Hydrochemical and Irrigation Characteristics of Surface Water from Creeks around Okrika Communities, Rivers State, Nigeria

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Abstract: This study evaluated the hydrochemical characteristics, drinking water suitability and irrigation potential of surface water from selected creeks in Okrika communities, Rivers State, Nigeria. Surface water samples were collected from designated stations across Okochiri, Ekerekana, Okpoka-Toru, and Oba Ama Creeks during both wet and dry seasons to capture spatial and temporal variability. Standard analytical procedures were employed to determine physicochemical parameters, and hydrochemical indices including Water Quality Index (WQI), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Hazard (MH), Residual Sodium Carbonate (RSC), Kelly's Index (KI), and Permeability Index (PI) were computed to assess suitability for drinking and irrigation. Hydrochemical facies and irrigation classifications were further evaluated using Piper, Wilcox, and United States Salinity Laboratory (USSL) diagrams. WQI values ranged from 178.43 to 235.72 across stations, categorizing all sampled waters as unsuitable for drinking according to WHO and Nigerian standards. The elevated WQI values were primarily driven by very high electrical conductivity (17,130–20,086 µS/cm) and chloride concentrations (up to 7,846.02 mg/L), indicating strong saline influence and possible anthropogenic inputs. Hydrochemical facies identified from the Piper diagram revealed a dominant Ca–Mg–Cl–SO₄ water type, characteristic of hard, saline waters influenced by seawater intrusion and industrial discharges. Irrigation indices showed mixed suitability. SAR values (0.554–1.446) placed all samples in the "excellent" sodium hazard category; however, SSP and KI indicated moderate sodium risk at one station (SSP = 54.11%; KI = 1.058). Wilcox and USSL diagrams classified the waters predominantly as C4–S1 (very high salinity, low sodium hazard), implying that salinity, rather than sodicity, is the principal constraint to irrigation use. Overall, the creek waters of Okrika exhibit significant salinity-driven degradation linked to estuarine mixing, tidal influence, and anthropogenic pressures. While sodium hazard remains relatively low, elevated ionic strength severely limits domestic and agricultural applications without substantial treatment or management interventions. Continuous monitoring and integrated pollution control strategies are therefore recommended to mitigate long-term ecological and agricultural impacts in this coastal environment.

Keywords: Hydrochemical, Irrigation, Surface Water, Okrika, Nigeria

I. INTRODUCTION

Surface water and sediments including fishes are critical essential components of the earth's hydrological cycle, playing critical roles in shaping the marine ecological environment, supporting life and influencing human activities and well-being (Ogaga *et al.,* 2018). Surface water therefore refers to water that flows over the land surface, including rivers, streams, lakes, wetlands, and oceans (Green *et al.,* 2023). It is a vital component of the earth system accounting for about 2.5% of the planet total water resources (Green *et al.,* 2023).

Surface water qualities are poorer in rivers, streams, estuaries and creeks, than in reservoirs. This is because these sources of water play a major role in the assimilation of pollutants, carrying of municipal and industrial wastewater as they flow, and run off from agricultural land which constitute polluting point and non-point sources (Uzamere *et al.,* 2023a). It is worthy to note that with the rapid and increased rate of urbanization, industrialization and population increase couple with rapid rate of development in the various sectors of the economy, the rivers, creeks, streams and their surface water, especially at the peripheral areas of urban centers are constantly and continuously contaminated with hazardous wastes, effluent discharges, sludges, heavy metals, and waste waters which have become a common phenomenon (Uzamere *et al.,* 2013b). Thus, surface water, sediment pollution has undoubtedly, become a serious and dynamic challenge and a threat to the sustainability of the human race

and the well-being of the environment, marine ecosystem and biodiversity (Ogolo & Abam, 2021). Ogolo and Abam (2021) noted that as water sources for drinking and human use are contaminated, it is very difficult, costly and almost impossible to threat and restore it to its original state. However, till today, about eighty (80%) percent of our global wastes containing human wastes, toxic substances, heavy metals and xenobiotic are released into the water bodies (United Nation (UN), 2019). UN (2019).

The rivers, creeks and streams in Okrika Local Government Area have been polluted due to industrial effluents discharges, wastewater, sludges and other contaminants and pollution from the Refinery, Petrochemical Plants and the Fertiliser Company (Ideriah *et al.,* 2023; Obire *et al.,* 2008a). This has affected the littoral zone, the shallow surface in the creek along the shore, including the livelihood of the people of the area. Thus, the Okrika creek, rivers and streams in Rivers State, Nigeria are very important and vital component of the Niger Delta region's marine ecosystem that supports various aquatic lives and socioeconomic activities. However, this marine ecosystem is facing significant environmental challenges due to anthropogenic activities such as oil and gas exploration, production operations, chemical and fertiliser production operations including

marine transportation which have led to the release of various pollutants including xenobiotics into the marine environment, thus, changing the physicochemical quality of the water ecosystem (Uzamere *et al.,* 2023a; Luo *et al.,* 2023). Xenobiotic, including Polycyclic Aromatic Hydrocarbons (PAHs), heavy metals, and pesticides, have been shown to have detrimental effect on human health (Iyama *et al.,* 2020).

II. METHODOLOGY

➢ Study Area

Okrika is a local government area in Rivers State, South-South Nigeria of Niger Delta area. Its headquarters is in Okrika main land, an island in Rivers State, South-South Nigeria. The town is situated on an island south of Port Harcourt, making it a suburb of the larger city (Ogolo & Abam, 2021). It lies on the north of the Bonny River and on Okrika Island, 35 miles (56km) upstream from the Bright of Bonny, and can be reached by vessel of a draft of 29 feet (9 metres) or less (Otokunefor & Obiukwe, 2005). Geographically and at the North by Obio/Akpor and Eleme Local Government Areas. It is located approximately on latitude 4º44′23″ N and longitude, 7º4′58″ E on the Greenwich Meridian (Okoye *et al.,* 2013) (Figures. 1, 2).
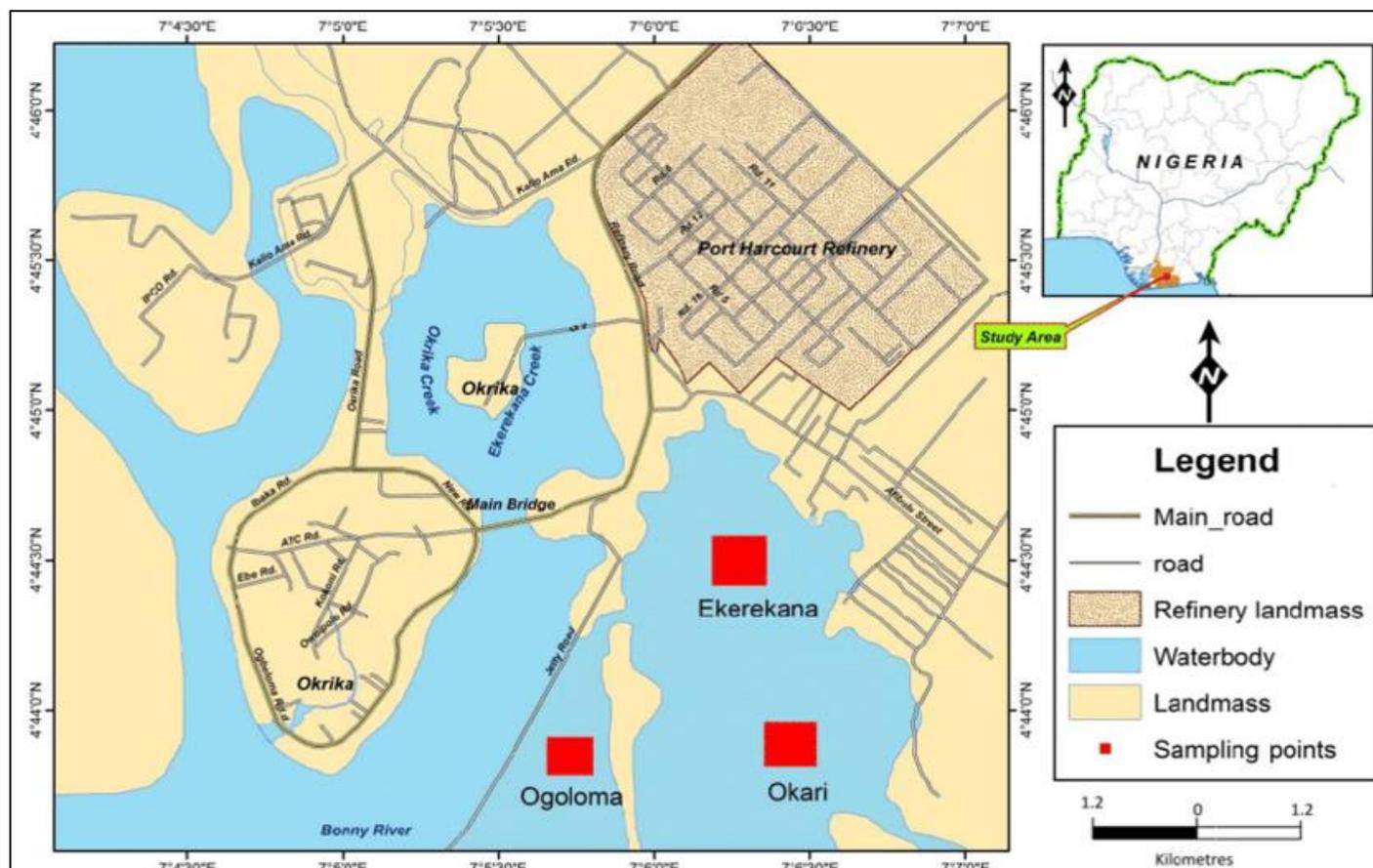

Fig 1 Map of Nigeria showing Rivers State, and Creeks around Okrika Local Government Area

➢ Sample Collection

Samples were collected from multiple designated points across selected creeks to assess spatial variability in environmental conditions. The sampling locations include

Okochiri Creek, Ekerekana Creek, Okpoka-Toru Creek, and Oba Ama Creek. At each site, samples were collected from consistent, predefined coordinates to ensure comparability across space. This spatial approach allows for the

identification of localized differences in water quality and potential impacts of nearby anthropogenic activities such as industrial effluent discharges. Samples were collected during both wet and dry seasons to maintain temporal consistency across the spatial grid of sampling points.

