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# Hydrogeochemical Characteristics and Irrigation Indices of Water Resources in Eyaa Community Onne Rivers State

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***Abstract***
*Surface and groundwater in Eyaa Community, Onne, Rivers State were assessed in this study. Hydrogeochemical properties were determined by plotting the Piper, Durov and Gibbs diagrams were determined using an adopted mathematical model, and classification of water for irrigation purposes made by plotting the Wilcox diagrams. The results of plot of the Durov diagram showed that the Hydrogeochemistry of groundwater in the area was characterized majorly by Ion Exchange and Simple Dissolution processes. Plots of the Wilcox diagrams indicate that fresh and ground water in the area is suitable for irrigation. The results show that the fresh and ground water bodies are very suitable for irrigation purposes and should be well utilized.*
***Keywords: Hydrogeochemical, Irrigation, Eyaa Community, Onne, Piper, Durov, Wilcox diagrams***

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## I. Introduction

Water, a prime natural resource and precious national asset, forms the chief constituent of the ecosystem. Water sources may be mainly in the form of rivers, lakes, glaciers, rain water, ground water etc. Besides the need of water for drinking, water resources play a vital role in various sectors of economy such as agriculture, livestock production, forestry, industrial activities, hydropower generation, fisheries and other creative activities. The availability and quality of water either surface or ground, have been deteriorated due to some important factors like increasing population, industrialization, urbanization, etc (Tyagi *et al.,* 2013).

United Nations (2021) stated that water is a precondition for human existence and for the sustainability of the planet, it is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself, it is vital for reducing the global burden of disease and improving the health, welfare and productivity of populations and is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society and the environment.

Rivers are indispensable freshwater systems that are essential for the continuation of life. They are resources of great importance across the globe. The benefits of these systems to all living organisms cannot be over emphasized as they remain one of the most vital human needs (Edwin & Murtala, 2013).

The quality of any surface water body is a function of either or both natural influences and human activities. Of all the human activities, industrial waste is the most common source of water pollution in recent times. The quantum of these pollutants is such that rivers receiving these effluents cannot give dilution needed for their continued existence as good quality water sources (Edwin & Murtala, 2013).

Surface water sources in pristine environments are always of better quality when compared to those prone to anthropogenic influences. Surface waters are the best sinks for several point and non-point sources of pollution such as wastewater from agricultural and industrial processes, storm runoff amongst others (Edokpayi *et al.,* 2017, Odiyo *et al.,* 2012).

Groundwater is often the first alternative choice of many consumers due to its perceived cleanness and safeness. However, many studies have shown that groundwater can appear clean but houses a wide variety of pathogenic organisms (Olasoji *et al.,* 2019). The safety of groundwater (shallow and deep groundwater sources) depends on a number of factors amongst which are (I) the geology of the area (II) human activities/land use activities of the area (III) environmental and meteorological conditions of the area (Olasoji *et al.,* 2019).

Rural dwellers rely basically on hand-dug wells for potable water supply as the streams usually dry up in dry season. These resources are under threat from pollution either from human lifestyle manifested by the low level of hygiene practiced in the developing nations (Punmia & Jain, 1998; Akujieze *et al.,* 2003). The neglect of rural areas in most developing countries in terms of basic infrastructures such as pipe-borne water and sanitation facilities exposes the villagers to a variety of health related problems such as water – borne diseases (Sridhar, 2000).

Groundwater pollution is mainly due to the process of industrialization and urbanization that has progressively developed over time without any regard for environmental consequences (Longe & Balogun, 2010).

Landfills have been identified as one of the major threats to groundwater resources (Fatta *et al.*, 1999; USEPA, 1984). The dumped solid wastes gradually release its initial interstitial water and some of its decomposition by-products get into the water moving through the waste deposit. Such liquid containing innumerable organic and inorganic compounds is called *Leachate*. This leachate accumulates at the bottom of the landfill and percolates through the soil (Mor *et al.*, 2006).

Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate originating from the nearby site. Such contamination of groundwater resource poses a substantial risk to local resource user and to the natural environment. The impact of landfill leachate on the surface and groundwater has given rise to a number of studies in recent years (Saarela, 2003; Abu-Rukah & Al-Kofahi, 2001; Looser *et al.*, 1999; Christensen *et al.*, 1998; De Rosa *et al*., 1996; Flyhammar, 1995).

When there is an interference of pollutant chemicals with water, there is a resultant decrease in its quality and this can only be known when the different parameters of water assessment have gone beyond the regulated limit for consumption, through laboratory measurements (Edori, 2020).

Research has shown that eighty percent of all the diseases which claim lives in the third world countries are directly related to poor drinking water quality (Jeffre, 2008). More than six million children die yearly (about 20,000 children per day) as a result of waterborne diseases linked to shortage of safe drinking water or sanitation (TWAS, 2002). The deterioration of water in physical and chemical properties is often slow and not readily noticeable as the water system adapts to the changes until an obvious alteration of the water occurs (Al-Janabi, 2018).

Oni & Fasakin (2016), remarked that ever since the *Earth Summit* in Rio de Janeiro in June 1992, awareness on the environment and sustainable development has increased tremendously all over the world. More importantly, is the greater awareness of and concern over the growing scarcity of potable water (United Nations, 1992).

This is not surprising as clean water supplies and sanitation remain persistent problems in many parts of the world, with approximately a fifth of the global population lacking access to potable water (UNEP, 2008).

It becomes imperative to monitor the quality of the river in order to prevent it from further deterioration and ensure availability of quality water for domestic and agricultural purposes (Edwin & Murtala, 2013).

Evaluation of water quality can be defined as the analysis of physical, chemical and biological characteristics of water. Water quality indices aim at giving a single value to the water quality of a source reducing great amount of parameters into a simpler expression and enabling easy interpretation of monitoring data (Bharti & Katyal, 2011)."

## II. Materials And Methods

### Study Area

Eyaa community is located between latitude 4°43′58N and longitude 7°9′28E in Onne, Eleme Local Government Area, Rivers State, Nigeria. The fresh water (*Aji Nmu)* is of strategic importance to the community in Onne as it constitutes the major source of their domestic water including hand dug wells (groundwater).

The river flows from the ground water aquifer and especially surface run-offs during the raining (wet) season. It empties into *Nmu kpokiri* brackish water and becomes mixed with brackish water during high tide or flow of the brackish water.

