Suitability and Appraisal of Surface Water for Irrigation Purpose

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Abstract

Abogunde village relies heavily on river water for crop irrigation, and water quality is critical for maximum crop production. Samples of Abogunde river water were collected during the dry and rainy seasons and analyzed for various parameters. The results indicated that the pH range was slightly acidic in the dry season but more alkaline during the rainy season. Calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), bicarbonate (HCO_3^-), phosphate (PO_3^-P), electrical conductivity (EC), nitrate (NO_3^-N), sulphate ($SO4^{2-}$) and total dissolved solids (TDS) were within the recommended limits set for irrigation standard water, indicating that the river water in Abogunde village is suitable for irrigation purposes. The water quality indicators, including MAR, SAR, SSP, KR, PS, PI, RSC, and TH, were all within safe limits for both seasons. Overall, the findings suggest that the Abogunde river water is suitable for irrigation purposes, and farmers in the area can use it to grow their crops without adverse effects. However, continuous monitoring of water quality is essential to ensure that it remains within safe limits, and appropriate measures should be taken to address any issues that may arise.

Keywords: Abogunde village, Irrigation., Water quality, River water, Crop production

INTRODUCTION

River water is a fundamental natural resource that plays a crucial role in human life, with essential values in supporting irrigation and economic sectors. The knowledge of irrigation water quality is vital for soil conservation and maximum agricultural productivity. According to the Food and Agriculture Organization (FAO) statistics, 20% of the land is irrigated, but it produces 40% of the crops (Tiri et al., 2018). Rivers are one of the visible bodies of water available and accessible throughout the world, but unfortunately, in many areas, especially developing countries like Nigeria, obtaining a steady source of water for agricultural uses is not easy. Therefore, the quality and quantity of surface water are dynamic processes that are equally important, but both vary from place to place and season to season (Omran et al., 2014).

Although the quality of river water is generally affected by diffuse contamination originating from intensive irrigated agriculture (Saidi et al., 2009), the water quality of any specific area or source can be assessed using physical, chemical, and biological parameters. The values of these parameters are harmful to crops if they exceed certain threshold values.

In recent times, it has been realized that the synergy between the physicochemical properties of the soil and the irrigation water is also a very crucial parameter in grading the suitability of water for irrigation and water management. Therefore, the main purpose of this research work is to evaluate the suitability of Abogunde river in Abogunde village, Ogbomoso, for irrigation purposes by appropriate parameters and indices, and hence, to criticize the quality of river water resources for irrigation purposes. The results of this study can provide useful insights into water management practices in the study area and contribute to sustainable agricultural development.

MATERIALS AND METHODS

Description of the study area

Abogunde River is a significant river located on the northern part of Ogbomoso land in Oyo state, southwest Nigeria. Ogbomoso is situated on Latitude 8° 10’ N and Longitude 4° 10’ E, with an altitude of about 342 m above the mean sea level. The region has a bimodal rainfall pattern, with rainfall peaks occurring in June and September and a break in August, with an average annual rainfall of around 1200 mm. The mean maximum temperature was not above 33°C, while the minimum temperature was not below 16°C. The relative humidity of the area is not less than 80% between the months of April-November, while it is low between December-March when dry wind (harmattan) blows from the northeastern part of the country (Olaniyi, 2006). Abogunde River, recognized as Odo Oba in the village, leads to the main river Oba (Odo Oba) along Oyo-Ogbomoso road.

Sample collection and analysis

Sampling for the analysis of physiochemical properties was conducted in Abogunde River at 7:00 am, with twelve replicates of water samples collected during each sampling in sterilized labeled bottles. The research was carried out during November 2018 for the dry season and July 2019 for the rainy season. After sampling, the bottles were marked, sealed, and transported in ice-packed containers to the laboratory for further analysis.

The water quality indicators that were analyzed were: EC, Ca^{2+}, CO_3, HCO^-_3, K^+, Mg^{2+}, Na^+, pH, PO_3-P, SO_4, NO_3-N Cl^- and TDS (All analyses were done according to APHA (2005) standard method. The concentrations of Na^+, Ca^{2+} and Mg^{2+} were used to quantify the sodium adsorption ratio (SAR) according to the equation:

$$SAR = \frac{Na^+}{\frac{\sqrt{Ca^{2+}+Mg^{2+}}}{2}} \quad 1$$

Where Na^+ is sodium concentration, meq/L; Ca^{2+} is calcium concentration, meq/L; Mg^{2+} is magnesium concentration, meq/L.