➢ *Samples Analysis*

The samples collected will be analyzed for physical and chemical parameter using the standard laboratory analytical methods by (ASTM, 2005; APHA, 2017; AOAC, 2019).
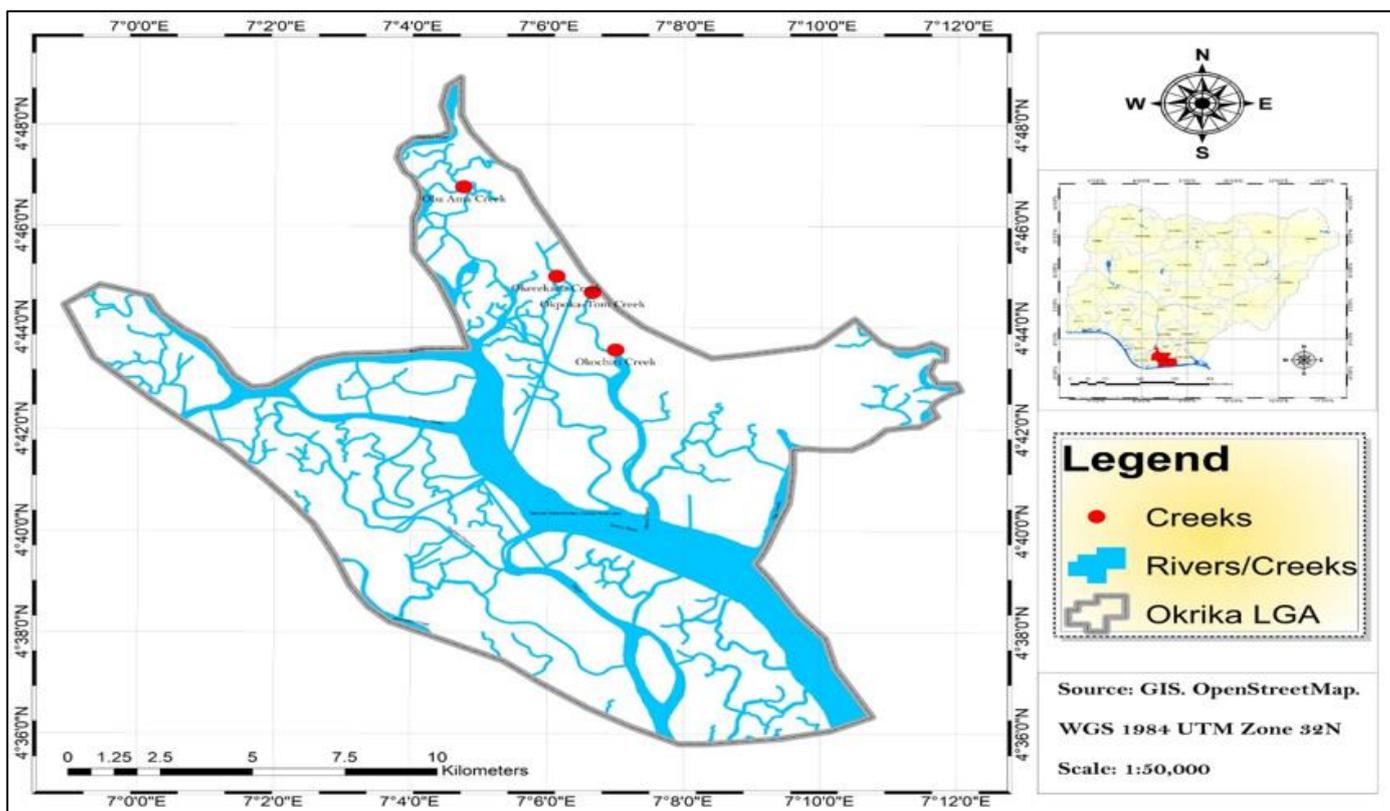

Fig 2 Locations of Sampling at the Study Area

➢ *Water Quality Index (WQI)*

A Water Quality Index (WQI) according to Liou *et al.,* (2004) in simplified concept is a way of combining complex water quality data into a single value or single statement. WQI was calculated as follows:

$$WQI = \sum (q_i w W_i)/EW_i$$

Where the unit weight of the *ith* parameter (W_i) can be calculated as follows:

$$W_i = \frac{K}{S_i}$$

$$K = \frac{1}{\sum \frac{1}{S_i}}$$

K is the constant of proportionality and S_t is water standards for the parameters. Then, q_t which is the quality rating for all the parameters can be calculated as follows:

$$q_t = 100\left(\frac{V_t - V_o}{S_i - V_o}\right)$$

V_i is the concentration of the *ith* parameter of interest in the investigated surface water, while *t* is the ideal value of the *ith* parameter in pure water. $V_o = 0$ (except pH= 7.0; and DO = 14.6 mg/l).

Furthermore, the grade of Water Quality Index (WQI) and status of water rating is shown in Table 1.

Table 1 Rating for WQI and Status of Water

Class	WQI	Category of Water and Quality
1	<50	Excellent
2.	50-100	Good
3.	100-200	Poor
4.	200-300	Very poor
5.	> 300	Unsuitable

Source: APHA, (2017)

III. RESULTS AND DISCUSSION

Table 2 presents the Water Quality Index (WQI) values for water samples collected from the three creek stations (WS1–WS3) in Okrika communities. The WQI values ranged from 178.43 in WS3 to 235.72 in WS2, with all stations classified as *unsuitable for drinking*. This classification indicates that the physicochemical composition of the creek water exceeds permissible limits for potable use, as defined by the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ). The high WQI values reflect the combined influence of elevated concentrations of dissolved salts, ions, and possible pollutants such as chlorides, sulphates, and total dissolved solids, which collectively degrade water quality.

Among the three stations, WS2 recorded the highest WQI value (235.72), suggesting that it is the most degraded site in terms of water chemistry and pollution load. This elevated index may be attributed to higher electrical conductivity (20,086.14 μS/cm) and chloride concentration (7,605.36 mg/L) observed earlier in the physicochemical data, indicating saline intrusion or anthropogenic discharges from nearby industrial and domestic activities. Conversely, WS3, with a WQI of 178.43, exhibited slightly lower ionic content and may be less impacted by direct effluent discharge, although still far beyond acceptable drinking water thresholds. WS1 (181.84) displayed intermediate pollution

status, consistent with its moderate conductivity (18,710.71 μS/cm) and chloride content (7,846.02 mg/L).

Scientifically, these results imply that the water bodies in Okrika are heavily influenced by saline water mixing, industrial waste, and urban runoff. The high WQI values indicate substantial deviation from natural freshwater composition, suggesting contamination from both geogenic (saltwater intrusion through the estuarine interface) and anthropogenic sources (oil exploration, effluent discharge, and domestic waste). Elevated salinity and ionic strength also contribute to increased corrosion potential and reduced suitability for agricultural and domestic purposes.

The uniform classification of all stations as *unsuitable for drinking* signifies that water from these creeks requires substantial treatment before human consumption. The trend observed—highest WQI in WS2, followed by WS1, and lowest in WS3—reflects spatial variations in pollution sources and hydrological mixing patterns. These findings align with similar studies in estuarine and industrialized zones of the Niger Delta, where elevated WQI values are frequently linked to oil-related discharges and saline inflow. Overall, Table 4 demonstrates that the creek water in Okrika has been significantly impacted by chemical pollution, posing potential ecological and public health concerns, and emphasizing the need for effective pollution control and water treatment interventions.

Table 2 Water Quality Index (WQI) of Water Samples from Creeks around Okrika Communities

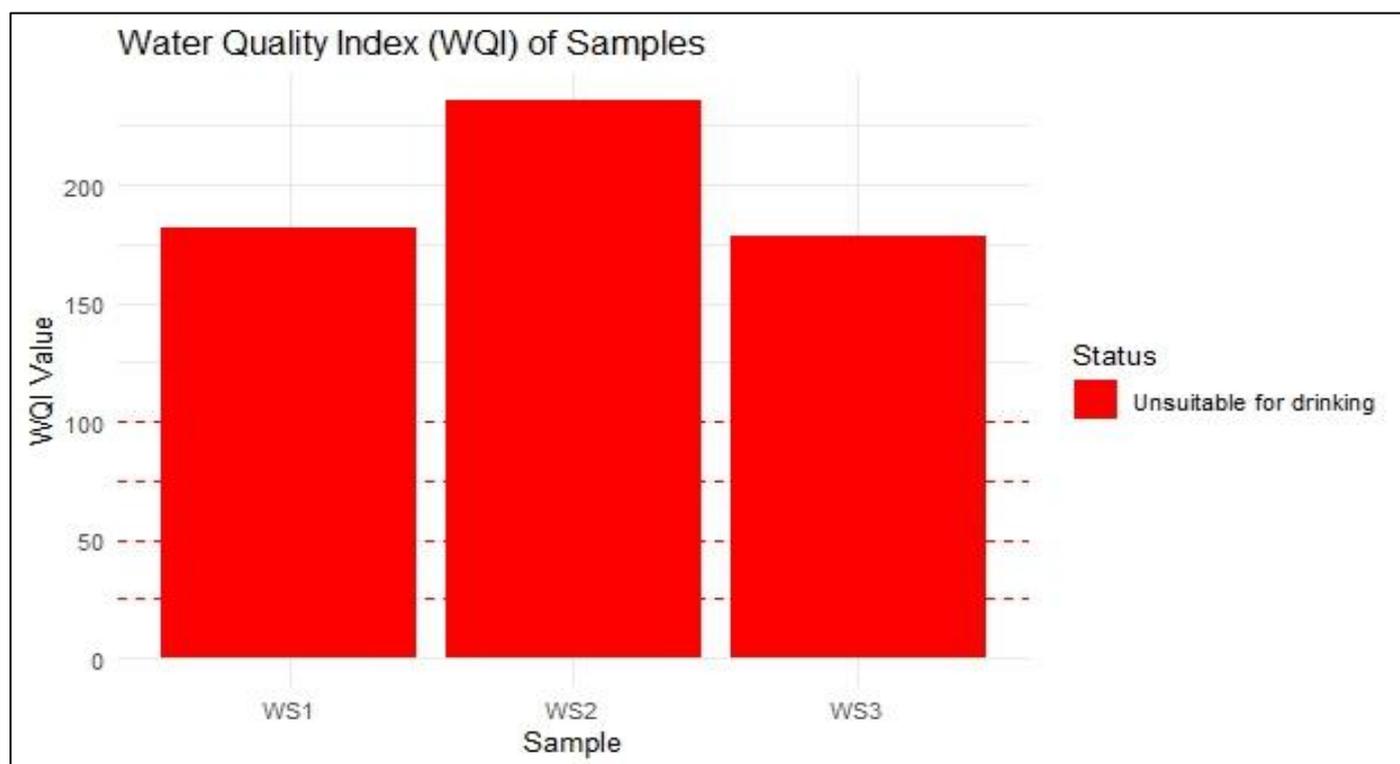| Sample	WQI	Status
WS1	181.84	Unsuitable for drinking
WS2	235.72	Unsuitable for drinking
WS3	178.43	Unsuitable for drinking

