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Seasonal Sodium Percentage (%NA), Absorption Ratio (SAR) and Irrigation Water Quality Index (IWQI) Determination for Irrigation Purposes Along River Ethiope, Southern Nigeria

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Abstract

The improvement of agriculture through irrigation farming is now of great need in the country Nigeria and Delta State. The country is going through a phase of famine and food insecurity caused by climate change and rain dependent agricultural practices. The aim of the study therefore, was to evaluate the quality of water from River Ethiope in Southern Nigeria for irrigation agriculture purposes using the percentage sodium (%Na), sodium-adsorption ratio (SAR) and irrigation-water quality index (IWQ1) techniques. The study deployed the experimental design and water samples were collected from different segments of the Ethiope River. A total of 144 water samples were collected and analysed for physicochemical parameters quality (EC, HCO_3, Cl^-, Na^+, Mg^{2+}, Ca^{2+} and K^+) from January to December, 2022. The results showed that all the calculated values for %Na were within the classified rating of $20 < N \le 40$ and $60 < Na \le 80$; while SAR were within the range of $0 < SAR \le 10$. The recorded values of IWQI were within the range of 70 - 55 and 55 - 40. This implies that the water is good to doubtful for %Na, excellent for SAR and of moderate and high restrictions for IWQI. Water was adjudged to be good for irrigation activities, and should be applicable in areas with moderate and high soil permeability. The routine testing of the water to ascertain physicochemical parameters quality regularly, in order not to affect its use for irrigation was among the recommendations. This finding herein shall be of use to Water Resources and Agriculture ministries in Nigeria.

Keywords

Evaluation, Irrigation-Agriculture, IWQI, River-Ethiope, SAR, %Na

1. Introduction

The significance of water (H_2O) for agricultural development is well recognized throughout the world [1] [2]. However, climate change, increase in population, industrialisation and demands for water for various uses, are beginning to make water a scarce commodity in many countries of the world [3] [4]. The lack of water hampers socio-economic development through constraining food production [5]. Furthermore, the usage and utility of water are generally limited by its quality, which may make it unsuitable for particular uses [6]. Assessment of water quality is therefore an important aspect of water resource evaluation [7].

The quality and quantity of water are fundamental to human development in the area of human health and food security [8]. Improved water supply and water resource management boost a country's economic growth and this has led to the enactment of decrees to protect this resource (water) in Nigeria [9]. However, these laws and decrees have not improved the quality and quantity of water for agricultural purposes [10]. It is pertinent to note that water problems (through climate change, pollution and pressure of use) have contributed to high incidences of food insecurity in many parts of Nigeria [11] [12]. As a result, there is the need to assess the water characteristics (particularly surface water) through proper monitoring for the purpose of assessing impurities and additionally, help the government deploy land-use decisions targeted at engendering sustainable water use while improving irrigation water quality and life of locals [13].

When managing soil for agricultural use a very important factor to consider is the quality of water used for the irrigation of such soils [14] especially when there is a drop in the inter-annual moisture content [15] amongst other numerous water challenges [16]. Water used for irrigation has an impact on crops and soil physical states, as well as, the fertility needs of crops and soil yields [17]. Thus, water quality has been correlated to crop yields [18]; because irrigation water having a high concentration of electrical conductivity (EC) reduces field potential [19]. Additionally, the growth and development of plants can be limited by the salinity of irrigation water [20]. Thus, when water high in sodium is used for irrigation, it could further aggravate the soil quality and crop yields [21]. These challenges affect the yield of crops and result in poor agricultural productivity and increase food insecurity [22]. Nigeria is at a particular time in history where food is scarce and prices very high [23]. It therefore follows logically that finding ways to improve food production and cultivate plants all year round, through irrigation, should be the top priority in the country [24].