Water samples analysis

Water sample analysis of Abogunde river in Ogbomoso were done for the major and minor ions (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (NO_3, CO_3, HCO_3, SO_4^{2-} and PO_4^{2-}) and other chemical parameters (SAR, SSP, RSC, PI, KR, MAR, TH and PS) have also evaluated by using standard empirical formulas. Beside this, measurements of pH, EC, TDS were done on the spot by means of a mercury thermometer and digital pH meter. The samples were then carefully sealed, labeled and taken for analysis. Chemical analyses were performed in the laboratory using Atomic Absorption Spectrophotometry for cations and conventional titration for anions Chopra and Kanwar (1980).

Data analysis

The obtained results were analyzed using descriptive statistics to determine the minimum, maximum, mean, standard deviation, and coefficient of variation of the pooled data, regardless of sampling points and periods. The raw data and computed water quality indicators were subjected to analysis of variance (ANOVA), and means were separated using Fisher's least significant difference (LSD) test at a 5% level of probability. The software used for all analyses was SPSS (v. 20) and Grapher (version 10.0). The analytical results were compared with the standard specification provided by Salifu et al. (2017).

Residual sodium carbonate (RSC)

The residual sodium carbonate was calculated simply by subtracting the quantity of Ca^{2+} + Mg^{2+} from the sum total of carbonates and bicarbonates determined separately in a given sample and expressed in meq/L. Thus,

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \qquad 2$$

Sodium adsorption ratio (SAR)

Sodium adsorption ratio was calculated using the formula equation 3. The concentrations of Na^{+}, Ca^{2+} and Mg^{2+} were used to determine the sodium adsorption ratio (SAR)

$$SAR = \frac{Na^{+}}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}} \qquad 3$$

Where, Na^{+} is sodium concentration, meq/L; Ca^{2+} is calcium concentration, meq/L; Mg^{2+} is magnesium concentration, meq/L.

Soluble sodium percentage (SSP)

Wilcox (1955) has proposed classification scheme for rating irrigation water on the basis of soluble sodium percentage (SSP). The SSP was calculated by using following formula:

$$SSP = \frac{Na \times 100}{Ca + Mg + Na} \qquad 4$$

Where, the concentration of ions is expressed in meq/L.

Permeability index (PI)

The permeability index was calculated by the following formula:

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \times 100 \qquad 5$$

Where, all the values are in meq/L.

Kelly's ratio (KR)

Kelly's ratio was calculated by using the following expression:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad 6$$

Where, concentrations are expressed in meq/L

Magnesium adsorption ratio (MAR)

Magnesium adsorption ratio was calculated by using the following expression:

$$MAR = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \qquad 7$$

Where, concentrations are expressed in (%).

Total hardness (TH)

Total hardness was calculated by using the following expression:

$$TH = \left[\left(2 \times \frac{Ca^{2+}}{40} \right) + \left(2 \times \frac{Mg^{2+}}{24} \right) \right] \times 50 \quad 8$$

Where, concentrations are expressed in mg/L.

Potential salinity (PS)

$$PS = Cl^{-} + \sqrt{SO^{2-}} \quad 9$$

Where, concentrations are expressed in meq/L.

RESULTS AND DISCUSSION

Table 1 presents the physicochemical qualities of Abogunde River water. The bicarbonate levels ranged from 180mg/L in the dry season to 210-220mg/L in the rainy season with mean values of 180mg/L and 213.33mg/L, respectively. Bicarbonate plays a role in regulating sodium hazard and the levels observed were within the permissible limit of 620mg/L (FAO, 1989). The water had no trace of carbonate due to its pH.

Table 1: Descriptive statistics of the river water parameters for irrigation

Parameters	Dry season					Rainy season					Irrigation standard (MPL)
	Min	Max	Mean	CV (%)	SD	Min	Max	Mean	CV (%)	SD	
HCO_3^-	180	180	180	0.00	0.00	210	220	213.3	2.71	5.77	620
NO_3-N	0.04	0.05	0.05	2.22	0.00	0.07	0.07	0.07	1.47	0.00	10
SO_4^{2-}	18.00	21.00	19.67	7.17	1.53	34.00	34.00	34.00	0.00	0.00	960
PO_3-P	0.05	0.09	0.07	31.22	0.02	0.08	0.10	0.09	11.11	0.01	2
Ca^{2+}	24.00	26.00	25.33	4.56	1.15	26.00	28.00	26.67	4.33	1.15	400
Mg^{2+}	15.00	16.00	15.67	3.69	0.58	14.00	16.00	15.33	7.53	1.15	61
Na^+	1.28	1.30	1.29	0.90	0.01	1.92	1.94	1.93	0.52	0.01	400
K+	1.80	2.10	1.97	7.77	0.15	3.60	3.70	3.63	1.59	0.06	2
pH	6.92	6.98	6.95	0.44	0.03	7.20	7.44	7.32	1.64	0.12	6.0-8.5
Cl-	7.50	9.00	8.25	7.59	0.62	12.00	14.00	12.67	9.12	0.62	1065
EC	0.06	0.06	0.06	0.47	0.00	0.09	0.09	0.09	0.00	0.00	3
TDS	28.00	28.20	28.13	0.41	0.12	44.50	44.80	44.60	0.39	0.17	2000