Fig 3 Water Quality Index (WQI) of Water Samples from Creeks around Okrika Communities

Table 3 and Figs. 3-12 present the computed hydrochemical and irrigation suitability indices—Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Hazard (MH), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC), Kelly's Index (KI), and Permeability Index (PI)—for the three water sampling stations (WS1–WS3) in Okrika communities. These indices provide insight into the chemical quality of the water for irrigation and the potential impact of dissolved ions on soil permeability, salinity, and crop productivity.

The Sodium Adsorption Ratio (SAR) values ranged from 0.554 at WS2 to 1.446 at WS3. All stations fall within the "excellent" category for irrigation, as SAR values less than 10 indicate minimal sodium hazard to soil structure. However, the higher SAR value at WS3 suggests relatively greater sodium influence, which may, over time, lead to slight reductions in soil permeability. The Soluble Sodium Percentage (SSP) followed a similar trend, with WS3 exhibiting the highest value (54.11%), exceeding the 50% threshold that marks the onset of sodium hazard. In contrast, WS1 (19.1%) and WS2 (17.94%) were well below the critical limit, suggesting these stations contain water more suitable for agricultural use.

The Magnesium Hazard (MH) and Magnesium Adsorption Ratio (MAR) values were identical at each station, with WS1 and WS2 showing 35.66% and 41.95%, respectively—both within the safe range (<50%), indicating balanced calcium-magnesium proportions beneficial to soil structure. WS3, however, recorded a value of 0%, which may suggest minimal magnesium presence or data limitation at that site. Residual Sodium Carbonate (RSC) values ranged from -4.28 to -0.93 across stations, all negative, indicating no residual carbonate hazard. Negative RSC values imply excess calcium and magnesium over carbonate and bicarbonate, thus reducing alkalinity risk and improving water suitability for irrigation.

Kelly's Index (KI) values were below unity (0.224 and 0.194) at WS1 and WS2, suggesting good irrigation quality, but WS3 recorded a higher value (1.058), slightly exceeding the safe limit (KI < 1). This suggests that water at WS3 may pose moderate sodium hazard if used for prolonged irrigation. Similarly, the Permeability Index (PI) ranged from 16.33% at WS2 to 51.61% at WS3. Values between 25% and 75% generally indicate moderate suitability, so WS3 falls within this acceptable range, while WS1 and WS2 remain on the lower side, implying limited permeability potential likely due to elevated calcium and magnesium concentrations.

Overall, Table 3 demonstrates spatial variability in hydrochemical characteristics across the creek systems of Okrika. While WS1 and WS2 show water of acceptable irrigation quality, WS3 exhibits higher sodium and permeability indices, reflecting localized geochemical influences such as saline intrusion, evaporation effects, or anthropogenic discharges. These variations suggest that though the water may not be fit for domestic use, it remains largely acceptable for irrigation, particularly in stations with lower sodium and carbonate content. The results highlight the need for periodic monitoring to prevent soil salinization and ensure sustainable agricultural practices in the coastal region.

Figure 10 presents the Piper diagram illustrating the hydrochemical facies of water samples collected from creeks within the Okrika communities. The diagram combines two ternary plots (cation and anion triangles) and a central diamond-shaped field that classifies the overall hydrochemical composition. This visual representation helps in understanding the geochemical evolution of groundwater and surface water, indicating the dominant ions influencing water chemistry.

The left triangle represents the relative concentrations of major cations—calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+)—while the right triangle shows the distribution of major anions—carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), nitrate (NO_3^-), and sulfate (SO_4^{2-}). The plotted points for the Okrika water samples are positioned towards the calcium and magnesium apices on the cation side, and towards the chloride and sulphate apices on the anion side. This distribution indicates that the water chemistry is dominated by calcium-magnesium-chloride-sulphate (Ca–Mg–Cl–SO₄) type.

The central diamond field further confirms that the majority of samples fall within the "chloride and sulfated calcium and magnesium" region, characteristic of hard, saline water types. This type of water is often associated with geogenic sources such as dissolution of carbonate and evaporite minerals, as well as anthropogenic contributions like industrial effluents or domestic wastewater infiltration. The dominance of chloride and sulfate ions suggests potential influences from marine intrusion or surface runoff carrying salts into the creek system.

Additionally, the Piper plot indicates that none of the samples belong to the bicarbonate-rich or sodium-bicarbonate facies, which are typically associated with fresh recharge zones. Instead, the observed pattern implies progressive water-rock interaction and ion exchange processes, resulting in increased mineralization. The near absence of sodium or bicarbonate dominance suggests limited cation exchange between Ca/Mg and Na ions, pointing to a stable ionic balance in the water system.

Overall, Figure 10 reveals that the hydrochemical nature of the creek water in Okrika is predominantly Ca–Mg–Cl–SO₄ type, reflecting moderately hard to hard water influenced by both natural geochemical processes and possible anthropogenic inputs. This classification supports previous findings from the water quality and hydrochemical indices, which suggest the presence of elevated ionic concentrations and reduced suitability for domestic consumption, though some stations may still serve limited irrigation purposes

Figure 10 presents the Wilcox diagram, which evaluates the suitability of water samples from creeks in Okrika communities for irrigation purposes. The diagram plots the percentage sodium (%Na) on the y-axis against the electrical

conductivity (EC) in µS/cm on the x-axis. This relationship helps classify irrigation water into categories such as *Excellent*, *Good*, *Admissible*, and *Doubtful*, based on salinity and sodium hazards. These two parameters are crucial because excessive sodium or high salinity can adversely affect soil permeability, structure, and crop yield.

The water samples (WS1, WS2, and WS3) show relatively high electrical conductivity values ranging between 17,130 µS/cm and 20,086 µS/cm, indicating high salinity levels. In the Wilcox classification, such high conductivity values generally correspond to *saline water*, which can pose significant challenges for irrigation use. Regarding sodium content, WS1 and WS2 exhibited moderate %Na values (19.1% and 17.94%, respectively), while WS3 recorded a notably higher value of 54.11%. These differences suggest varying levels of sodium contribution across the sampled stations.

According to the plotted positions on the diagram, WS1 and WS2 fall within the "Admissible to Doubtful" category, indicating moderate sodium hazard and high salinity. This implies that these water samples could be used for irrigation only on salt-tolerant crops and in well-drained soils to minimize salinity accumulation. In contrast, WS3, with a higher sodium percentage, falls near the "Doubtful" category, suggesting limited suitability for irrigation unless adequate soil management practices (such as leaching or gypsum application) are employed.

The dominance of high conductivity values across all stations points to the influence of seawater intrusion, industrial effluents, and tidal mixing processes, which are common in coastal regions like Okrika. Such processes increase the dissolved ion content, thereby raising both salinity and sodium concentrations. The relatively high %Na values further indicate potential cation exchange reactions, where calcium and magnesium are replaced by sodium ions in the soil, reducing soil permeability.

Figure 11 demonstrates that the creek waters in Okrika are not ideal for irrigation without proper management, primarily due to elevated salinity levels and moderate-to-high sodium hazards. Continuous use of such water could lead to soil degradation, reduced crop productivity, and long-term salinization, underscoring the need for periodic monitoring and mitigation strategies in agricultural practices near the creeks.

Figure 12 presents the United States Salinity Laboratory (USSL) diagram, which classifies irrigation water based on

two critical parameters: electrical conductivity (EC) and sodium adsorption ratio (SAR). The EC value (in µS/cm) indicates the salinity hazard, while the SAR value measures the relative proportion of sodium to calcium and magnesium ions, reflecting the sodium hazard. Together, these parameters determine the suitability of water for agricultural irrigation, as high salinity or sodium concentrations can affect soil structure, permeability, and crop yield.

The plotted data for the creek water samples (WS1, WS2, and WS3) reveal EC values ranging from approximately 17,130 to 20,086 µS/cm and SAR values between 0.554 and 1.446. On the diagram, these values place all the samples within the C4–S1 classification, representing very high salinity hazard (C4) and low sodium hazard (S1). This means that while the sodium concentration is not problematic, the high salinity poses serious limitations for irrigation use. Water of this class is generally unsuitable for irrigation except for salt-tolerant crops and only when efficient drainage systems and leaching practices are applied.

The low SAR values observed (< 2) suggest that sodium ions do not dominate over calcium and magnesium, thus minimizing the risk of soil sodicity. However, the very high EC values indicate that the water contains excessive dissolved salts, which can hinder water uptake by plants through osmotic stress and may cause soil salinization over time. The ionic composition inferred from earlier hydrochemical indices (Table 3) supports this interpretation—high chloride and sulphate levels were recorded, both of which contribute to the elevated conductivity values.