Studies [25]-[27] on water quality and quantity which are supposed to proffer solutions to the problem of food insecurity through all-year cultivation of crops, by irrigation methods are scanty and lacking especially along the course of River Ethiope in Southern Nigeria. Hence, this study assessed the quality of water from River Ethiope in Southern Nigeria for irrigation purposes, through the evaluation of the %Na, SAR and IWQI of the surface water. The intention was to ensure that the water quality was good enough for irrigation agriculture and by implication achieve food security. Again studies of this magnitude are intended to protect water resources in Nigeria.

2. Materials and Methods

2.1 Area of Study

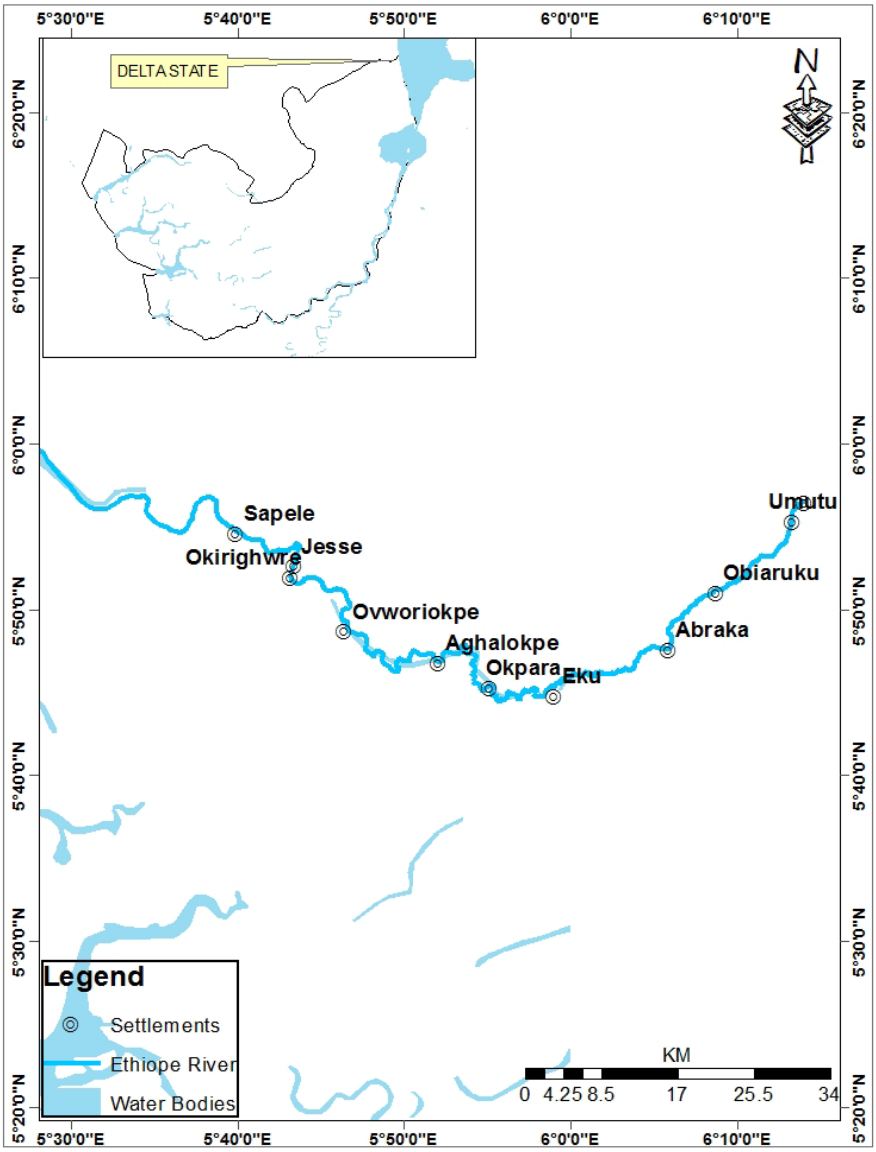

Figure 1. River Ethiope and the settlements along it. Source: Modified after the ministry of lands, surveys and urban development (2008).