All parameters measured in mg L^{-1}, except EC (dS m^{-1}) and pH. (no unit); TDS: Total dissolved solid; EC: Electrical conductivity; TH: Total hardness; Min.: minimum; Max.: maximum; SD: standard deviation; CV: coefficient of variation; MPL: Maximum permissible limit; Irrigation standard: Salifu *et al*. (2017).

The mean and maximum Nitrate nitrogen (NO3-N) concentration in Abogunde River water were 0.05mg/L and 0.05mg/L in the dry season, and 0.07mg/L and 0.07mg/L in the rainy season, respectively. These values are below the maximum limit of 10mg/L recommended by FAO for irrigation purposes. The low NO_3-N concentration could be due to a low percentage of cropland in the area and lower use of nitrogen-based fertilizers. However, even with the low concentration of nitrogen, the water is still suitable for irrigation purposes.

Sulphates (SO_4^{2-}) are naturally occurring in surface waters. However, discharges from industries as well as atmospheric precipitation could add significant quantities to surface waters (Khudair, 2013). The concentrations of SO_4^{2-} in the studied water ranged from 18mg/L to 21 mg/L with a mean value of 19.67 mg/L in dry season and within 34 mg/L with a mean value of 34 mg/L in rainy season (Table 1). These values was within the maximum limit of 960 mg/L (Salifu *et al.*, 2017), however, indicating no threat.

Phosphate (PO_3-P) in irrigation water are more of fertility issue, however high levels of PO_3-P in the water sources is not desirable, as it is an indication of eutrophication of surface water bodies (Davis *et al.* 2001). Although, the total phosphate concentration of the Abogunde River during dry season ranged from 0.05mg/L to 0.09 mg/L with a mean value of 0.07 mg /L; and in rainy season ranged from 0.08mg/L to 0.10 mg/L with a mean of 0.09 mg /L; (table 1).

When excess nitrogen and phosphorus are transported to surface water, they cause eutrophication and elevated algal (Davis *et al.,* 2001). Waters with elevated N can also cause quality problems in crops such as barley and sugar beets as well as excessive vegetative growth in vegetables, thus delaying fruit setting and maturity (Bauder *et al.,* 2014).

High concentrations of Ca^{2+} and Mg^{2+} ions in irrigation water will cause increase in soil pH, leading to reduction in the availability of phosphorous to plants (Al-Shammri *et al*., 2005). According to Khodapanah *et al.,* (2009), water containing Ca^{2+} and Mg^{2+} above 400mg/L and 61 mg/L respectively, are not suitable for irrigation. The observed concentrations of these elements was not more than 26mg/L and 16 mg/L for Ca^{2+} and Mg^{2+} in dry season, 28mg/L and 16mg/L in rainy season respectively, this indicated that none of the samples exceeded the threshold value.

Sodium (Na^+) content is another major indicator when evaluating irrigation water quality, however, its concentrations ranged from 1.28mg/L to 1.30 mg/L with a mean value of 1.29mg /L during the dry season and was 1.92 mg/L to 1.94mg/L with a mean value of 1.93mg/L in rainy season; The range and mean values were less than 400mg/L (Salifu *et al.,* 2017), indicating no restriction of use. Irrigation water with high sodium (Na^+) content could cause the displacement of exchangeable cations, such as Ca^{2+} and Mg^{2+}, from the soil clay minerals, which would be replaced by Na^+ (Matthess *et al.*,1982) stated that soils saturated by sodium peptize and they lose their permeability, leading to decrease in fertility and their suitability for cultivation.

The potassium concentrations in the study water in dry season have a minimum, maximum and mean of 1.80mg/L, 2.10mg/L and 1.97 mg/L and 3.60mg/L, 3.70 mg/L and 3.63mg/ in rainy season respectively; the maximum concentration in dry season and minimum, maximum and mean in rainy season exceeds the threshold value of 2 mg/L. Inorganic fertilizers containing at least one of three basic nutrients; nitrogen, phosphorus, and potassium, are widely used in the study area to replenish crop and soil nutrients. Half to one- third of this fertilizer are absorbed by the crop and the remaining becomes residual in the soil and may join water body (Tomer and Burkart, 1998; Taiwo, 2016). Potassium is both an important fertilizer and common rocks constituent, high concentration of potassium ion found in the water could have been induced by leachates from agricultural fertilizer as observed by Falowo *et al.,* (2017) or dissolution of rock constituent. A major concern of high potassium concentrations in irrigation water is its deleterious effects on soil hydraulic properties, which has negative impacts on infiltration, water availability and plant growth (Oster *et al.,* 2016).