Scientifically, the presence of such high salinity levels in Okrika creek waters can be attributed to seawater intrusion, industrial discharges, and tidal mixing processes typical of estuarine environments. These factors increase the ionic load of the water, particularly with sodium, chloride, and sulphate ions. The relatively low SAR values suggest that while the sodium contribution is modest, the overall salinity hazard remains severe.

Figure 12 indicates that the creek waters of Okrika are unsuitable for irrigation without significant management interventions. The combination of high salinity (C4) and low sodium hazard (S1) implies that salinity—not sodicity—is the primary limiting factor for agricultural use. Therefore, any attempt to use such water for irrigation should incorporate soil leaching, periodic freshwater flushing, and cultivation of salt-tolerant crops to mitigate the negative impacts on soil and plant health.

Table 3 Hydrochemical and Irrigation Water Quality Indices of Water from Creeks around Okrika Communities

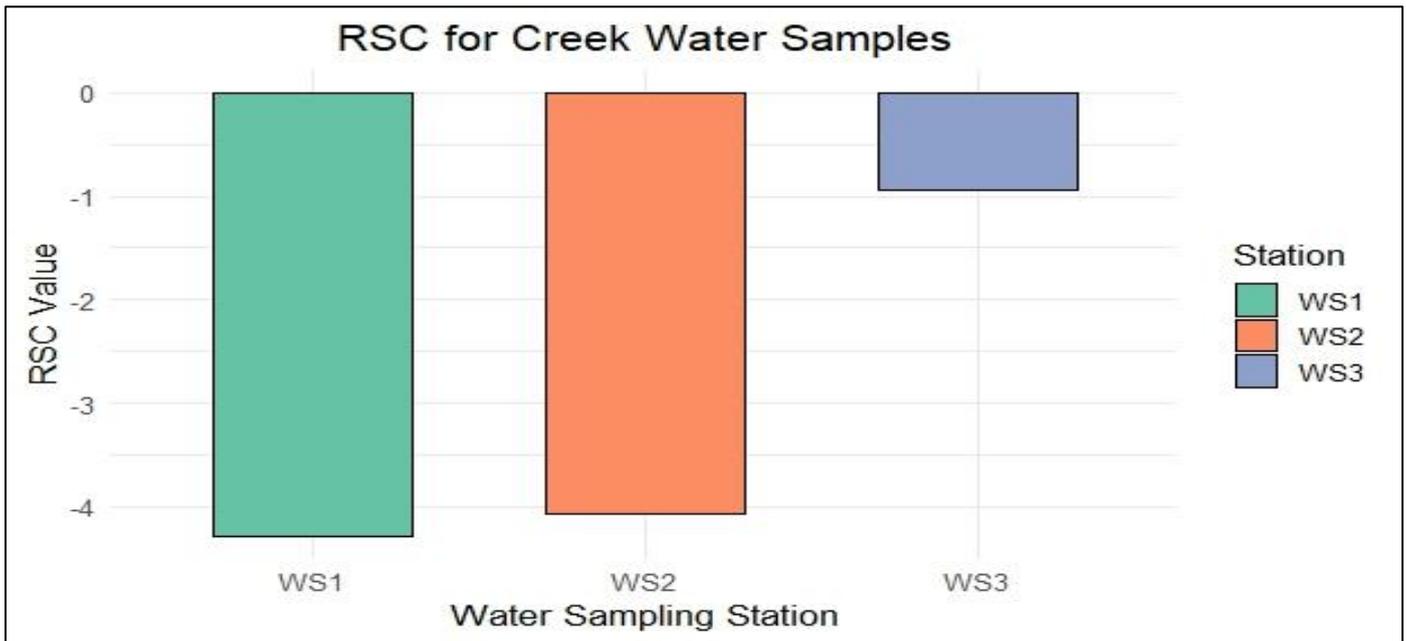| Station	SAR	SSP	MH	MAR	RSC	KI	PI
WS1	0.656	19.1	35.66	35.66	-4.28	0.224	18.39
WS2	0.554	17.94	41.95	41.95	-4.08	0.194	16.33
WS3	1.446	54.11	0	0	-0.93	1.058	51.61

Fig 4 Residual Sodium Carbonate of Water Samples from Creeks around Okrika Communities
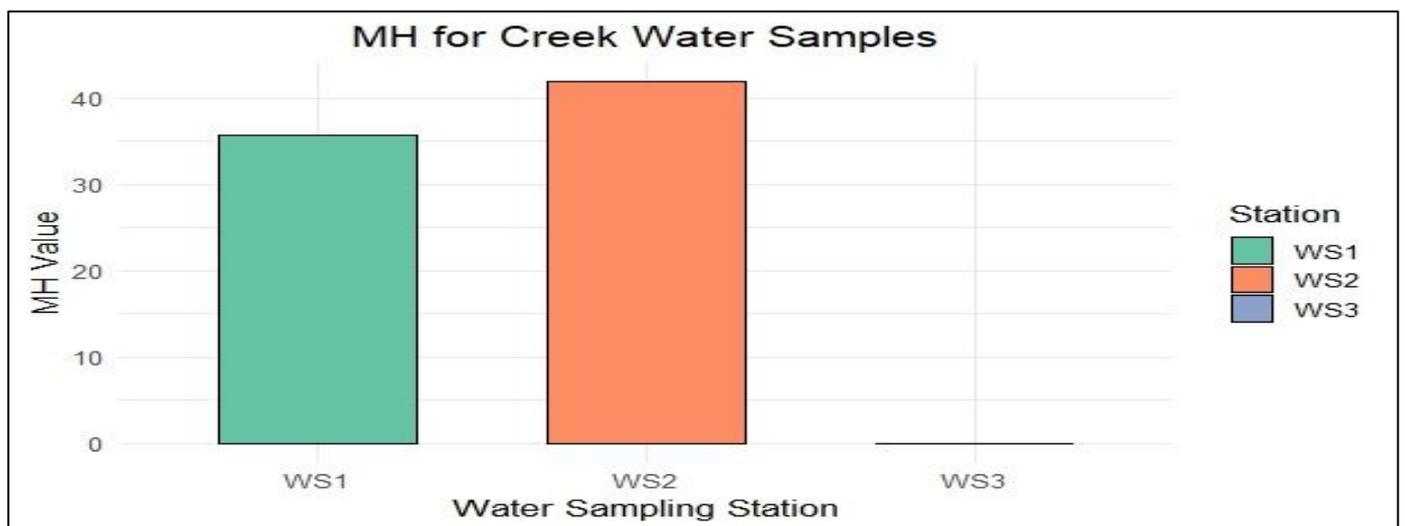

Fig 5 Magnesium Hazard of Water Samples from Creeks around Okrika Communities
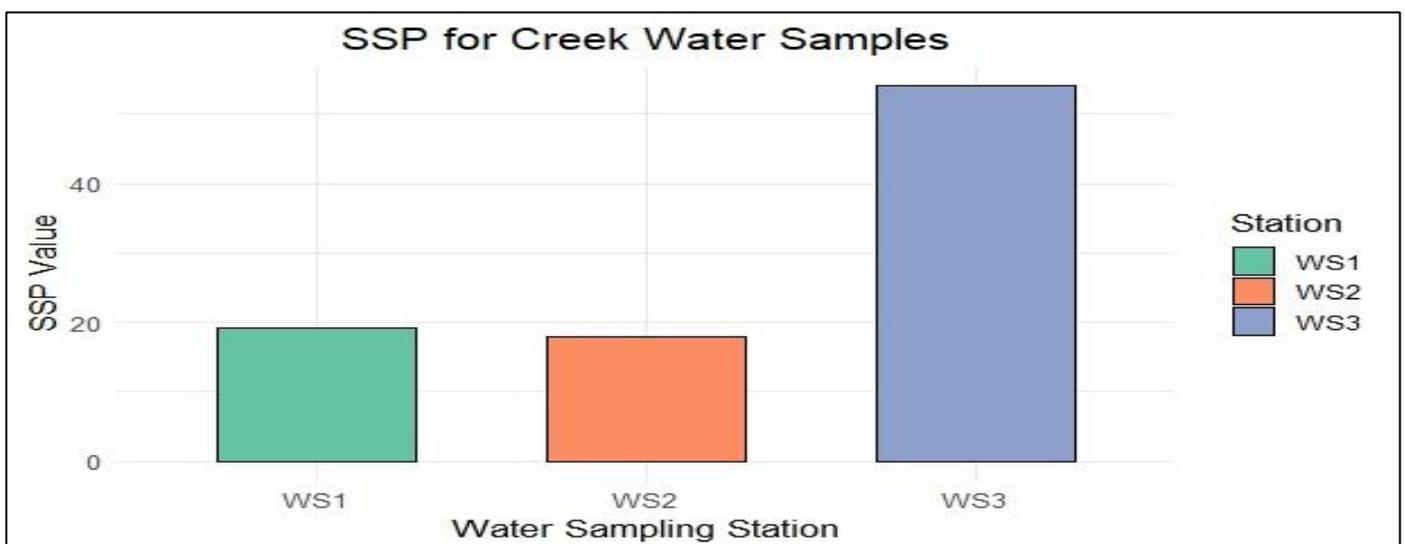