River Ethiope is located in Southern Nigeria and found on latitudes 5˚40'N & 6˚00'N of the Equator and longitudes 5˚39'E & 6˚10'E of the Greenwich Meridian (**Figure 1**) [5]. River Ethiope is over 100 km and flows through Umuaja, Umutu, Abraka, Oria, Okpara, and Sapele among other communities [28]. The Ethiope River is the upstream section of the Benin River and takes its rise at Umuaja in the undulating high plain province where topographic elevation is less than 25 meters above sea level [5].

2.2. Methods

This study employed an experimental research design. Water samples were collected on the course of the river [29]-[33]. The river was split into three (3) segments (upstream, midstream & downstream) for easy and relatable sample collection [34]. Two sites were selected each from the three sections of the river using the simple random sampling technique [35]. A total of six sites were selected, two from the upstream (Umuaja and Umutu), two from the midstream (Abraka and Okpara), and two from the downstream (Sapele and Jesse). This was done to reflect adequate representation of samples along the course of the river and to ensure that the findings were not by chance [36].

Water samples were collected at dawn using 2-litre sterilised container fitted with information tag for the water collection [37]. The collection was done early in the morning, between the hours of 6 am and 8 am to eliminate temperature effects [38]. A total of 144 water samples were collected from the sites. This meant 12 samples from a site for 12 months of 2022. The collected samples were corked and put in iced-packed containers; and transported to the laboratory for analysis within six(6) hours of sample collection [39] [40].

Table 1. Laboratory techniques used for physicochemical parameters determination.

Parameters	Chloride (Cl^-)	Calcium as Ca	Magnesium (Mg^{++})	Sodium (Na^+)	Potassium (K^+)	Electrical conductivity (EC)	Bicarbonate (HCO_3)
Unit	mg/l	ppm	ppm	ppm	ppm	µS/Cm	mg/l
Method used in measuring at the laboratory	Titrimetric method	Titrimetric method	Titrimetric method	Flame photometry	flame photometry	Conductivity meter (Jeneway)	Titrimetric method
Detection limit	Titrated using silver-nitrate	Titrated using EDTA	calculated	(0 - 50.05) ppm	(0 - 10.01) ppm	(0 - 19.99) µS (0 - 199.9) mS	0 - 50 mg/l

The physicochemical analysis of the water sample was carried out to test for "electrical conductivity (EC) bicarbonate (HCO_3), Chloride (Cl^-), magnesium (Mg^{2+}) sodium (Na^+), potassium (K^+) and calcium (Ca^{2+})" of the water. Apparatus and reagents that were used for the analysis include burettes, flasks, retort stand, potassium chromate, silver nitrate titrant, standard sodium chloride, sodium hydroxide, aluminium potassium sulphate, distilled water, diluted aqueous ammonia, ammonia chloride solution and disodiumhydrogen tetraoxophosphate (V). The apparatus and reagents used are standard analytical equipment recommended and validated by the World Health Organisation (WHO). To determine the physicochemical properties of the water samples (EC, HCO_3, Cl^-, Mg^{2+}, Na^+, K^+, Ca^{2+}) the techniques as presented in **Table 1** were deployed. These techniques have also been used by [41].

The calculated Percentage Sodium (%Na), Absorption Ration (SAR) and Irrigation Water Quality Index (IWQI) were computed using Equations (1)-(4). The data from it were summarized below.

$$\text{Percentage Sodium}\left(\%\text{Na}\right)=\frac{\text{Na}^{+}+\text{K}^{+}}{\text{Ca}^{2+}+\text{Mg}^{2+}+\text{Na}^{+}+\text{K}^{+}}\times 100 \quad (1)$$

where: Na^+ is Sodium

K^+ is potassium

Ca^+ is calcium

Mg Magnesium

$$\text{Absorption Ration}\left(\text{SAR}\right)=\sqrt{2}\times\frac{\text{Na}^{+}}{\sqrt{\text{Ca}^{2+}+\text{Mg}^{2+}}} \quad (2)$$