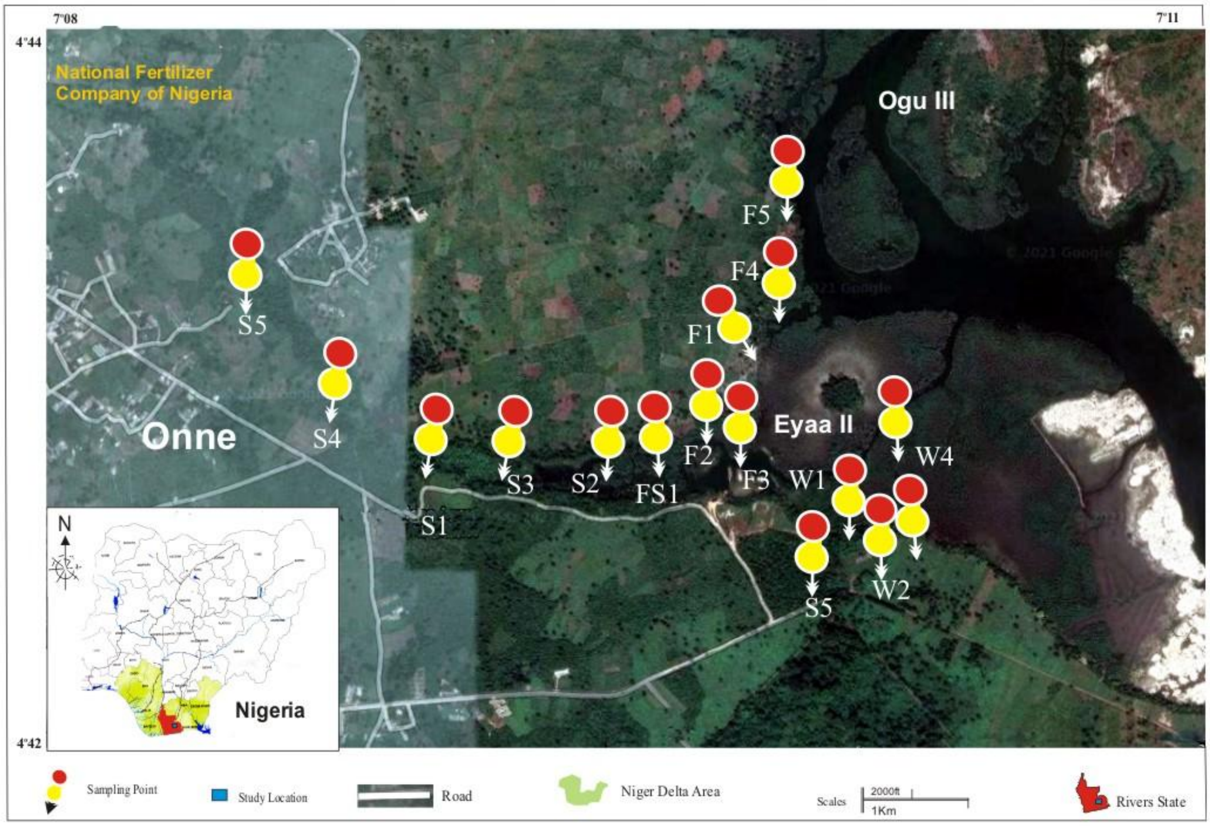


**FIG. 1: Map of Study Area showing Sampling Locations**

**Determination of Irrigation Parameters**

The Sodium Adsorption Ratio (SAR) was calculated by the following equation given as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (3.21)$$

Where, all the ions are expressed in meq/L.

Soluble Sodium Percentage (SSP) was calculated by the following equation:

$$SSP = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \quad (3.22)$$

Where, all the ions are expressed in meq/L.

The Residual Sodium Bi-carbonate (RSBC) was calculated as:

$$RSBC = HCO_3^{-} - Ca^{2+} \quad (3.23)$$

Where, RSBC and the concentration of the constituents are expressed in meq/L.

The Permeability Index (PI) was calculated by the following Equation:

$$PI = Na^{+} + \left(\frac{\sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}}\right) X\ 100 \quad (3.24)$$

Where, all the ions are expressed in meq/L.

Magnesium Adsorption Ratio (MAR) was calculated by the equation:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} X\ 100 \quad (3.25)$$

Where, all the ionic concentrations are expressed in meq/L.

The Kelly's Ratio was calculated using the equation:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (3.26)$$

Where, all the ionic concentrations are expressed in meq/L.

# III. RESULTS

**Irrigation Parameters**

Table 1 shows values obtained for the various Irrigation Parameters assessed in the study area. Sodium Adsorption Ratio (SAR) values ranged from 0.16 – 6.61; Soluble Sodium Percentage (SPP) values ranged from 13.80 – 68.90; Permeability Index (PI) values ranged from 19.2 – 112.2; Kelly Ratio (KR) values ranged from 0.16 – 2.21, Magnesium Adsorption Ratio (MAR) values ranged from 67.4 – 97.8 and Residual Sodium Carbonate (RSC) values ranged from-214.51 to 0.03 across all hand dug wells in the study area.

**Wilcox Diagram**

Sodium Adsorption Ratio and Soluble Sodium Percentage are widely used for assessing the suitability of water for irrigation purposes and the Wilcox diagram (Wilcox, 1995) relates a plot of SAR vs Electrical conductivity (EC) and Na% vs EC to designate irrigation water quality.

The different classes of the Wilcox SAR vs EC diagram include low, C1 (EC < 250 µS/cm); medium, C2 (EC 250–750 µS/cm); high, C3 (EC 750 -2250 µS/cm); and very high, C4 (EC > 2250 µS/cm), and the sodium hazard classes include: low, S1 (SAR < 10); medium, S2 (SAR 10 -18); high, S3 (SAR 18–26); and very high, S4 (SAR > 26)". The SAR vs EC diagram is shown in Fig. 8.

The different classes of the Wilcox Na% vs EC diagram include: "Excellent to Good, Good to Permissible, Permissible to Doubtful, Doubtful to Unsuitable and Unsuitable" (Figure 9).

**Table 1: Values for Irrigation Index Parameters**

| STATION | Sodium Adsorption Ratio | Soluble Sodium Percentage | Kelly Ratio | Residual Sodium Carbonate | Permeability Index | Magnesium Ratio |
|---|---|---|---|---|---|---|
| S1 | 6.61 | 25.8 | 0.35 | -179.88 | 25.9 | 97.5 |
| S2 | 8.26 | 28.5 | 0.40 | -214.04 | 28.6 | 97.8 |
| S3 | 7.93 | 27.7 | 0.38 | -214.51 | 27.8 | 97.5 |
| S4 | 6.43 | 29.1 | 0.41 | -122.33 | 29.3 | 97.8 |
| S5 | 6.13 | 28.9 | 0.41 | -113.18 | 29.1 | 97.1 |
| W1 | 0.23 | 14.8 | 0.17 | -0.74 | 30.2 | 67.4 |
| W2 | 0.27 | 14.0 | 0.16 | -1.28 | 19.2 | 84.3 |
| W3 | 0.83 | 68.9 | 2.21 | 0.03 | 112.2 | 76.2 |
| W4 | 0.52 | 17.5 | 0.21 | -2.93 | 20.2 | 83.1 |
| FS | 0.53 | 27.9 | 0.39 | -0.78 | 40.8 | 94.7 |
| F1 | 0.17 | 16.5 | 0.20 | -0.28 | 32.5 | 80.5 |
| F2 | 0.63 | 45.1 | 0.82 | -0.18 | 66.5 | 91.3 |
| F3 | 0.27 | 18.6 | 0.23 | -0.57 | 35.7 | 94.4 |
| F4 | 0.42 | 23.3 | 0.30 | -0.78 | 37.1 | 91.6 |
| F5 | 0.16 | 13.8 | 0.16 | -0.37 | 39.7 | 75.1 |