Fig 6 Soluble Sodium Percentage of Water Samples from Creeks around Okrika Communities
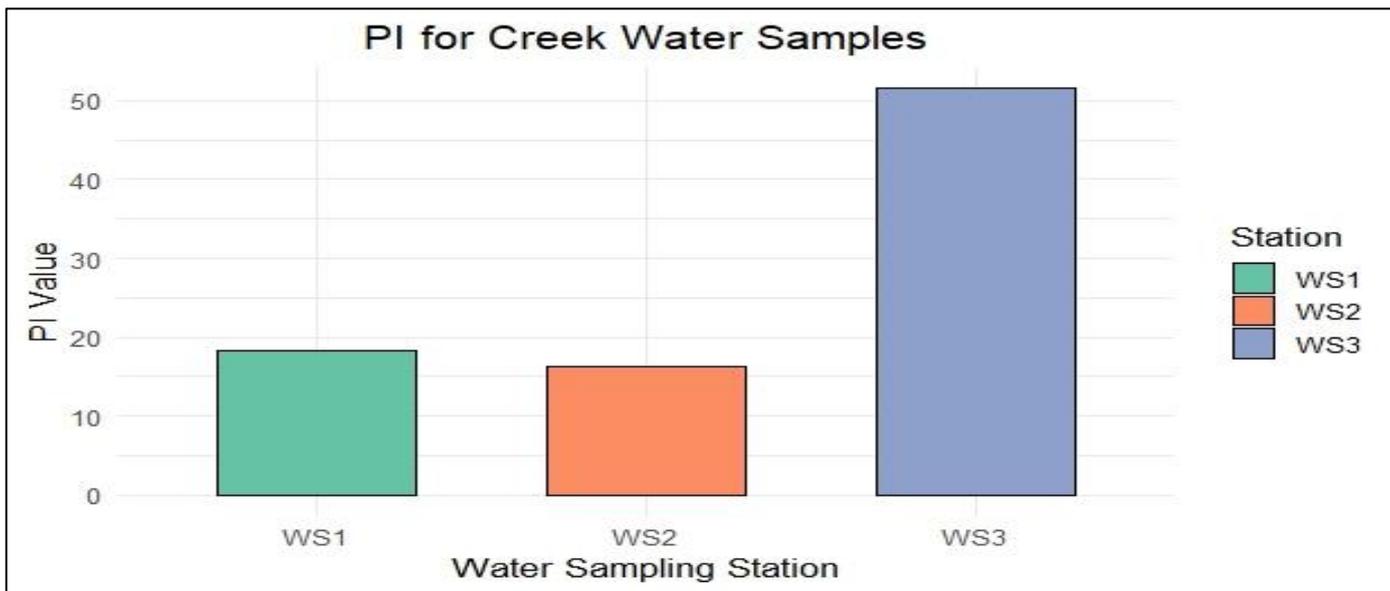
Fig 7 Permeability Index of Water Samples from Creeks around Okrika Communities
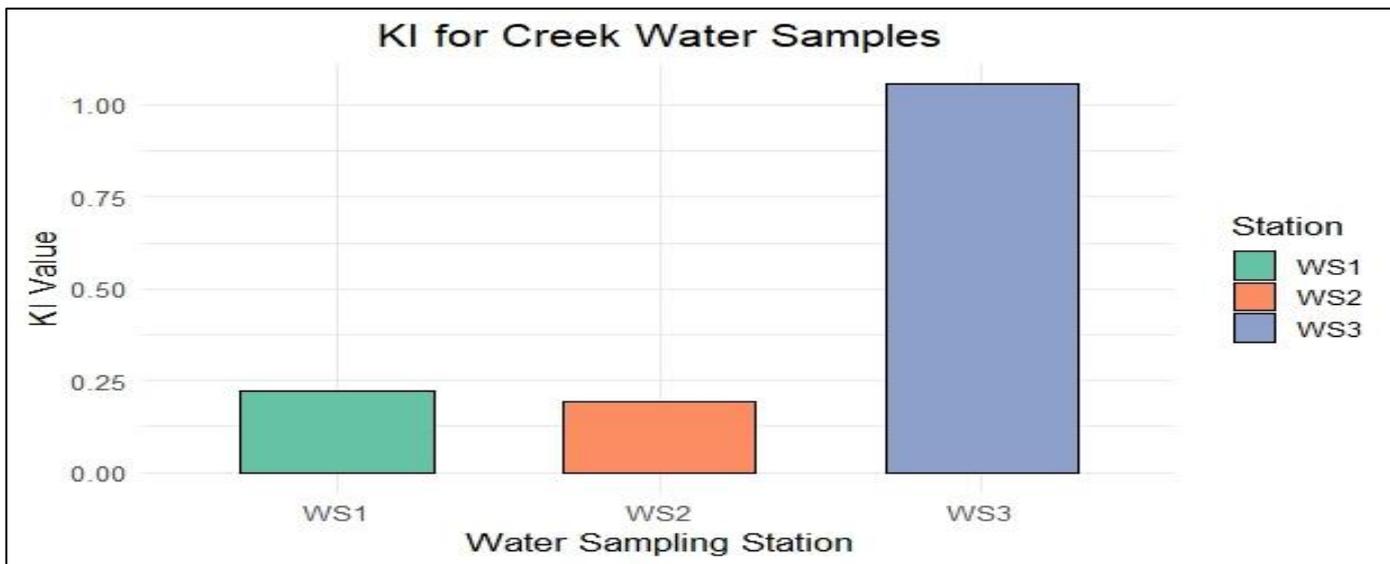

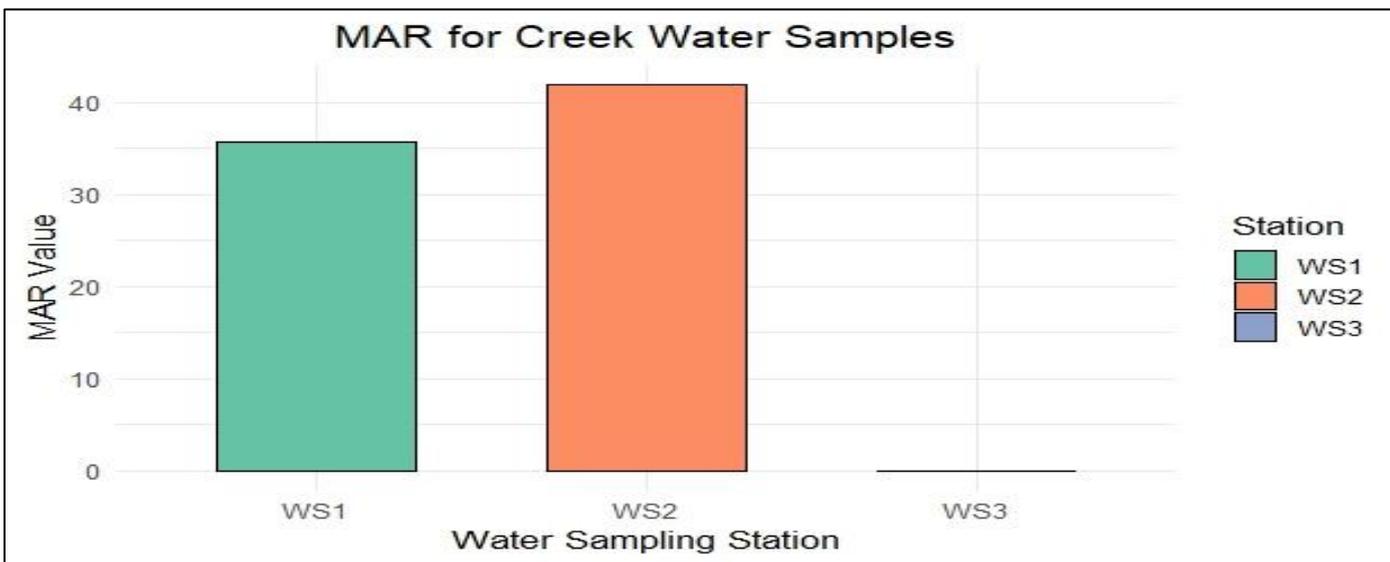Fig 8 Kelly's Index of Water Samples from Creeks around Okrika Communities