where: Na^+ is Sodium

Ca^+ is calcium

Mg^{2+} Magnesium

The Irrigation Water Quality Index was calculated (IWQI) thus:

$$\text{IWQI}=\sum\nolimits_{qiwi}^{n} \quad (3)$$

where: Wi is weight (of parameter)

n is number (of parameter)

qi is value of water quality parameter, and was computed using Equation (4)

$$q_i=q_{i\max}=\frac{\left(x_{ij}-x_{\inf}\right)xq_{iamp}}{x_{iamp}} \quad (4)$$

where: X_{iamp} refers to the class amplitude to which the parameter belongs;

$X_{\inf}$ is the lower limit of that class

X_{ij} shows the concentration of parameter i in site j;

q_{iamp} is the class amptitude for gi classes;

$q_{i\max}$ is the maximum amount of qi for the class.

3. Results

The determination of the percentage (%) of Na, SAR and IWQI were based on the physicochemical data obtained from the analysis of water samples that were collected from the three segments of the Ethiope River (upstream, midstream, and downstream). The results are shown in **Figures 2-8** and used for the calculation of the %Na, SAR and IWQI. The units of the parameters—EC, HCO_3, Cl, Mg^{2+}, Ca^{2+}, Na^+ and K^+ were converted to meq/l for the purpose of the determination of %Na, SAR and IWQI of the water from the river for irrigation purposes.

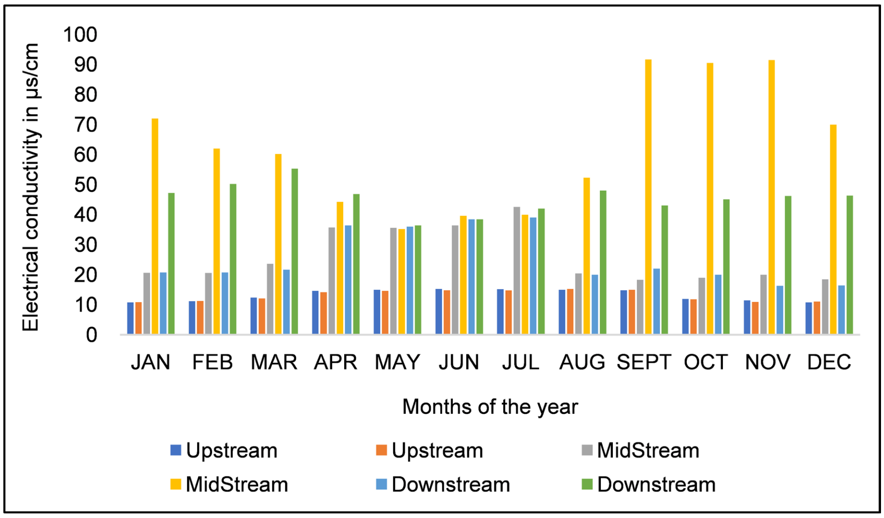

Figure 2. Electrical conductivity (EC) distribution along River Ethiope.