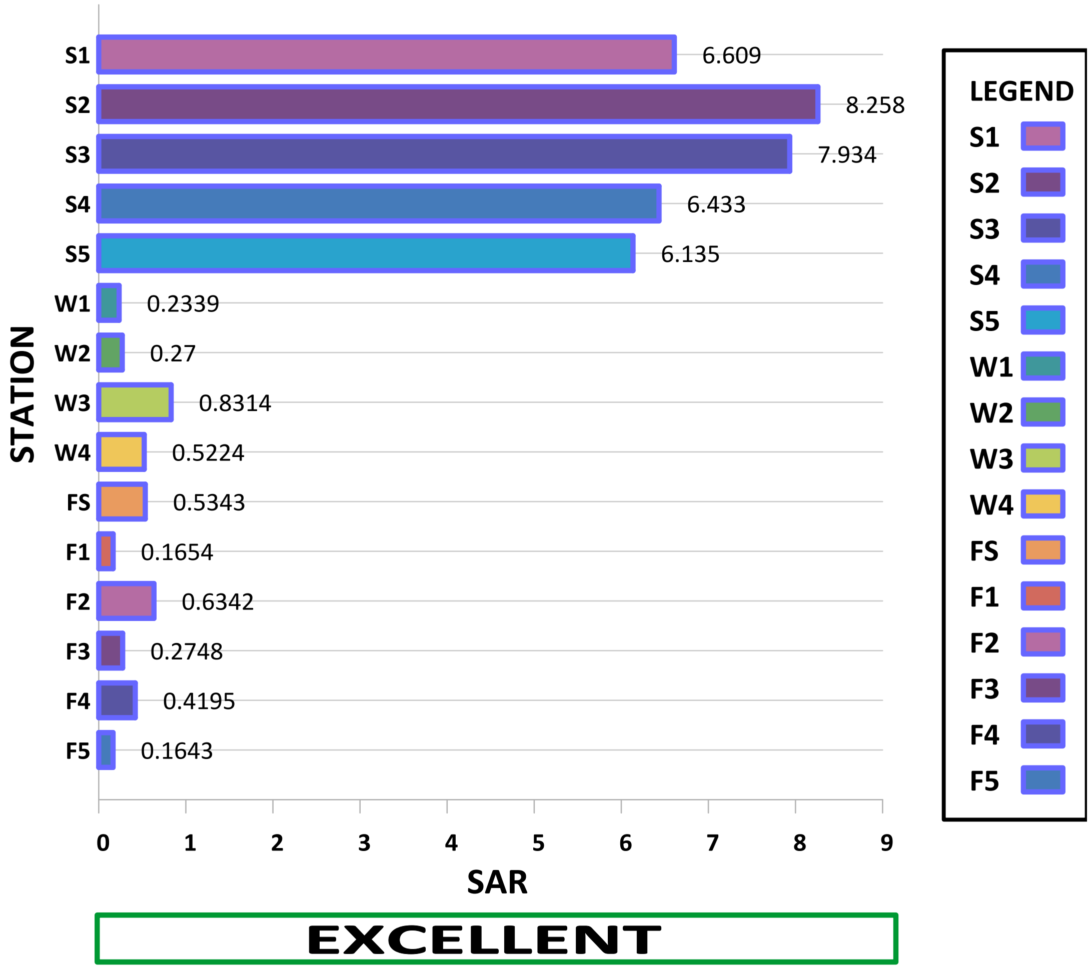


**Fig. 2: Sodium Adsorption Ratio (SAR) Values and Ratings for Surface and groundwater in the Study Area**

**SAR RATING:**
SAR<10= Excellent
SAR= 10-18 = Good/Safe
SAR= 18-26 = Doubtful/moderate
SAR > 26 =Unsuitable

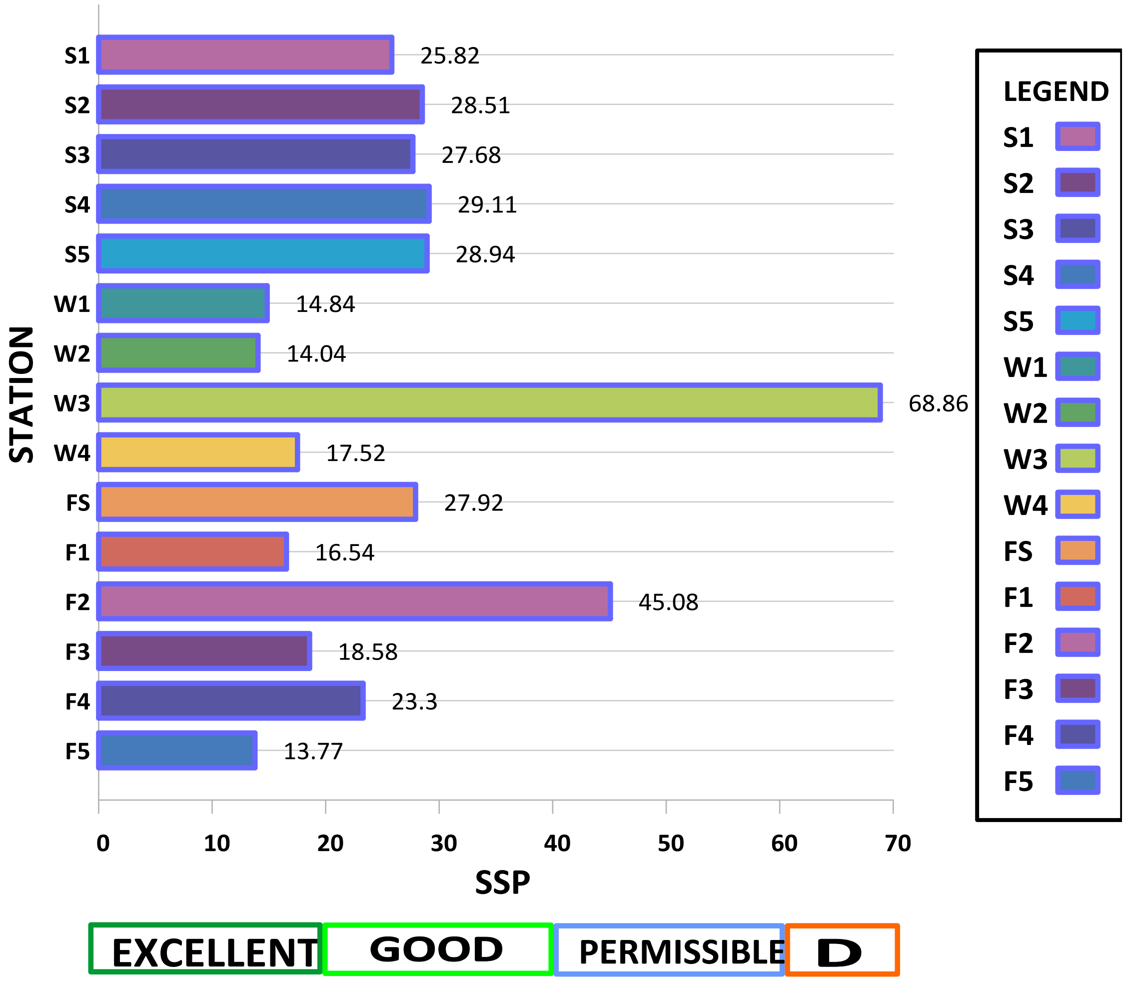


**Fig. 3: Soluble Sodium Percentage (SSP) Values and Ratings for Surface and groundwater in the Study Area**

**SSP RATING:**

| | | |
|---|---|---|
| SSP < 20 | = | EXCELLENT |
| SSP (20 – 40) | = | GOOD |
| SSP (40 – 60) | = | PERMISSIBLE |
| SSP (60 – 80) | = | DOUBTFUL (D) |
| SSP > 80 | = | UNSUITABLE |