Fig 9 Magnesium Hazard of Water Samples from Creeks around Okrika Communities
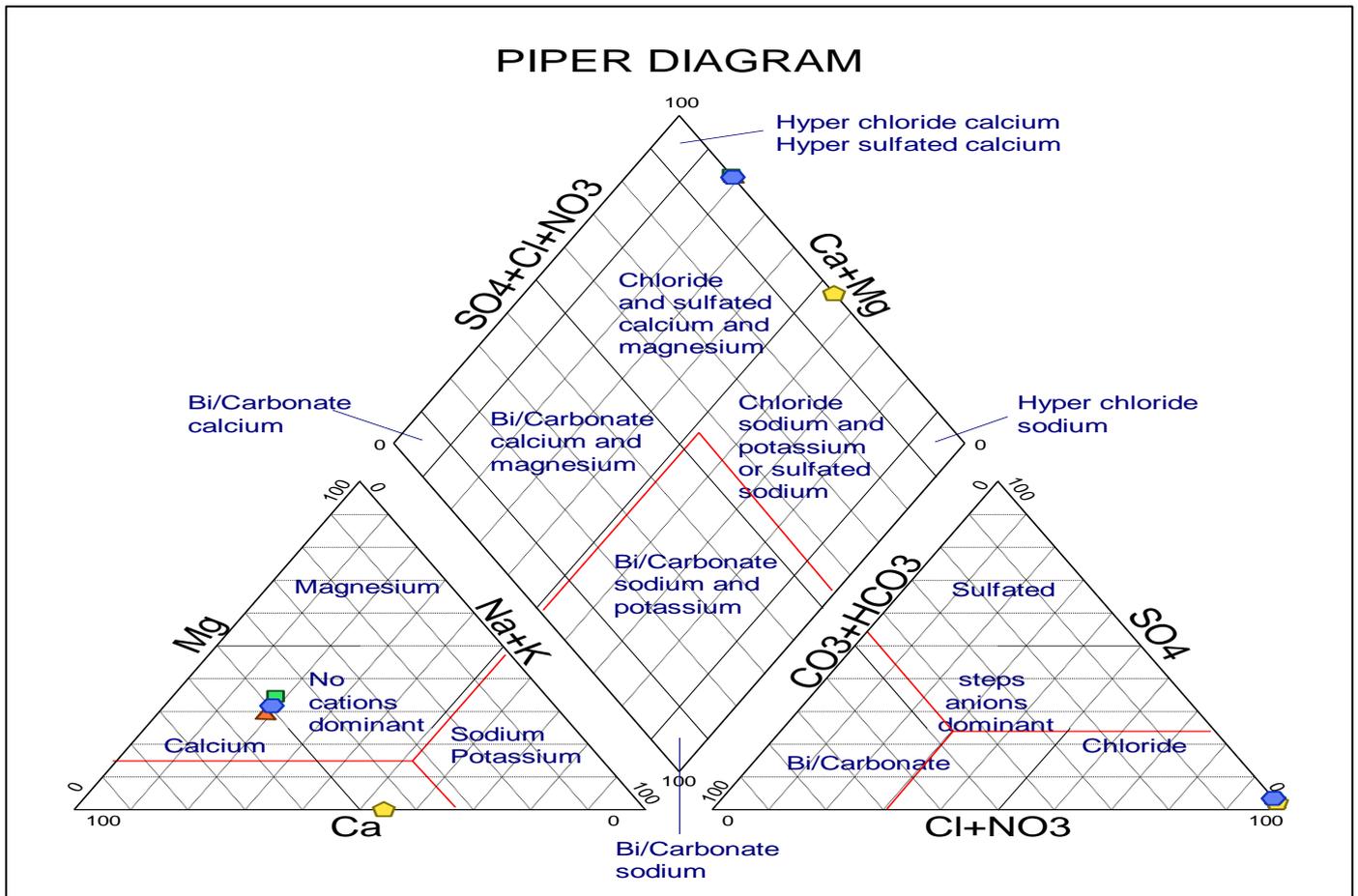
Fig 10 Piper Diagram Showing the Hydrochemical Facies of Water Samples from Creeks around Okrika Communities
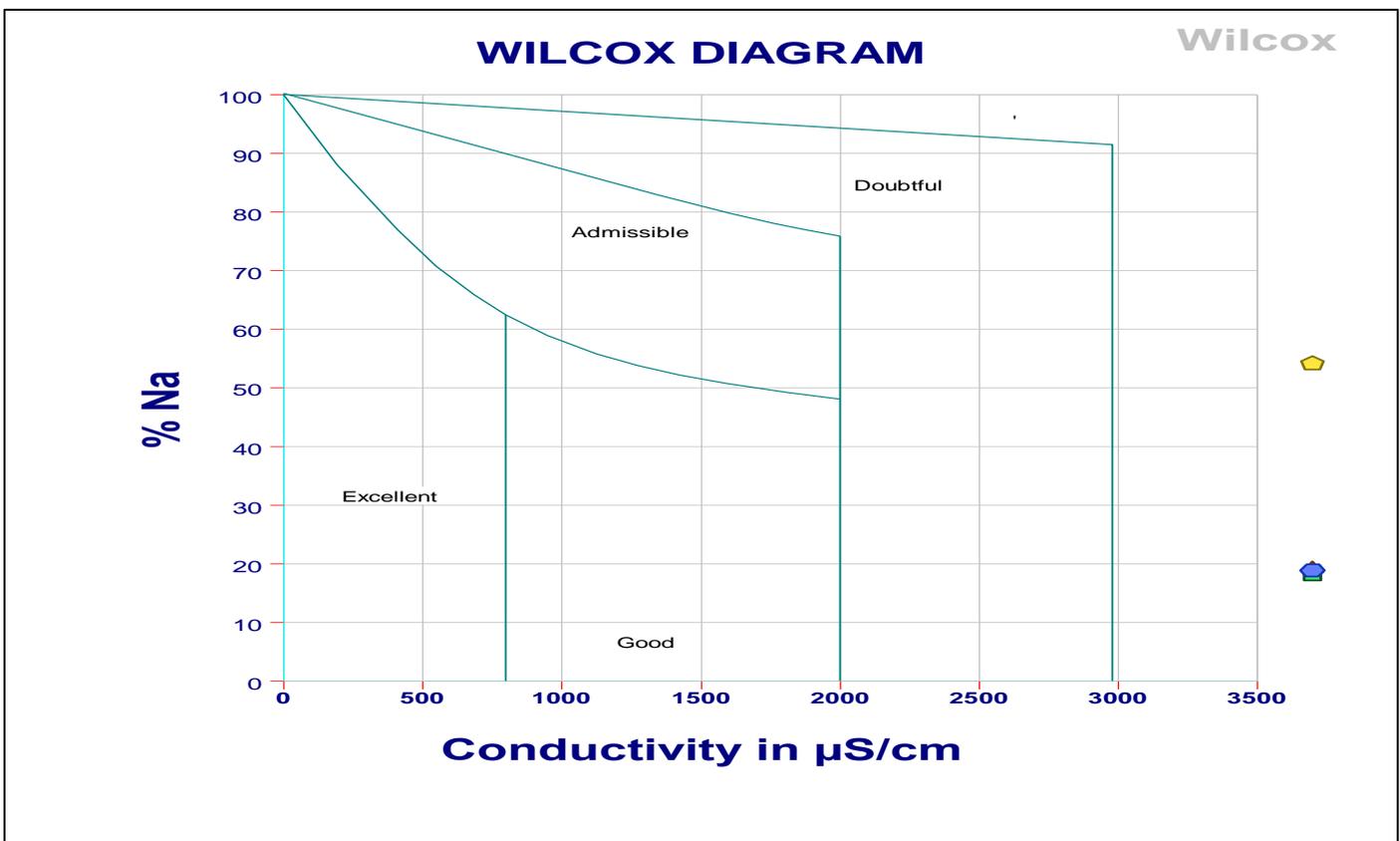

Fig 11 Wilcox Diagram Showing the Suitability of Creek Water Samples for Irrigation in Okrika Communities
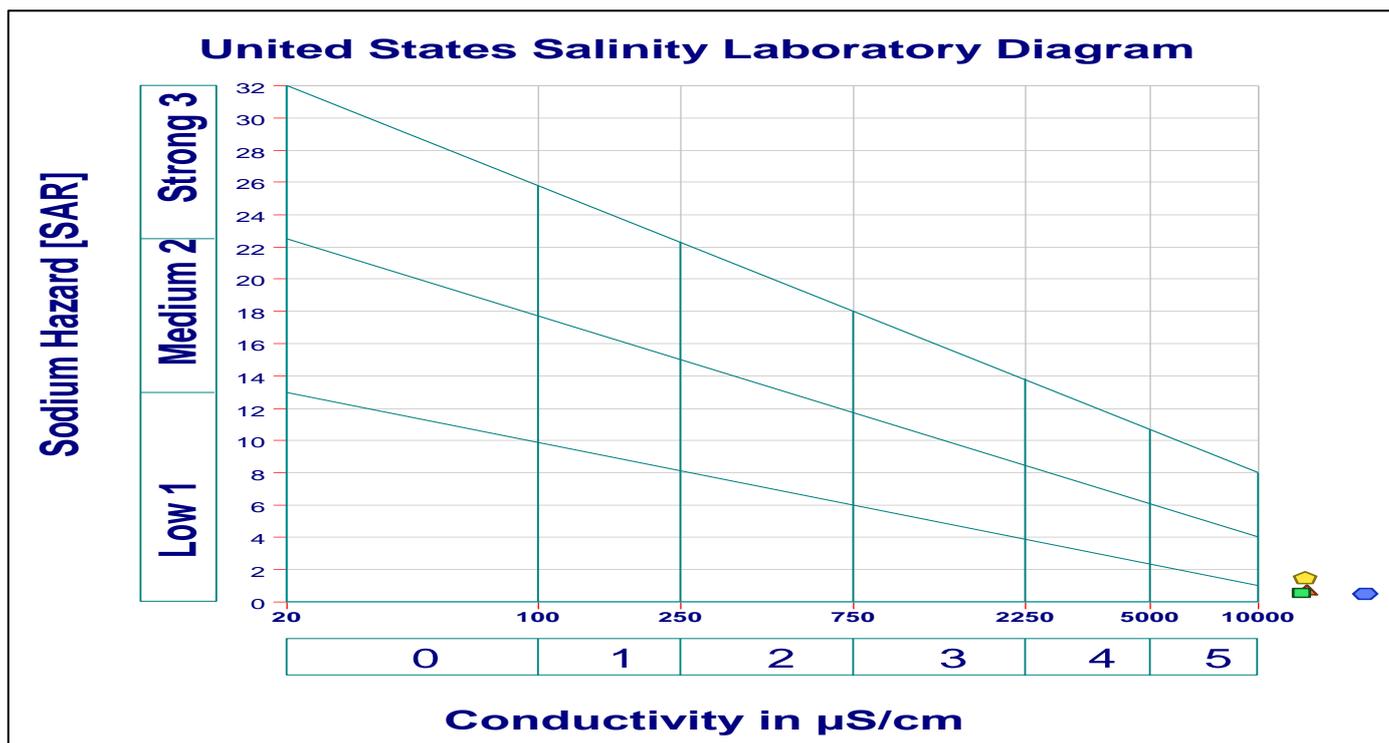
Fig 12 United States Salinity Laboratory (USSL) Diagram for Irrigation Suitability of Creek Water Samples in Okrika Communities

The Water Quality Index (WQI) is a widely used integrative tool that expresses the overall quality of water through a single numerical value derived from several physicochemical parameters. It provides a convenient means of classifying water as suitable or unsuitable for drinking, agricultural, or industrial purposes. In the present study, the WQI values of creeks around Okrika communities ranged from 178.43 at WS3 to 235.72 at WS2, with all stations exceeding the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) permissible limit of 100. These results classify all sampled stations as unsuitable for drinking purposes. WS2, which recorded the highest WQI (235.72), also exhibited elevated electrical conductivity (20,086.14 µS/cm) and chloride concentration (7,605.36 mg/L), suggesting strong ionic enrichment. WS1, with a WQI of 181.84, displayed moderate contamination, while WS3 recorded the lowest WQI (178.43), indicating slightly reduced contamination. The general WQI pattern, following the order WS2 > WS1 > WS3, indicates spatial variation linked to salinity and ionic concentrations across the Okrika creek system.

When compared to similar studies conducted in different parts of Nigeria and globally, the Okrika results are consistent with findings from areas affected by industrial and anthropogenic activities. High WQI values are commonly associated with environments impacted by pollution, saline intrusion, or high mineralization. Thus, this comparative discussion evaluates how the findings from the Okrika creeks align or contrast with results obtained from other Nigerian and international water bodies in terms of magnitude, causative factors, and environmental implications.