The observed pH values ranged from 6.92 to 6.93, with the mean values of 6.95 in dry season while pH values ranged from 7.20 to 7.44 with the mean value of 7.32 in rainy season, both are tolerable to crops and within World Health Organization (WHO) limits. The water is good for irrigation use. The mean pH values indicated that the rivers did not have alkaline. Although, application of irrigation water with pH outside the threshold could cause nutritional disparity or lead to toxic ion build up in the soil (Ayers *et al*., 1985).

Suitability of Abogunde river water in Ogbomoso for irrigation

Magnesium content of water is an important criterion in determining irrigation water quality, as excessive magnesium can negatively affect crop yields due to increased soil salinity (Joshi et al., 2009). In this study, the magnesium adsorption rate of the water sampled ranged from 36.5% to 38.2% during the dry and rainy seasons, respectively, indicating that it is below the maximum limit of 50% recommended by Ayers and Westcot (1985) and therefore considered acceptable and suitable for irrigation (Table 2 and 3).

However, a high magnesium adsorption ratio can have a negative effect on soil when it exceeds 50%. Additionally, the Kelly's ratio of unity or less than one is indicative of good quality water for irrigation, while above one suggests unsuitability for agricultural purposes due to alkali hazards (Karanth, 1987). The Kelly's ratio values of greater and less than unity in this study describe the sampled water as being not suitable and suitable for irrigation, respectively (Table 4) (Sundaray et al., 2009). Both the dry and rainy seasons were observed to be 100% good based on these criteria. Therefore, the water in the study area has good quality for irrigation purposes due to the absence of alkali hazards.

Table 2: Descriptive statistics of the water quality indices for irrigation

Parameters Indicator		MAR	KR	PS	PI	SAR	RSC	TH	SSP	EC	TDS
Quality Rate	Dry season	38.22	0.02	0.91	67.56	0.05	0.38	196	2.13	0.06	28.13
	Rainy season	36.5	0.03	1.48	72.60	0.07	0.89	397	3.12	0.09	44.60

MAR: Magnesium absorption ratio, %, KR: Kelly's ratio, meq/L; PS: Potential salinity, meq/L; PI: Permeability Index, meq/L; SAR: sodium adsorption ratio, meq/L; RSC: Residual sodium carbonate, meq/L; TH: Total hardness, mg/L; SSP: Soluble sodium percentage, meq/L; EC: Electrical conductivity dS/m and Total dissolved solid

Potential salinity (PS) is an important parameter for assessing the suitability of water for irrigation uses. The water samples from the study river ranged from 0.91 meq/L to 1.48 meq/L from dry to rainy season with an average of 1.20 meq/L (Olawoyin et al., 2019). This indicated that the water samples from the study area is good for irrigation purposes in both dry and rainy season and on soil of low permeability and on class I (Table 4) (Sundaray et al., 2009). PS means chloride concentration plus half of the sulfate concentration (Doneen, 1961).

Table 3: Summary of sampling point delineation under different limits (Meq/L)

SAR	Class	PI	Class	RSC	Class	KR	Class	SSP	Class	MAR	Class
<10	Excellent	<25	Unsuitable	<1.25	Suitable	<1	Good	<50	Safe	<50	Acceptable
10-18	Good	25-75	Good	1.25-2.50	Doubtful	>1	Unsuitable	>50	Unsuitable	>50	Non-acceptable
18-26	Fair	>75	Excellent	>2.50	Unsuitable						
>26	Unsuitable										

SAR: sodium adsorption ratio; Mg/Ca: Magnesium-calcium ratio; KR: Kelly's ratio; SSP: soluble sodium percentage; PI: permeability index; RSC: residual sodium carbonate. MAR: Magnesium adsorption ratio (%).

The quality of water for irrigation can be determined using several indices, including the Permeability Index (PI), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), total hardness, Soluble Sodium Percentage (SSP), Electrical Conductivity (EC), and Total Dissolved Solids (TDS).