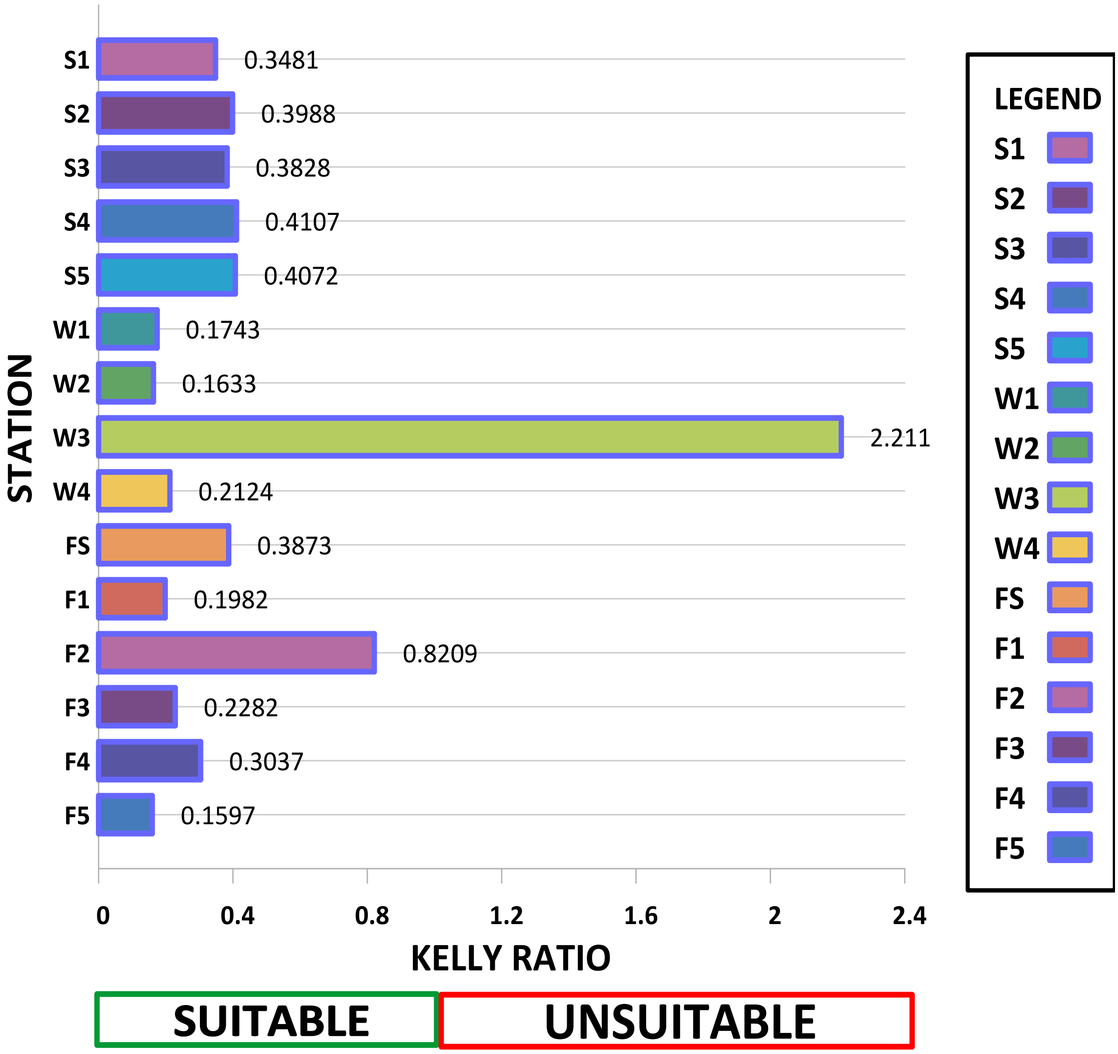


**Fig. 4: Kelly ratio (KR) Values and Ratings for Surface and groundwater in the StudyArea**

**KR RATING:**
KR < 1 = Suitable
KR > 1 = Unsuitable

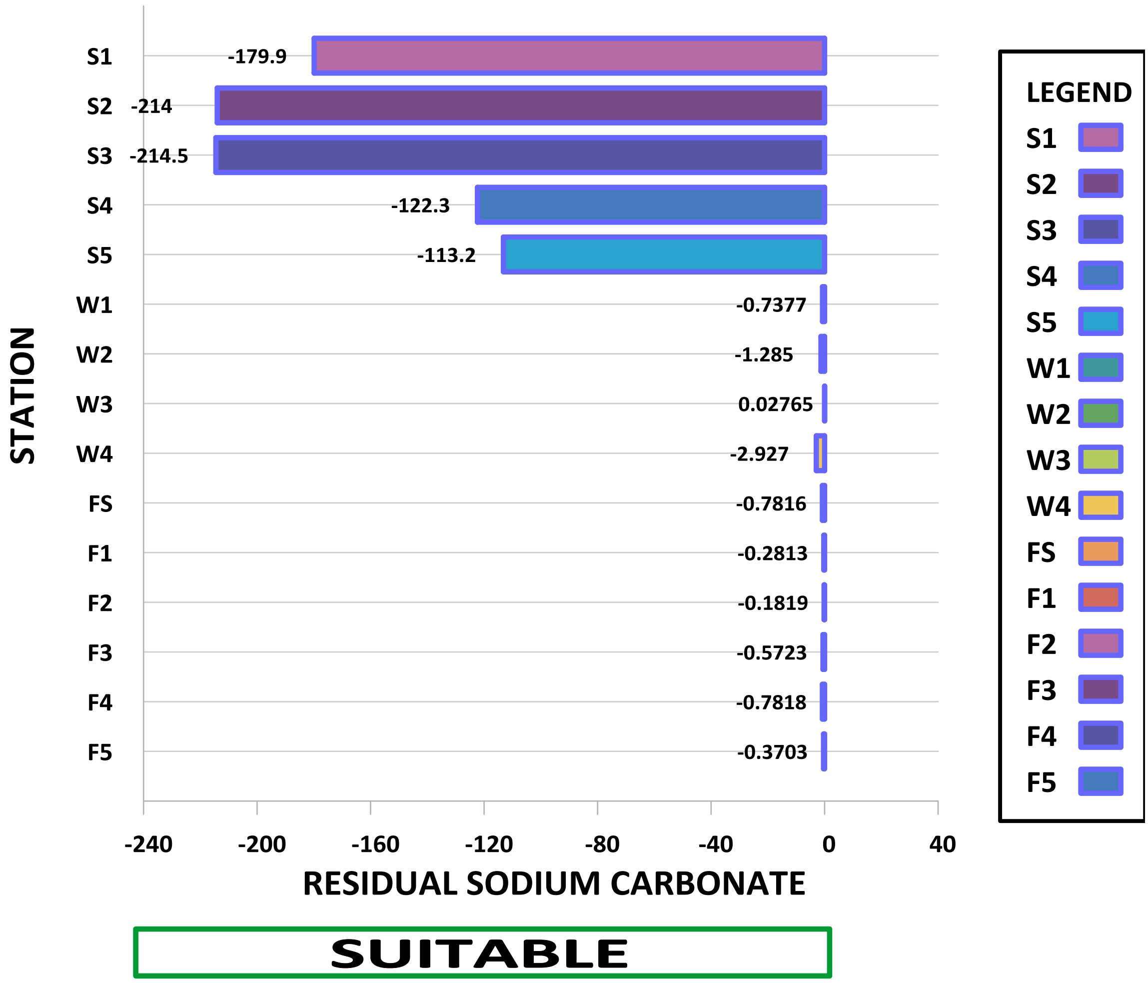


**Fig. 5: Residual Sodium Carbonate (RSC) Values and Ratings for Surface and groundwater in the Study Area**

**RSC RATING:**
RSC < 1.25 = Suitable
RSC (1.25 - 2.5) = Doubtful
RSC > 2.5 = Unsuitable

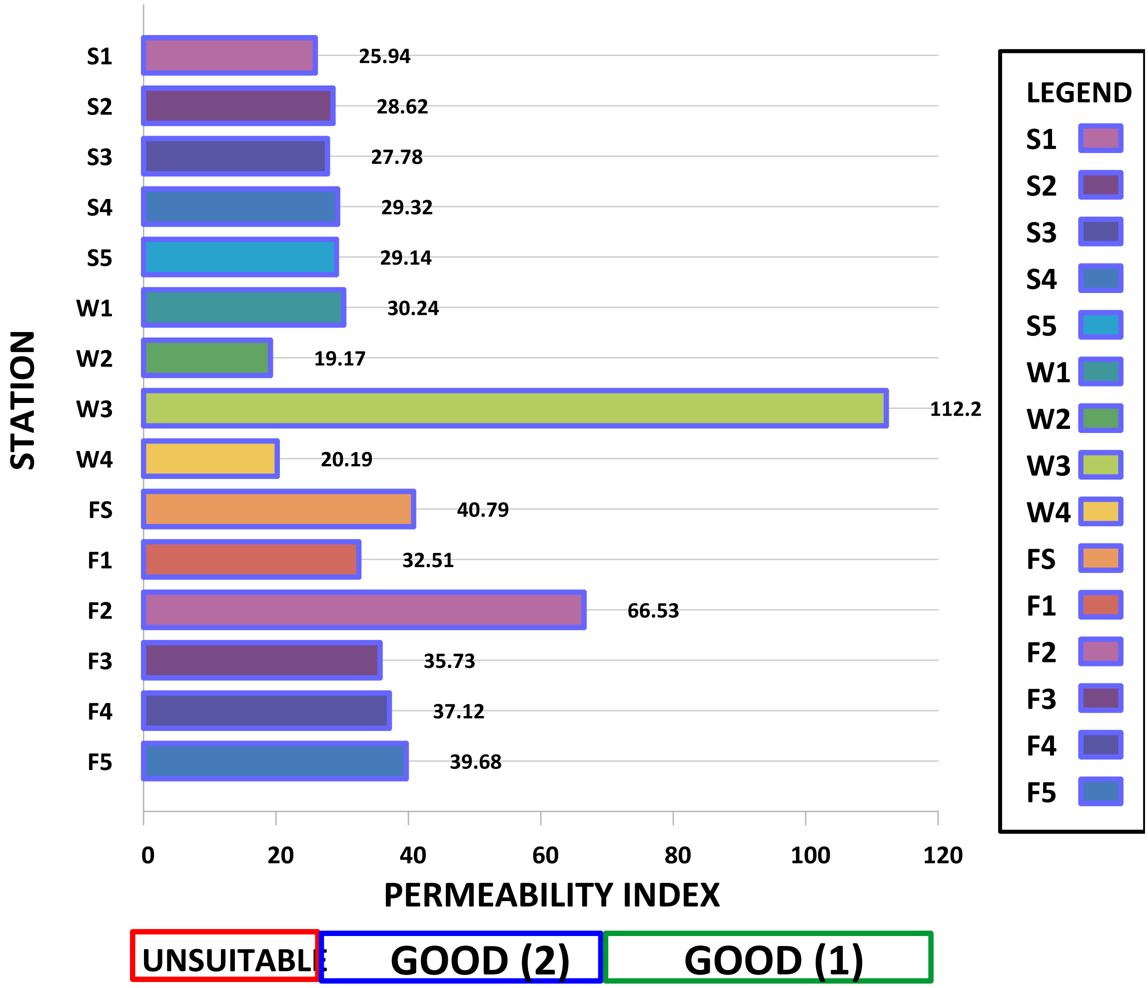


**Fig. 6: Permeability Index (PI) Values and Ratings for Surface and groundwater in the Study Area**

**PI RATING:**
PI >75% = Good (Class 1)
PI (25% - 75%) = Good (Class 2)
PI < 25% = Unsuitable

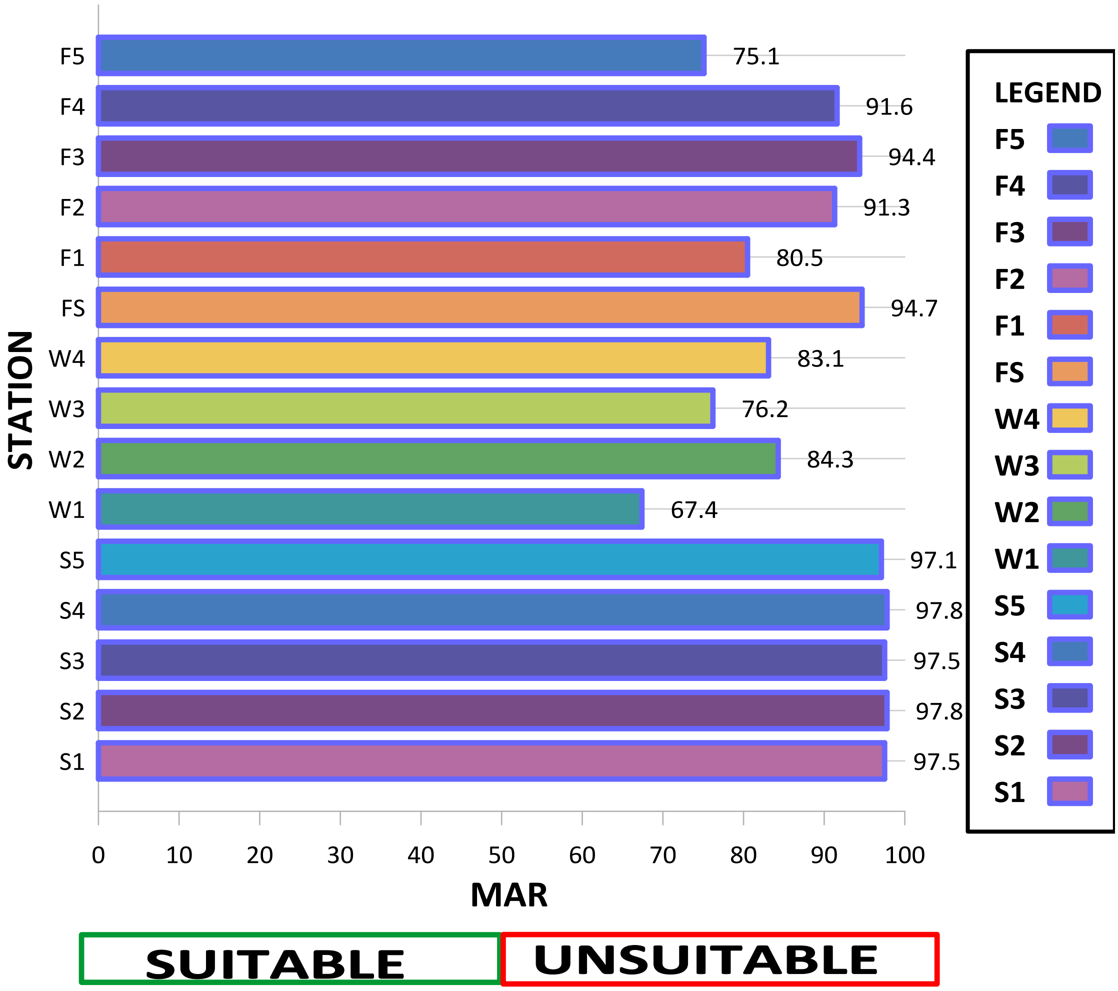


**Fig. 7: Magnesium Adsorption Ratio (MAR) Values and Ratings for Surface and groundwater in the Study Area**

**MAR RATING:**
MAR < 50 = Suitable
MAR > 50 = Unsuitable

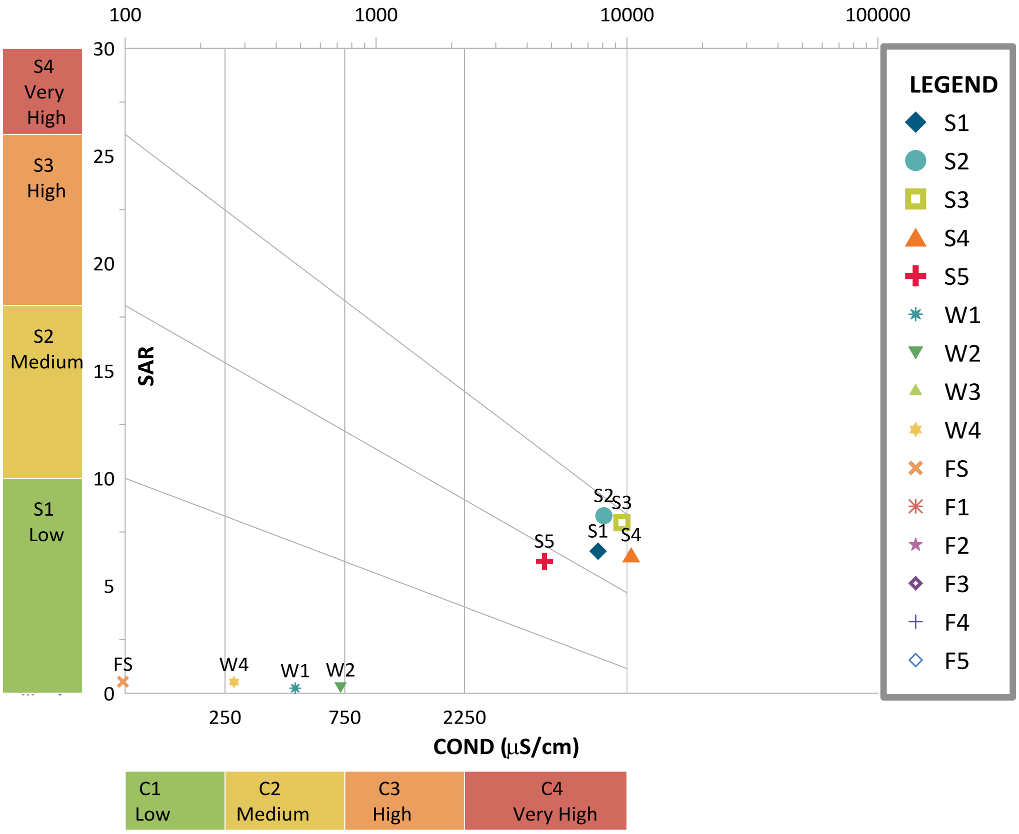


**Fig.8: Wilcox SAR vs Conductivity Plot for Suitability of Water for Irrigation Purposes**

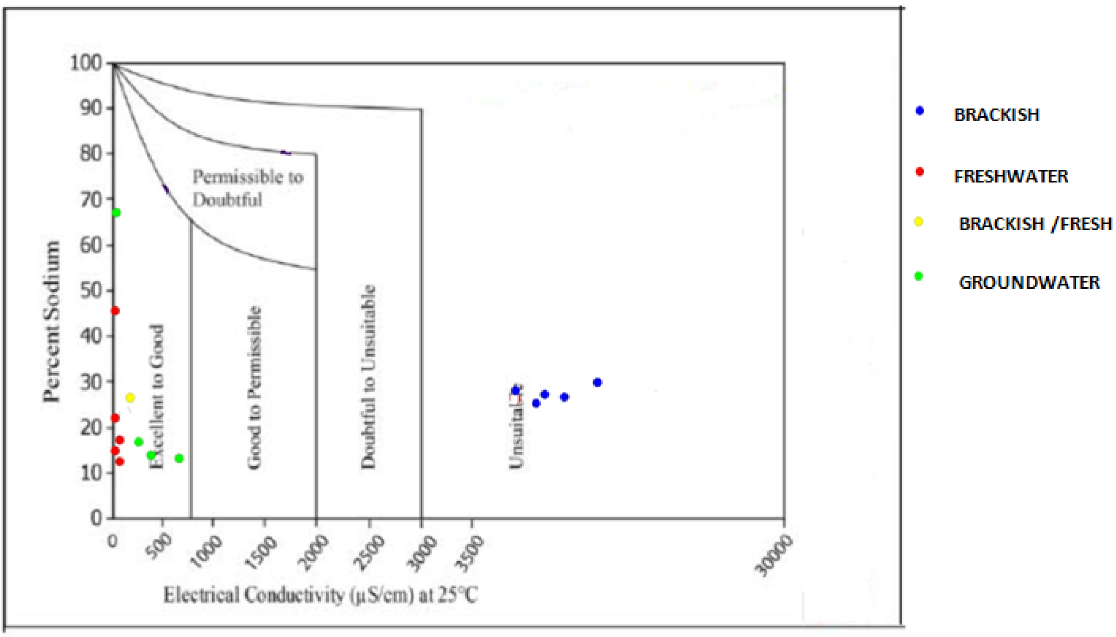