In Nigeria, numerous studies have applied the Water Quality Index to evaluate the potability and ecological status of surface and groundwater systems. The WQI values obtained from the Okrika creeks (178.43–235.72) place the water firmly in the "unsuitable for drinking" category, comparable to results reported for heavily impacted environments such as the coastal slums of Lagos, groundwater systems of southeastern Nigeria, and industrial zones in the northern and Niger Delta regions. For instance, Okimiji et al. (2024) documented WQI values exceeding 100 in Lagos slum settlements, where saline intrusion, domestic waste discharge, and industrial runoff have collectively deteriorated water quality. Similarly, Alum et al. (2021) reported WQI values ranging from 48 to 85 for groundwater in southeastern Nigeria, classifying most samples as marginal to unsuitable for consumption. These findings, like those of Okrika, reveal the pervasive influence of anthropogenic activities—particularly effluent discharge, urban runoff, and saltwater intrusion—on the chemical composition and potability of Nigerian waters.

The similarity between the Okrika results and those from Lagos slums underscores a shared environmental challenge: the intrusion of saline and industrial contaminants into surface waters. Okrika, located in the coastal zone of Rivers State, is surrounded by industrial installations, oil refining operations, and maritime activities that contribute to the high electrical conductivity and chloride levels recorded in the water. Likewise, Lagos coastal settlements face continuous saline intrusion from the Atlantic Ocean coupled with contamination from urban effluents. Both regions exhibit WQI values that surpass safe drinking limits,

reflecting the cumulative effect of urbanization and industrialization on water chemistry.

In contrast, certain relatively pristine or less industrially influenced Nigerian water bodies exhibit much lower WQI values, demonstrating better water quality. For example, Ogidìaka-Obende et al. (2025) reported WQI values ranging between 13 and 24 for Akassa Creek, classifying the water as "excellent" for domestic use. This stark contrast between Akassa Creek and Okrika creeks highlights the significant role of anthropogenic inputs in determining water quality status. Akassa Creek, located in a region with limited industrial development and lower population density, experiences minimal contamination. The low WQI values recorded there primarily reflect natural background levels of dissolved ions, rather than pollution-derived enrichment. In comparison, the high WQI values in Okrika creeks are direct consequences of human activities, particularly those linked to industrial waste discharge, hydrocarbon pollution, and saline encroachment.

Another Nigerian study that provides a useful comparison is the assessment of water quality at Ashaka Quarry (M, 2024). The WQI values there ranged from 67 to above 100, with classifications ranging from "poor" to "very poor." Although these values are lower than those of Okrika creeks, the similarity in classification (unsuitable or poor quality) indicates a common trend of water degradation associated with industrial and mining operations. The presence of dissolved solids, high conductivity, and chloride enrichment were also cited as the main contributors to the high WQI values in Ashaka Quarry waters. Therefore, both Okrika and Ashaka studies illustrate the profound impact of industrialization on aquatic environments in Nigeria, where effluent discharges and mineral dissolution processes elevate ionic loads and consequently increase WQI.

In the broader global context, the WQI results of Okrika creeks align closely with findings from some of the world's most polluted river systems, such as the Jamuna River in Bangladesh and the Citarum River in Indonesia. Khan et al. (2023) reported WQI values exceeding 97 in the Jamuna River, classifying it as "poor" and unsuitable for drinking. The elevated WQI in the Jamuna River was attributed to industrial effluents, agricultural runoff, and urban discharges, which collectively raised concentrations of total dissolved solids (TDS), chloride, and heavy metals. Similarly, Marselina et al. (2022) documented WQI values between 39 and 66 for the Citarum River, corresponding to "fair to bad" water quality. Despite lower absolute values compared to Okrika, both studies identify the same primary drivers of water quality deterioration—excessive ionic content and anthropogenic pollution. This global comparison suggests that the processes affecting Okrika's water chemistry are not unique but form part of a broader environmental pattern linking industrialization, urban growth, and declining water quality.

On the other hand, studies from relatively less impacted aquatic environments in South Africa and China show WQI values below 100, classifying their waters as "good" to "moderate." Wu et al. (2018, 2021) and Banda & Kumarasamy (2020) reported WQI ranges between 59 and 95 in several river systems across both countries. These comparatively lower values indicate lower levels of salinity, chloride, and conductivity, likely due to more effective pollution control and wastewater management measures. The difference between these cleaner environments and the Okrika creeks underscores the consequences of inadequate environmental regulation and waste management in developing industrial regions. While South Africa and China have implemented stronger environmental monitoring systems and periodic wastewater treatment programs, Nigerian coastal regions such as Okrika continue to experience direct effluent discharges and unregulated waste inflows, leading to elevated ionic concentrations and higher WQI values.

Across all regions, the consistent pattern emerges that the principal contributors to high WQI are electrical conductivity, chloride, and total dissolved solids. In Okrika creeks, these parameters were particularly elevated, with electrical conductivity reaching 20,086.14 μS/cm at WS2 and chloride concentrations exceeding 7,000 mg/L across stations. These parameters serve as proxies for salinity and dissolved mineral content, which directly increase the WQI score. The correlation between high conductivity and poor WQI is also evident in other Nigerian studies, such as those by Okimiji et al. (2024) in Lagos and Alum et al. (2021) in southeastern Nigeria. Similarly, Khan et al. (2023) identified conductivity and chloride as the main determinants of high WQI in the Jamuna River, while Marselina et al. (2022) noted that TDS and sulfate levels drove water quality deterioration in Indonesia's Citarum River. Thus, the dominance of ionic enrichment as a determinant of poor water quality represents a global phenomenon, with Okrika creeks fitting squarely within this pattern.

Although the WQI of Okrika creeks aligns with many polluted environments, the magnitude of the index (178–236) indicates a relatively more severe level of ionic contamination. The values exceed not only the WHO limit but also those reported for several other polluted Nigerian and international water systems. This suggests that the Okrika creeks may experience stronger saltwater intrusion or prolonged exposure to industrial effluents than most other studied sites. The proximity of Okrika to oil refineries, petrochemical facilities, and the Atlantic estuarine system likely explains this elevated WQI. Continuous exposure to saline water from tidal movements and effluent discharge from hydrocarbon-related industries would collectively increase the dissolved solid and chloride content, leading to consistently high WQI values.

In contrast, environments such as Akassa Creek and the Citarum River exhibit periodic fluctuations in contamination due to seasonal or regulatory variations, resulting in lower average WQI values. Okrika's consistently high WQI across all stations indicates a more chronic, persistent form of pollution, suggesting limited freshwater dilution and poor hydrological renewal in the system. The spatial pattern of WS2 > WS1 > WS3 further reinforces this interpretation,

with the central station (WS2) likely receiving the highest pollution load, possibly due to proximity to effluent discharge points or reduced tidal flushing efficiency.

When interpreted in ecological and public health contexts, the Okrika WQI results align with other studies' conclusions that high WQI values correspond to reduced water usability, potential toxicity, and elevated risk to aquatic biota and human health. The classification of Okrika waters as unsuitable for drinking reflects similar assessments made for the Lagos coastal waters, Jamuna River, and Ashaka Quarry, where contamination renders the water unsafe without extensive treatment. However, a subtle contrast emerges in the sources of contamination: while Lagos and Jamuna suffer primarily from domestic and industrial wastewater inflows, Okrika's pollution profile is dominated by saline and industrial ionic contributions. This contrast highlights the diversity of processes that can lead to high WQI values, reinforcing that elevated index scores do not always signify identical contamination types but rather indicate poor overall water quality due to differing combinations of factors.

The comparison with global estuarine systems also reveals that Okrika's high WQI is consistent with what has been observed in other coastal industrial zones worldwide. Estuarine systems, being transitional zones between marine and freshwater environments, are particularly prone to elevated ionic loads and chemical enrichment. The presence of chloride and high conductivity as dominant variables in Okrika creeks mirrors findings from estuaries in India, Southeast Asia, and parts of Africa, where similar salinity-induced contamination has been reported. Therefore, while Okrika's WQI values may appear high, they are not anomalous within the context of coastal and industrial estuaries, which typically show poorer water quality than inland freshwater systems.

Overall, the comparative discussion demonstrates that the findings of the present study on Okrika creeks largely align with existing national and international research on water quality assessment using WQI. The high WQI values, indicative of unsuitability for drinking, are consistent with those from polluted and industrially influenced environments in Nigeria, Bangladesh, and Indonesia. The principal driving factors—elevated chloride, total dissolved solids, and electrical conductivity—are universally recognized as key determinants of poor water quality. Although the magnitude of Okrika's WQI is among the highest reported, the underlying causes and patterns are similar to those documented elsewhere.

In conclusion, the WQI results from the Okrika creeks confirm that the water is unsuitable for drinking due to excessive ionic and chemical enrichment. The study's findings align with broader national and global trends showing that high WQI values correspond to pollution from anthropogenic and natural sources such as industrial effluents, saline intrusion, and poor waste management. While less polluted systems such as Akassa Creek and certain South African rivers contrast sharply with Okrika's degraded

state, the overall consistency of findings reinforces that WQI serves as a reliable diagnostic tool for identifying and comparing water quality issues across diverse environments. The persistently high WQI values in Okrika emphasize the urgent need for improved environmental monitoring, stricter regulation of industrial effluents, and enhanced management of coastal ecosystems to protect public health and sustain aquatic life.

The hydrochemical and irrigation water quality indices of the present study on creek waters from Okrika communities reveal a complex hydrochemical system characterized by excellent sodium adsorption properties but extremely high salinity levels. The evaluation of parameters such as Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Hazard (MH), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC), Kelly's Index (KI), Permeability Index (PI), and the interpretation of Piper, Wilcox, and USSL diagrams provides a detailed insight into the suitability of these waters for irrigation. When compared with similar studies from different parts of Nigeria and the world, the hydrochemical signature of the Okrika creeks shows both similarities and contrasts. While the ionic dominance pattern (Ca–Mg–Cl–SO$_4$ type) aligns with the findings in many coastal and mining-impacted regions, the exceptionally high electrical conductivity (EC) values distinguish the Okrika water as one of the most saline among comparable sites.