Table 4: Classification of irrigation water based on potential salinity (Meq/L)

Class of water/soil characteristics	Class I	Class II	Class III
Soil of low permeability	< 3	3-5	>5
Soil of medium permeability	< 5	5-10	>10
Soil of high permeability	< 7	7-15	>15

Source: Doneen (1961)

Permeability Index (PI) values > 75meq/L indicates excellent quality water for irrigation. PI values between 25meq/L and 75meq/L indicate good quality of water for irrigation. However, if the PI values are less than 25meq/L, it shows unsuitable nature of water for irrigation. PI values are a function of sodium, calcium, magnesium, and carbonate in the soil (Vasanthaiviger, 2010; Stewart and Hielsen, 1990). Based on this assessment, water samples from this location indicate good quality of water in both the dry and wet seasons, therefore suitable for irrigation purposes.

Waters having SAR values less than 10meq/L are considered excellent, 10meq/L to 18meq/L as good, 18meq/L to 26meq/L as fair, and above 26meq/L are unsuitable for irrigation use (USDA, 1954). In this work, the SAR values are lesser than 10meq/l for the samples taken in both dry and rainy seasons, therefore it is graded as excellent for irrigation use (Table 3). SAR is a measure of the tendency of sodium (Na) ions to displace Ca2+ ions in the irrigation water soil (Al-Tabbal and Al-Zboon, 2012).

The Residual Sodium Carbonate (RSC) did not exceed the value of 2.5meq/l in both dry and rainy seasons; therefore, the water is generally suitable for irrigation. If the value of RSC is between 1.25meq/l and 2.5meq/l, the water is doubtful (Table 4), while a value less than 1.25meq/l indicates safe water quality (Cuena, 1989). In this respect, it is evident from Table 3 that RSC values in both dry and rainy seasons are less than 1.25meq/l, indicating safe water quality and suggesting that the study location is under a safe limit for irrigation use.

Total hardness simply means the sum of calcium and magnesium. The values of total hardness varied from 196 to 397 mg/L with an average of 297 mg/L where the maximum value is below the prescribed limit for irrigation water of 712 mg/L set by (FAO, 1989). The low values of total hardness are probably due to the presence of alkaline earth ions (Ca^{2+} and Mg^{2+}) of weak acids (HCO_3^- and CO_3^-) and strong acids (Cl^-, $SO4^{2-}$ and NO_3^-) (Roy et al., 2018; Rao et al., 2012). Therefore, low alkalinity values reflect immature hydrochemistry of surface water during seepage and hypodermic flow (Demetriades, 2011). The water sample was classified as hard water during the dry season and very hard in the rainy season.

Wilcox (1955) proposed a classification scheme for rating irrigation waters based on the soluble sodium percentage (SSP), with values below 50 meq/L indicating good quality water and values above 50 meq/L indicating water that is unsafe for irrigation (USDA, 1954). In this study, the SSP values were not reported. However, the electrical conductivity (EC) of the irrigation water was within the standard irrigation water categories, with a maximum limit of 3 dS/m, and ranged from 0.06 dS/m with a mean of 0.06 dS/m in the dry season and within

0.09 dS/m with a mean of 0.09 dS/m in the rainy season. Therefore, the water is suitable for irrigation use in terms of EC and total dissolved solids (TDS).

Excessive concentrations of calcium, magnesium, sodium, and potassium salts in irrigation water can be detrimental to plant growth by reducing osmotic activities and aeration. In this study, the salt concentration in the Abogunde river water ranged from 28.00 mg/L to 28.20 mg/L with a mean of 28.13 mg/L in the dry season, and ranged from 44.50 mg/L to 44.80 mg/L with a mean of 44.60 mg/L in the rainy season. The higher concentration falls below the permissible limit of the standards set by FAO (1985), which is 2000 mg/L. According to the irrigation water quality classification by Ayers et al. (1985), the values fall within the permissible limit for irrigation (< 450 mg/L) and have no restriction. The coefficient of variation for the TDS of water in the study area was 0.39 mg/L, indicating that the TDS of water varied in the study area.

CONCLUSION

The study evaluated the quality of water for irrigation purposes using various indices including Permeability Index (PI), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), total hardness, Soluble Sodium Percentage (SSP), Electrical Conductivity (EC), and Total Dissolved Solids (TDS). The results showed that the water quality of the Abogunde river in both dry and rainy seasons was suitable for irrigation purposes based on PI, SAR, RSC, EC, TDS, and total hardness. The study found that the salt concentration in the water was below the permissible limit set by FAO, and the TDS of water varied in the study area. Therefore, it can be concluded that the water from the Abogunde river is safe and suitable for irrigation purposes. However, it is important to note that periodic monitoring of water quality is necessary to ensure that the water quality remains suitable for irrigation use.

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