than 75%. This is consistent with the SAR and CROSS values for all the river water under study because the main culprit of soil dispersion and hence permeability hazard for irrigation water is sodium accumulation. The correlation coefficient between PI and SAR and PI and CROSS were low (0.42 and 0.45 respectively) but supportive of the linear correlation between the indices.

IV. Conclusion

The assessment of river water quality using multiple indices allows for the following categorization pairs SAR and CROSS;SAR and KR; CROSS and KR and SSP as well as KR and MAR and SSP. Most of the water samples used in this study were excellent for irrigation. This implies that irrigation agriculture along these riverbankswould be a potential for food security, especially with the impact of climate change on rainfed agriculture in the region.

REFERENCES

[1]. Tang, S., She, D. & Wang, H. Effect of salinity on soil structure and soil hydraulic characteristic. Canadian Journal of Soil Science, 2020. **101**: p. 62-73

[2]. Kim, H., Jeong, H., Jeon J., & Bae, S. Effects of irrigation with saline water on crop growth and yield in greenhouse cultivation. Water, 2016. **8**(127): p. 1-9

[3]. Suresh, K. R. & Nagesh, M. A. Experimental studies on Effect of water and soil quality on crop yield. Aquatic Procedia, 2015. **4** p. 1235-1242

[4]. Singh, R., Syed, T. H., Kumar, S., & Kumar, M. Hydrogeochemical assessment of Surface and groundwater resources of Korba coalfield, Central India; environmental implications". Arab Journal of Geoscience, 2018. **10**(318): p. 1-16

[5]. Elsayed, S., Hussein, H., Moghanm, F.S., Khaled, M. K., Eid, E. M., & Gad M. Application of irrigation water quality indices and multivariate statistical Techniques for surface water quality assessments in the Northern Nile". Water, 2020. **12**(3300): p. 1-26

[6]. Al-Saffawi A. Y. T., IbnAbubakar, B. S. U., Abbass, L. Y., & Monguno, A., K. Assessment of groundwater quality for irrigation using water quality index (IWQ Index) in Al-Kasik subdistrict Northwestern Iraq".Nigerian Journal of Technology, 2020. **39**(2): p. 632-638.

[7]. Shyamala, G., Ramesh, S., & Saravanakumar, N. Major ion chemistry and groundwater quality evaluation for irrigation. Journal of Applied Science Environment Management, 2020. **24**(4): p. 699-705

[8]. Udom, E. A., Ekpo A. E., & Oluka, S. I. Assessment of irrigation water qualities of Abak River, Abak, Akwa Ibom State Nigeria. Global Journal of Pure and Applied Science, 2019. **25:** pp 135-144

[9]. Aboukarima, A. M., Al-Sulaiman, M. A., & SA EI Marazky, M. Effect of sodium adsoription ratio and electric conductivity of the applied water on infiltration in a sandy-loam soil. Water SA, 2017. **44**(1): p. 105-110

[10]. Shakir, E., Zahraw, Z., Al-Obaidy, A. M. J. Environmental and health risks associated with reuse of wastewater for irrigation. Egyptian Journal of Petroleum, 2017 **26**: p. 95-102.

[11]. Subbarao, M. & Reddy, R. B. Groundwater quality assessment in Srikalahasthi Mandal, Chittoor District, Andhra Pradesh, South India. Journal of Engineering, 2018. **8**(8): p. 33-42

[12]. Joshi, D. M., Kumar, A., & Agrawal, N. Assessment of the irrigation water quality of River Ganga in Haridwar District.Rasayan Journal of Chemistry, 2009.**2**(2): p. 285-292

[13]. Elmabrok, F. M. & Abu-Libda, O. A. M. Evaluatioin of Groundwater quality and suitability for irrigation purposes in Alagilat Area, Libya". International Journal of Engineering Science Invention, 2017. **6**(5): p. 44-50

[14]. Jha, P., Srivastava, S. K. & Dubey, S. K. Effect of water quality and water use efficiency of irrigated wheat crop. Indian Journal of Soil Conservation, 2012. **40**(3): p. 236-239.

[15]. Batarseh, M., Imreizeeq, E., Tilev, S., Al Alawee, M., Suleiman, W., Al Alawneh, A. M., Al Tamini, M. K., & Al Alawneh, M. " Assessment of groundwater quality for irrigation in the arid regions using irrigation water quality index (IWQI) and GIS-zoning maps: Case study from Abu Dhabi, UAE". Groundwater for sustainable development, 2021. **14**: p. 1-17.

[16]. Reddy, K. S. Assessment of groundwater quality for irrigation of Bhaskar Rao Kunta watershed, Nalgonda District, India. International Journal of Water Resources and Environmental Engineering, 2013. **5**(7): p. 418-425

[17]. Batarseh, M., Imreizeeq, E., Tilev, S., Al Alawee, M., Suleiman, W., Al Remeithi, A. M., Al Tamini, M. K., & Al Alawneh, M. 2021. Dataset for the Physio-chemical parameters of groundwater in the Emirate of Abu Dhabi, UAE. Data in Brief, 2021. **38**: p. 1-16.

[18]. Ndubueze-ogaru, M. E., Udensi, U. E., & Adedokun, O. M. Assessment of perceived impacts of livelihood activities among the rural dwellers on the wetland areas of Rivers state, Nigeria. Journal of Agriculture and Ecology Research International, 2017. **13**(4): p. 1-14