The Sodium Adsorption Ratio (SAR) in the present study ranged from 0.554 to 1.446, placing all stations in the "excellent" irrigation class (SAR < 10). This indicates minimal risk of sodium hazard to soil permeability and structure when used for irrigation. This finding is in close agreement with studies from different regions of Nigeria and beyond. For instance, Adetunji et al. (2025) reported SAR values ranging between 0.1 and 0.8 in groundwater samples from southwestern Nigeria, categorizing them as excellent for irrigation. Similarly, Obasi et al. (2021) and Nwankwoala et al. (2023) documented SAR values below 2.0 in the Niger Delta and southeastern Nigeria, respectively, confirming that sodium hazards are rarely a limiting factor in Nigerian waters. Globally, Giri et al. (2022) observed SAR values less than 5.0 in surface and groundwater samples from India's coastal deltaic systems, while Manu et al. (2023) reported values below 2.0 in the Volta Basin of Ghana, all suggesting excellent irrigation potential. The consistency of the Okrika SAR values with these reports indicates that sodium adsorption remains a minor challenge for irrigation in saline coastal zones, even where other hydrochemical constraints exist.

However, the Soluble Sodium Percentage (SSP) in Okrika creeks, ranging from 17.94% to 54.11%, presents a more complex scenario. While WS1 and WS2 (17.94% and 19.1%) fall within the safe limit (SSP < 50%), WS3 exceeds this threshold (54.11%), indicating the onset of sodium hazard. This pattern aligns with observations from Obasi et al. (2021) and Nwankwoala et al. (2023), where localized areas in southeastern Nigeria showed SSP values between 30% and 60%, reflecting moderate sodium hazards due to

anthropogenic inputs and saline intrusion. In contrast, Adetunji et al. (2025) found lower SSP values (10–33%) in freshwater systems, suggesting that inland waters are less prone to sodium enrichment. On a global scale, studies from Egypt (Eid et al., 2023) and India (Giri et al., 2022) reported SSP values between 15% and 43%, slightly lower than those recorded in Okrika. Hence, the SSP data from Okrika both aligns with and slightly exceeds the global trend, particularly in WS3, where the combined effects of saline intrusion and anthropogenic contamination appear more pronounced.

Kelly's Index (KI) values in the Okrika creeks ranged from 0.194 to 1.058, with WS1 and WS2 within the safe limit (KI < 1), and WS3 slightly exceeding it (KI = 1.058). This indicates that while most stations have balanced calcium and sodium concentrations, WS3 reflects a marginal sodium hazard. Similar observations were made in the Niger Delta (Obasi et al., 2021) and southeastern aquifers (Nwankwoala et al., 2023), where KI ranged from 0.11 to 0.53, all within the acceptable range. Globally, Giri et al. (2022) and Manu et al. (2023) also found KI values below 1.0, suggesting that irrigation waters in diverse environments rarely exceed this limit unless impacted by saline or anthropogenic sources. Therefore, the Okrika data generally aligns with both Nigerian and global patterns, although WS3's slightly elevated KI indicates localized sodium enrichment possibly linked to industrial discharge or tidal mixing effects typical of estuarine creeks.

The Magnesium Hazard (MH) and Magnesium Adsorption Ratio (MAR) values in the present study further support the assessment of irrigation suitability. The MH ranged from 35.66% to 41.95%, and MAR was 0% for WS3, all below the 50% critical limit, indicating that magnesium does not pose a threat to soil quality or crop productivity. These findings are consistent with those reported by Obasi et al. (2021) and Nwankwoala et al. (2023), who recorded MH values between 30% and 81% across various Niger Delta aquifers, noting that values below 50% are generally safe. Internationally, Giri et al. (2022) and Manu et al. (2023) also identified MH values below 60% as indicative of non-hazardous irrigation waters. The Okrika creeks therefore align well with both local and global observations in terms of magnesium behavior, underscoring that the region's salinity is more chloride- and sodium-driven rather than magnesium-dominated.

Residual Sodium Carbonate (RSC) values in the Okrika creeks ranged from -4.28 to -0.93, with all samples showing negative values. This indicates the absence of carbonate or bicarbonate hazards, making the waters safe for irrigation from this perspective. Similar negative RSC values (–5 to +3.5) have been reported by Obasi et al. (2021) and Nwankwoala et al. (2023) for groundwater and surface water in southeastern Nigeria, as well as by Giri et al. (2022) for river waters in India. Negative RSC values signify that calcium and magnesium ions exceed carbonate and bicarbonate concentrations, preventing the precipitation of harmful sodium carbonate salts that can reduce soil permeability. Thus, the RSC results from Okrika strongly align with both national and global findings.

The Permeability Index (PI) values in the current study ranged from 16.33% (WS2) to 51.61% (WS3), suggesting moderate suitability for irrigation. PI values below 25% are considered unsuitable, while values between 25% and 75% indicate moderate to good quality. Adetunji et al. (2025) and Obasi et al. (2021) reported PI values between 22% and 185% across Nigerian water systems, while Giri et al. (2022) and Manu et al. (2023) found global ranges of 45%–95%. This suggests that the Okrika results fall on the lower end of the suitability spectrum, likely due to the influence of excessive salinity. Thus, while the Okrika waters remain moderately suitable based on PI, they contrast somewhat with more favorable global irrigation waters, where permeability tends to be higher under lower salinity conditions.

The most striking difference between the present study and comparable investigations lies in the Electrical Conductivity (EC) values. The Okrika creeks recorded extremely high EC levels, ranging from 17,130 to 20,086 $\mu S/cm$, placing all samples in the "very high salinity" (C4) class according to the USSL classification. In contrast, most Nigerian studies report EC values between 18 and 1,560 $\mu S/cm$ (Adetunji et al., 2025; Obasi et al., 2021; Nwankwoala et al., 2023), while global reports such as those by Giri et al. (2022) and Manu et al. (2023) indicate EC values generally below 2,000 $\mu S/cm$ for river and irrigation waters. The Okrika EC values therefore far exceed both national and international benchmarks. Such extreme salinity is typical of coastal or estuarine environments where tidal influence, industrial discharges, and saline groundwater interactions contribute to elevated ionic loads. Consequently, while Okrika waters share similar hydrochemical patterns with other regions, the magnitude of salinity represents a sharp contrast that restricts irrigation suitability to only salt-tolerant crops.

The Piper diagram for the Okrika creeks identifies a Ca–Mg–Cl–SO$_4$ water type, dominated by alkaline earth metals and strong acid anions. This hydrochemical facies aligns with patterns reported in Obasi et al. (2021) and Nwankwoala et al. (2023), where Ca–Mg–Cl and Ca–Cl water types were common in the Niger Delta and southeastern Nigeria. Globally, Giri et al. (2022) and Manu et al. (2023) also reported Ca–Mg–Cl or Ca–Cl types in coastal and industrially influenced waters, indicating that such ionic dominance is typical of environments with evaporative concentration and seawater mixing. Thus, the Okrika hydrochemical facies aligns closely with both national and global trends.

The Wilcox diagram further supports these observations. It places Okrika samples within the "Admissible to Doubtful" category due to %Na values between 17.94% and 54.11% and extremely high EC levels. WS1 and WS2 fall within the Admissible-Doubtful range, while WS3 lies close to the Doubtful zone. This pattern corresponds to those observed in the Niger Delta and other coastal areas, as documented by Nwankwoala et al. (2023) and Eid et al. (2023), though the EC values in those studies were significantly lower. The USSL diagram classification of C4–S1 (very high salinity, low sodium hazard) further

confirms that Okrika waters, though safe from sodium effects, are critically impacted by salinity, limiting their irrigation potential. Comparatively, other Nigerian and international sites mostly fall into the C1–S1, C2–S1, or C3–S1 classes, representing low to moderate salinity (Obasi et al., 2021; Eid et al., 2023; Giri et al., 2022). Hence, the Okrika results both align and contrast: they align in the pattern of low sodium hazard (S1) but sharply contrast in salinity magnitude (C4).

In summary, the comparative discussion reveals a strong alignment between Okrika's hydrochemical indices (SAR, MH, MAR, RSC, and ionic composition) and other Nigerian and global studies, indicating similar processes of ion exchange, mineral dissolution, and limited sodium hazard. However, the Okrika creeks stand out for their exceptionally high electrical conductivity and total dissolved solids, making them unsuitable for irrigation except for salt-tolerant crops. The Piper, Wilcox, and USSL diagram interpretations further confirm that Okrika waters belong to the Ca–Mg–Cl–SO₄ type with very high salinity—a pattern similar in type but not in intensity to other reported studies. Therefore, while the Okrika study aligns with global hydrochemical trends in structure and ionic dominance, it contrasts sharply in terms of salinity magnitude, reflecting the unique coastal and industrial influences of the Okrika environment.

IV. CONCLUSION

The Water Quality Index (WQI) results classified all creek water samples as unsuitable for drinking due to elevated salinity and chloride concentrations, despite other parameters being within acceptable limits. The WQI trend (WS2 > WS1 > WS3) confirms spatial variations in contamination, primarily driven by ionic enrichment from saline and anthropogenic inputs. These findings indicate that the water is more suited for aquatic and possibly industrial use than for domestic consumption.

Hydrochemical and irrigation indices revealed that the waters are generally excellent for irrigation in terms of Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), and Residual Sodium Carbonate (RSC). However, Soluble Sodium Percentage (SSP) and Kelly's Index (KI) values at WS3 exceeded safe limits, suggesting potential soil permeability challenges if used continuously for irrigation. The Piper, Wilcox, and USSL diagrams indicated a Ca–Mg–Cl–SO₄ water type with very high salinity but low sodium hazard, confirming that while irrigation use is possible, salinity management would be necessary to prevent soil degradation.

For irrigation purposes, it is recommended that the creek water be used with caution in areas where high salinity could impact soil permeability and crop productivity. Periodic soil salinity assessment and the application of proper drainage and leaching practices would help mitigate salinity-related challenges. Farmers should be sensitized to blend creek water with freshwater sources when available to maintain sustainable irrigation quality.

Overall, the findings underscore the importance of proactive environmental management, continuous water quality evaluation and sustainable utilization of creek resources to ensure ecological stability and safeguard human health in Okrika communities.

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