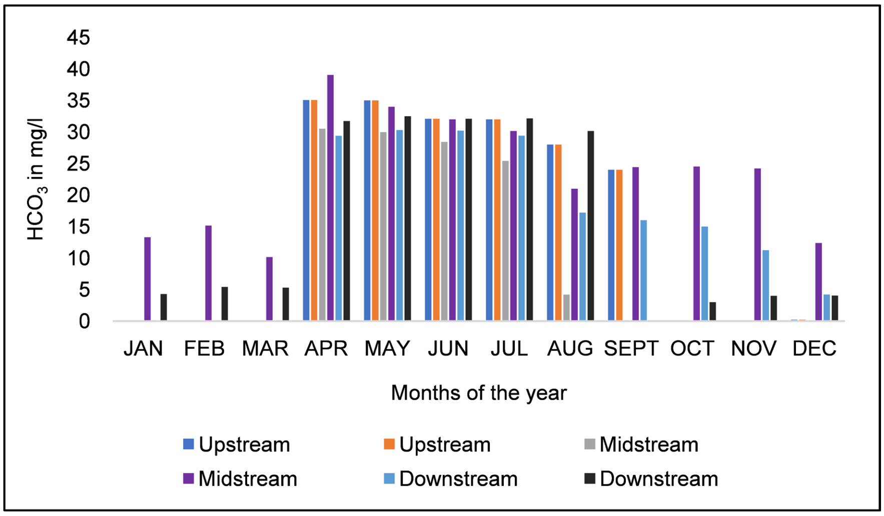

Figure 3. Bicarbonate (HCO_3) distribution along River Ethiope.

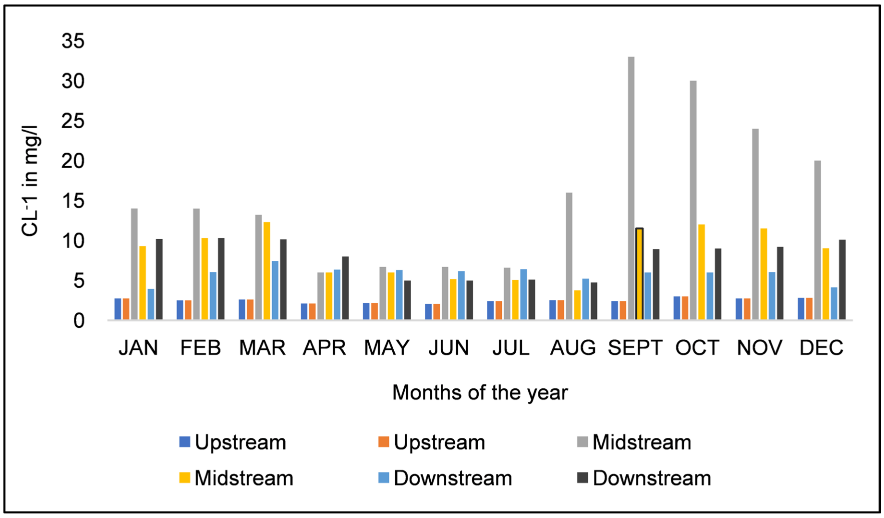

Figure 4. Chloride (Cl^-), distribution along River Ethiope.

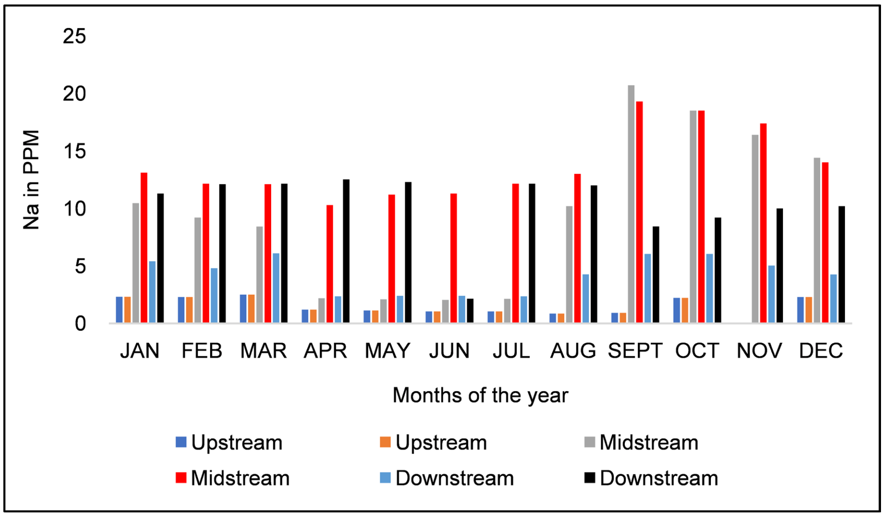

Figure 5. Sodium (Na^+) distribution along River Ethiope.