**Fig. 9: Wilcox SSP vs Conductivity Plot for Suitability of Water for Irrigation Purposes**

**Hydrogeochemistry**

Groundwater quality is dependent on nature of bedrock, topography, geology, soils, climate, atmospheric precipitation and quality of the recharged water in addition to anthropogenic pollution sources in terms of agricultural and industrial activities. Further, groundwater quality could be affected by means of subsurface geochemical reactions such as weathering, dissolution, precipitation, ion exchange and various biological processes. Gaining a clear understanding of the main factors governing groundwater chemistry is important for managing groundwater resources. The plots of the Piper, Durov and Gibbs Diagrams area used to investigate the hydrogeochemical properties of the water.

**Piper Trilinear Diagram**

Plotting of samples on the Piper Trilinear Diagram reveals the composition of the water in the different sampling stations, indicating the water type (Piper, 1944). The milliequivalents of the various anions and cations are used and are plotted in two different triangular graphs as shown in Figure 10. The points of these anions and cations on the x, y and z axes of the triangular graphs are extrapolated to determine the dominant ion types. The extrapolated points on the triangular graphs are further projected onto the diamond graph to determine the water type.

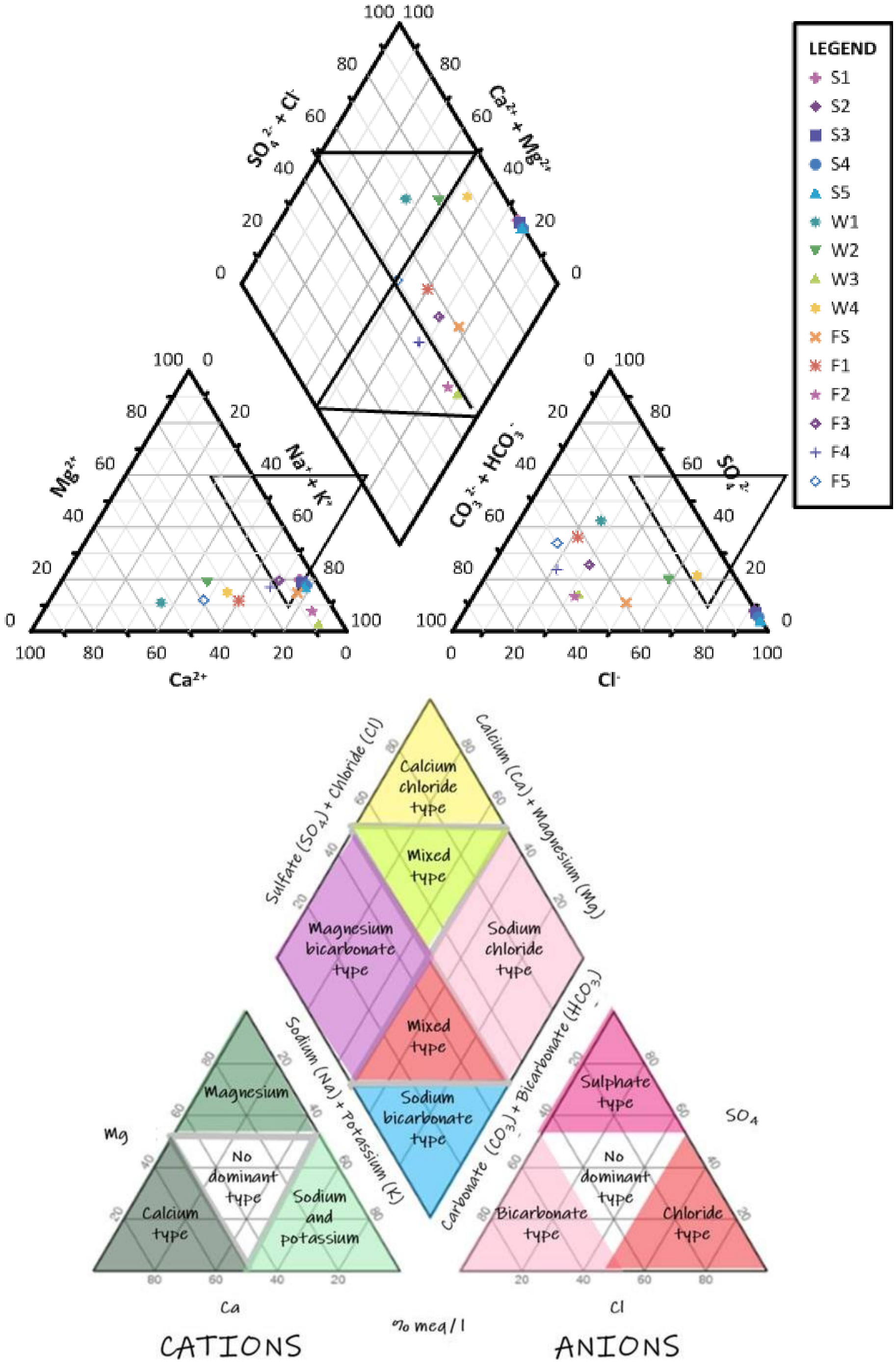


**Fig. 10: Piper Trilinear Diagram Showing the Classification of Water in the Hydrological Facieses**

**Durov's Diagram**

A Durov diagram (Figure 11) is a useful graphical tool that is widely used to identify the chemical relationship and evolution of groundwater samples (Chen *et al.*, 2019), and helps in the interpretation of the evolutionary trends and the hydrochemical processes occurring in the groundwater system. Like the piper diagram, milliequivalents of cations and anions are plotted on the triangular graphs and the extrapolated points are projected onto the square plot to determine the hydrogeochemical process. Water in the study areas was plotted on the Durov's diagram and classified according to Lloyd and Heathcoat (1985).