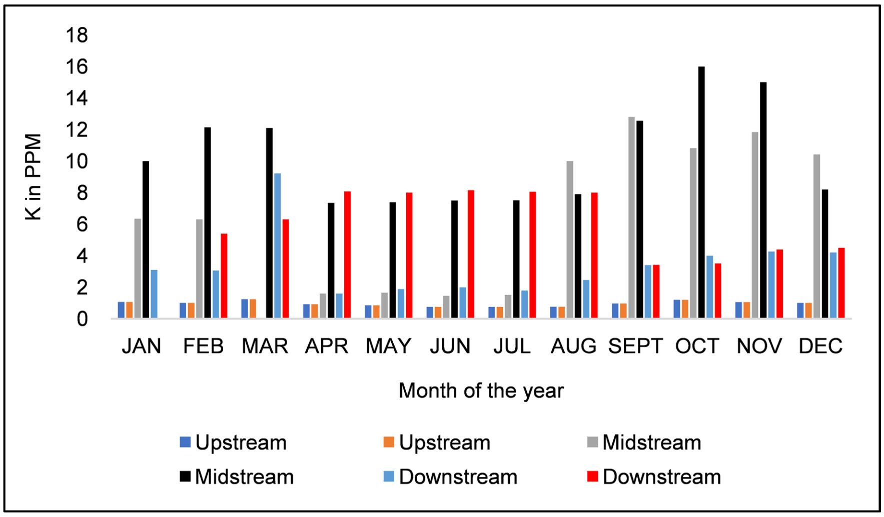

Figure 6. Potassium (K^+) distribution along River Ethiope.

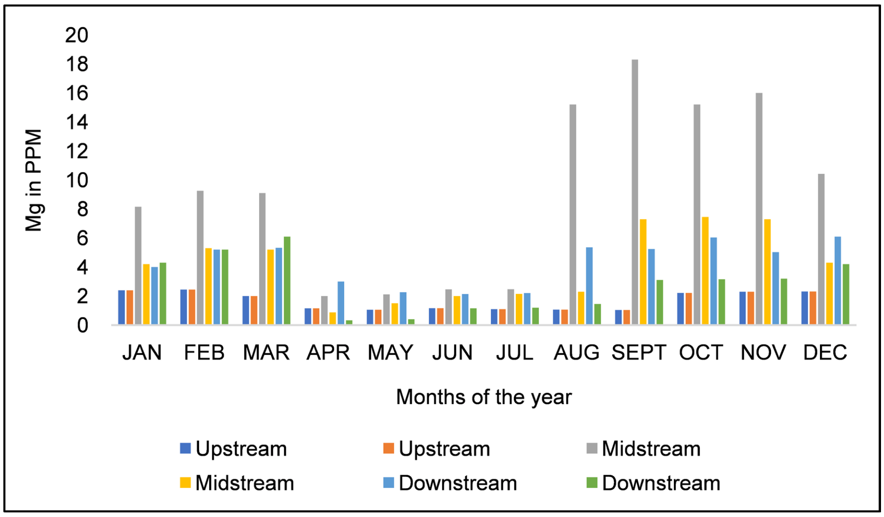

Figure 7. Magnesium (Mg^{2+}) distribution along River Ethiope.

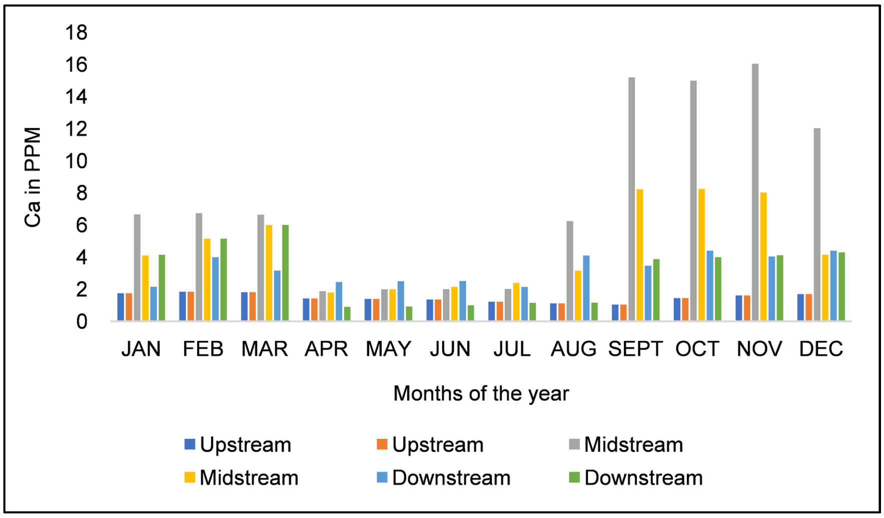

Figure 8. Calcium (Ca^{2+}) distribution along River Ethiope.

The computed %Na is revealed in **Table 2**. To arrive at the data in **Table 2**, equation one (1) was deployed.

Table 2. Water quality classification according to %Na.

Range of %Na (Meg/L)	<20	20 < Na ≤ 40	40 < Na ≤ 60	60 < Na ≤ 80	80 < Na
Rating	Excellent	Good	Permissible	Doubtful	Unsuitable

Source: Batarseh *et al.* 2021.

While water quality classification based on SAR is categorised into four as shown in **Table 3**

Table 3. SAR water quality classification.

Categories	<SI (0 < SAR < 10)	S2 (10 < SAR ≤ 18)	S3 (18 < SAR < 26)	S4 (SAR > 26)
Rating	Excellent	Good	Doubtful	Poor

Source: Batarsch *et al.*, 2021.

Table 4. The IWQI has five classifications as shown in **Table 3**.

Range	Rating
100 - 85	No Restriction
85 - 70	Low Restriction
70 - 55	Moderate Restriction
55 - 40	High Restriction
40 - 0	Severe Restrictions

Source: Batarsch *et al.*, 2021.

4. Discussion

The results of the %Na, SAR and IWQI calculated are shown below and discussed. 55.91 and 56.23 were recorded at Umuaje and Umutu, indicating that the water is of moderate restriction [43]. At the midstream, the sampled sites (Abraka and Okpara) recorded values of 51.89 and 54.6 respectively.

Table 5. Summary of calculated %Na, SAR and IWQI.

Site	Location	%Na	SAR	IWQI
1	Umuaja	33.22	0.24	55 - 91
2	Umutu	33.33	0.22	56.23
3	Abraka	34.33	0.56	51.89
4	Okpara	60.00	1.11	54 - 60
5	Jesse	34.51	0.39	54.38
6	Sapele	61.19	1.03	49.16

This shows that the IWQI is of high restriction [44], while downstream, the sampled sites at Jesse and Sapele recorded 54.38 and 49.16 respectively, indicating that the IWQI is of high restriction. This shows that 33.33% of sampled sites were of moderate restriction and 66.66% were of high restriction

In the upstream of the river, %Na recorded was 33.22 meg/l, and 33.33 meg/l respectively. These figures fell within the range of 20 < Na ≤ 40 classified as good; while in the midstream, 34.33 meg/l and 60.01 meg/l were recorded at Abraka and Okpara respectively. This implies that the water quality fell within the range of 20 < Na ≤ 40 and 40 < Na ≤ 60. That is the water is good and permissible for irrigation purposes. At the downstream, the values recorded were 34.51 meq/l and 61.19 meq/L at Jesse and Sapele respectively. These values fell within the range of good (20 < Na ≤ 40) and doubtful (60 < Na ≤ 80) water quality for irrigation. In all, 96 water samples representing 66.66% fell within the range of good, 24 samples representing 16.66% were permissible for use and another 24 samples representing 16.66% were doubtful. Thus, none of the water samples analysed was classified as unsuitable for irrigation purposes (**Table 4**).