**Gibbs Diagram**

The Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics (Gibbs, 1970). According to the relationship between TDS vs [$Na^+$/ ($Na^+$ + $Ca^{2+}$)] and TDS vs [$Cl^-$/ ($Cl^-$ + $HCO_3^-$)], groundwater formation mechanisms are classified in three distinct fields such as Precipitation Dominance, Evaporation Dominance and Rock–Water Interaction Dominance areas, as shown in the Gibbs diagram (Fig. 12).

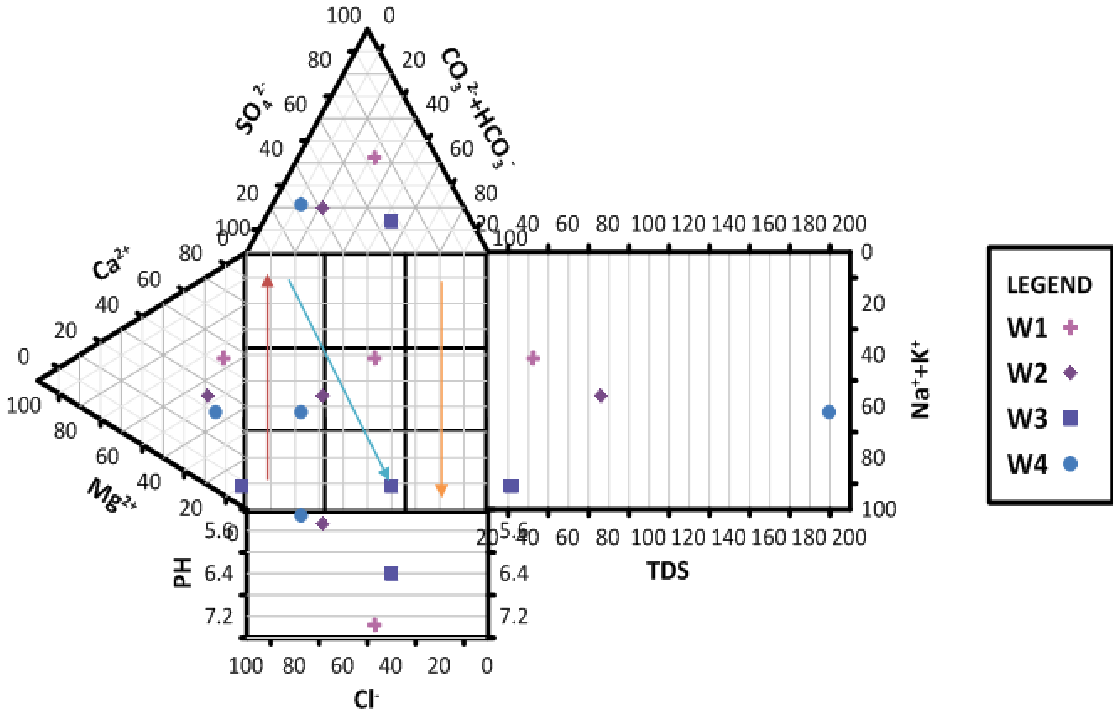


**Fig. 11: Extended Durov Diagram Depicting Hydrochemical Processes of Groundwater in the Study Area**
**Arrow showing Hydrochemical Processes of Groundwater:**

**Reverse ion exchange**

**Simple dissolution or mixing**
**ion exchange**

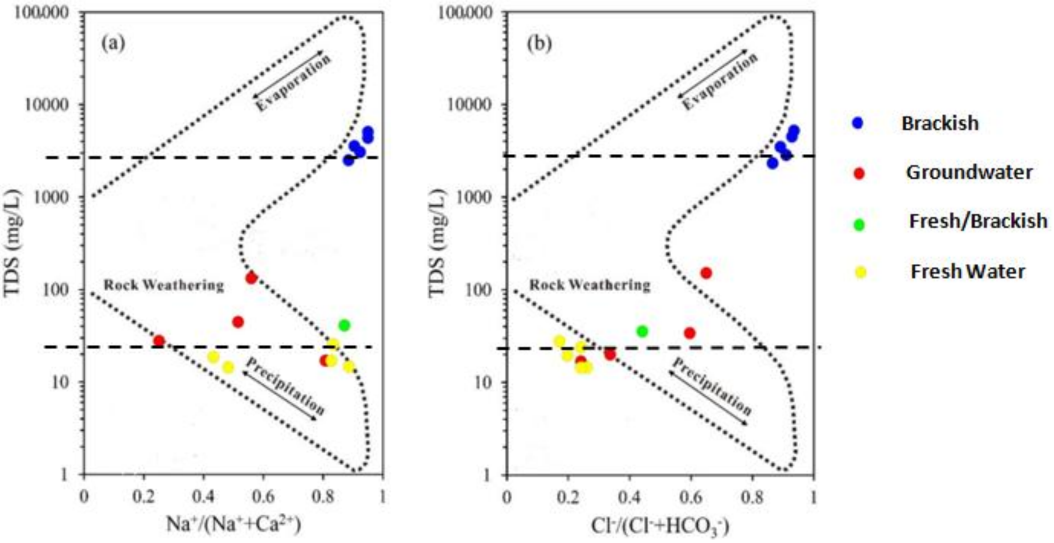


**Fig.12: Gibbs Analysis Chart of Groundwater Quality in the Study Areas**

## IV. DISCUSSION

**Irrigation Indices:**

Irrigation is an agricultural practice used to mitigate the lack of adequate soil moisture resulting from insufficient rainfall (George, 2004). The irrigation indices used in this study include Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Kelly Ratio (KR), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC) and Wilcox Diagrams. Ratings of the hand dug wells in the study area using these indices are shown in Figs. 2 – 7.

**Sodium Absorption Ratio (SAR)**

The SAR is a significant index for assessing the suitability of irrigated water to sodium hazard (Srinivasamoorthy *et al.*, 2014; Subramani *et al.*, 2005), and it relates more closely to the soil's exchangeable sodium percentages (Suarez *et al.*, 2006). The SAR classifies irrigation water as follows; [SAR<10 =Excellent], [SAR= 10-18 = Good/Safe], [SAR= 18-26 =Doubtful/moderate], [SAR> 26 =Unsuitable]. From the Sodium Adsorption Ratio (SAR) rating (Fig. 2), all the hand dug wells in the study area were rated as "Excellent" for irrigation purposes (SAR<10). According to Udom *et al.* (2017), "To determine whether the groundwater in the study area can be used for agricultural purposes will be based on the result obtained from the calculated sodium adsorption ratio (SAR). This is the most useful parameter that is used to determine the suitability of the groundwater of any area for agricultural purposes." The SAR value represents the sodium hazard.

**Soluble Sodium Percentage (SSP)**

The SSP is often utilized to identify the surface water suitability for agricultural application. The high contents of $Na^+$ in surface water, relative to $Ca^{2+}$ and $Mg^{2+}$ concentrations, react with the soil and decrease its permeability, which contributes to a deterioration of the soil structure, thus, development of stunting plant (Doneen, 1964; Todd, 1980). Irrigation water is classified according to the following SSP ranges; [<20 = Excellent], [20 – 40 = Good], [40 – 60 = Permissible], [60 – 80 =Doubtful] and [>80 = Unsuitable].

The Soluble Sodium Percentage (SPP) values (Fig. 3) show that 40% of the samples (F1, F3, F5, W1, W2, and W4) had water rated as "EXCELLENT" for irrigation purposes (SPP = 13.77 -17.57); 46% of the samples (S1, S2, S3, S4, S5, F4 and FS) had their water rated as "GOOD" for irrigation purposes (SPP= 23.30 – 29.11), 7% of the samples (F2) had their water rated as "PERMISSIBLE" for irrigation purposes (SPP= 45.08) and 7% (W3) was rated as "DOUBTFUL" (SPP= 68.86). According to Purushothman *et al.* (2012), "high contents of $Na^+$ in water, relative to $Ca^{2+}$ and $Mg^{2+}$ concentrations, react with soil and decrease its permeability, which contributes to a deterioration of the soil structure resulting to stunted plants".

**Kelly Ratio (KR)**

The KR is also used to assess the suitability of water used for irrigation. The KR reveals the excess quantity of sodium in water (Narsimha & Sudhakar, 2013). The KI values lower than one (KI < 1) are suitable for irrigation, whereas a value bigger than one (KI > 1) illustrate that excess sodium in the water was found (Kelley, 1940; Sundaray *et al.*, 2009).

Kelly Ratio (KR) values in this study (Fig. 4) show that 93% of samples (S1, S2, S3, S4, S5, F1, F2, F3, F4, F5, FS, W1, W2, W4) in the study area had their water rated as "SUITABLE" for irrigation purposes (KR = 0.1597 – 0.8209) while 7% of samples (W3) in the study area have their water rated as "UNSUITABLE" for irrigation purposes (KR = 2.211). The KR values lower than one (KR < 1) are suitable for irrigation, whereas values greater than one (KR > 1) are unsuitable due to high sodium concentration (Sundaray, 2009).

**Residual Sodium Carbonate (RSC)**

The alkalinity content plays an important role in determining the water suitability for irrigation water. The alkalinity concentration in excess of alkaline earth metals ($Ca^{2+}$ and $Mg^{2+}$) generates the term 'Residual Sodium Carbonate' (RSC) (Sundaray *et al.*, 2009; Ravikumar *et al.*, 2011), which indicates the hazardous effect of alkalinity on water quality for irrigation. The RSC classifies irrigation water based on the following ranges; [RSC < 1.25 =Good], [RSC= 1.25 - 2.5 =Doubtful], [RSC > 2.5 =Unsuitable].

Residual Sodium Carbonate (RSC) values (Fig. 5) show that all (100 %) the surface and groundwater samples in the study area had their water rated as "SUITABLE" for irrigation purposes (RSC < 1.25).

**Permeability Index (PI)**

The PI is often utilized to assess the appropriateness of the irrigation water, which is influenced by the long-term exposure of irrigation water with a high content of $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$ and alkalinity ions (Ravikumar *et al.*, 2011). The PI classifies irrigation water based on the following ranges; [PI >75% =Good (Class 1)], [PI = 25% - 75% =Good (Class 2)], [PI < 25% = Unsuitable].

Permeability Index (PI) values in this study (Fig. 6) show that 7% (W3 = 112.2) had their water rated as "Good (Class 1)", 80% (S1, S2, S3, S4, S5, F1, F2, F3, F4, F5, FS, W1,) had their water rated as Good (Class 2) (PI= 25.94 - 46.79) while 13% (W2 & W4) had their water rated as "Good (Class 1)" (P1 = 19.17 & 20.19). The PI assesses the suitability of irrigation water, which is influenced by high concentrations of $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$ and alkalinity ions (Ravikumar *et al.*, 2011).

**Magnesium Absorption Ratio (MAR)**

The MAR classifies irrigation water based on the following ranges; [MAR < 50% = Suitable], [MAR > 25% = Unsuitable].

Magnesium Absorption Ratio (MAR) values in this study (Fig. 7) show that 100 % of the surface and groundwater samples had their water rated as "Suitable" for irrigation purposes. Magnesium Adsorption Ratio (MAR) causes harmful effect to soil when it exceeds 50 (Gupta & Gupta 1987).

**Wilcox Diagrams**

The Wilcox (SAR vs Conductivity) diagram (Fig. 8) indicated that 47 % (FS, F1, F2. F3, F4, F5, W3) of the samples fell in the C1-S1 group indicating "Very Good" water quality; having low salinity and low sodium, 20 % (W1, W2, W4) of the samples fell in the C2-S1 group indicating "good" water quality and 33 % (S1, S2, S3, S4, S5) of the samples, representing all brackish water samples, fell in the C4-S3 group indicating "Poor" water quality. C1-S1 classes are perfect for irrigation. C2-S1 classes can be used for irrigation on almost all soils with little danger of sodium problem. C4-S4 classes are generally not suitable for irrigation. C2-S4, C3-S2 and C3-S4 classes are marginal /doubtful for irrigation. The Wilcox (Soluble Sodium Percent vs Electrical Conductivity) diagram (Fig. 9) also showed that all the freshwater, fresh/brackish water and groundwater samples in the study area fell into the "Excellent to Good" water class, suitable for irrigation purposes, while all brackish water samples were unsuitable for irrigation purposes.

**Hydrogeochemistry**

In this study, the cations plotted in the Piper diagram (Fig. 10) showed a dominance of the Sodium ($Na^{+}$) and Potassium ($K^{+}$) type, having 80 % of the samples (S1, S2, S3, S4, S5, F1, F2, F3, F4, FS, W3 & W4); 7 % (W1) was plotted in the calcium ion type while 13 % (W2 & F5) was plotted in 'no dominant ion type'. In the anion plot, Chloride ion type showed dominance, having 53 % of the samples (S1, S2, S3, S4, S5, FS, W2 & W4); 27 % (W3, F2, F4 & F5) was plotted in the bicarbonate ion type while 20 % (F1, F3 & W1) was plotted in 'no dominant ion type'. The diamond plot revealed that the 60 % of the samples (S1, S2, S3, S4, S5, FS, F1, F3, W4) were confined to the sodium chloride types, while 40 % (F2, F4, F5, W1, W2, W3) was plotted in the 'no dominant type' section.

From the Durov's diagram (Fig.11) of the study area, the square plots interpret the hydrogeochemical processes according to Lloyd and Heathcoat (1985). It was observed that groundwater in the study area had 50 % (W2 &

W4) of water samples indicating ion exchange while 50 % of the water samples (W1 & W3) indicated simple dissolution/mixing to be the main hydrogeochemical processes affecting the groundwater quality.

The rectangular plot also revealed that the water in the study area is fresh, having Total Dissolved Solids levels within 0 ppm – 1000 ppm (Carroll, 1962). The data points on the Gibbs diagram (Fig. 12) suggest that the brackish water chemistry is controlled principally by evaporation, freshwater principally controlled by precipitation while fresh/brackish water and groundwater was principally controlled by rock weathering.

## V. CONCLUSION

Results from the assessment of eleven surface water and four groundwater (well water) sample stations in the study area found pH levels of groundwater to be acidic and below acceptable limit. Very high sodium and electrical conductivity were measured. The Piper Diagram showed that Sodium and potassium ions and chloride ions were found to be the dominant cations and anions respectively. The hydrogeochemistry of water in the area, as shown in the Durov diagram, revealed that simple dissolution/mixing and ion exchange were the main processes governing groundwater evolution in the area; while the Gibb's diagram revealed that the brackish water chemistry is controlled principally by evaporation, freshwater principally controlled by precipitation while fresh/brackish water and groundwater was principally controlled by rock weathering. Irrigation indices showed that the freshwater and ground water samples in the area were suitable for irrigation while the brackish water samples were unsuitable for irrigation purposes.

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