The SAR measured showed that all the water samples, analysed fell within the range of (O< SAR ≤ 10). At the upstream 0.24 meq/$1^{½}$ and 0.22 meq/$1^{½}$ were recorded at Umuaja and Umutu respectively, 0.56 meq/$L^{1/2}$ at Abraka, and 1.11 meq/$1^{½}$ at Okpara in the midstream and 0.37 meq/$1^{½}$ at Jesse and 1.03 meq/$1^{½}$ at Sapele in the downstream respectively. These values were rated excellent and the water for SAR application is excellent and should be used for irrigation agriculture [42].

On the other hand, none of the sampled sites yielded irrigation water quality index (IWQI) of 100 - 85 and 85 - 70 in all the water samples analysed. The water samples fell within the range of 70 - 55 and 55 - 40 of moderate restriction to high restriction [43]. At the upstream of the river, 55.91 and 56.23 were recorded at Umuaje and Umutu, indicating that the water is of moderate restriction [43]. At the midstream, the sampled sites (Abraka and Okpara) recorded values of 51.89 and 54.6 respectively. This shows that the IWQI is of high restriction [44], while downstream, the sampled sites at Jesse and Sapele recorded 54.38 and 49.16 respectively, indicating that the IWQI is of high restriction (**Table 5**). This shows that 33.33% of sampled sites were of moderate restriction and 66.66% were of high restriction. The implication of this is that plants with a coping capacity of tolerance to moderate saltwater concentration be planted and on soils with high soil permeability [45]. While high restriction water is suitable for plants with normal-high salt resistance [46]. However, the water samples analysed in the area showed no severe restriction. As corroborated by Agwu *et al.* [47]

5. Summary of Findings

Based on the physicochemical analysis of the water samples and the determination of the %Na, SAR and the IWQI of the water, the following findings emerged.

1) The %Na (33.22 meq/l - 61.19 meq/1) recorded in the area showed that the water is good for irrigation [48].

2) All the analysed water samples (100%) for SAR fell within the range of ($0 < SAR \leq 10$). This implies that the water is excellent for irrigation [49].

3) The IWQI index survey fell within the range of 70 - 55 (moderate restriction) and 55 - 40 (high restriction. This implies that the water is good for irrigation but with caution. It can be used in areas with moderate to high soil permeability [50].

4) There is variation in the water quality from the upstream to the downstream in terms of %Na, SAR and IWQI, but does not affect negatively the use of the water for irrigation [51].

6. Recommendations

In line with the laboratory results of the analysed water samples and the calculation of the % Na, SAR and IWQI, the following are recommendations made for a sustainable irrigation water for agricultural productivity in the area.

1) The water from River Ethiope is good for the irrigation of crops and can be applied to farmlands throughout the year, especially during the dry season.

2) Plants that can withstand moderate salt concentrations be planted in areas of IWQI with high restriction.

3) The water from the river be tested from time to time to check if the physicochemical indices of EC, HCO_3, Cl^-, Na^+, Ca^{2+}, Mg^{2+} and K^+ are increasing or decreasing as not to affect the use of the water for irrigation.

4) Human activities along the bank and catchment area of the river be monitored, so as not to impair the quality of the water, either through overland flow

or through their activities in the area.

7. Conclusion

In the assessment of River Ethiope for irrigation purposes, % Na and SAR were more remarkable than IWQI in assessing the water quality. All 144 sample analyses for SAR indicated that the water quality is excellent for irrigation; while 66.66% and 33.33% showed good and permissible %Na water quality for irrigation respectively. The strictest index IWQI showed moderate to high restriction of the water for irrigation, the assessment of the water quality for irrigation is thus essential for crop cultivation. Indeed, a combination of good quality irrigation water is a pre-condition for crop production and an overall reduction in food insecurity in Nigeria, especially at this time of food scarcity and inflation. Irrigation water is critical to food security and therefore, there is a need to monitor and harness this resource (Ethiope River) for the benefit of the people of the river basin and adjoining areas.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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