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Suitability Assessment of Surface Water for Irrigation in Galma Floodplain, Zaria, Kaduna State North Western, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author JA designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors WBM and IAJ managed the literature searches. Authors ABS and MMI managed the experimental process. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted so as to determine the suitability of these surface waters for irrigation activities within the Galma irrigation scheme. Surface water was sampled from nine locations along Galma river in 2014 and analyzed for various irrigation water quality parameters. Electrical conductivity, Total dissolved solid, Total hardness, Sodium adsorption ratio, Soluble sodium percentage and Residual sodium bicarbonate were used to assess the quality of water for irrigation. Descriptive statistical methods were applied to data on the physico-chemical parameters of water from Galma river. The water samples analyzed had pH range (6.75 to 7.04) within the normal range for crop production and very low (electrical conductivity 0.15-0.72 dSm^{-1}). The sodium adsorption ratio values in all the samples were also very low (<0.4), indicating very low sodicity hazards. Soluble sodium percentage and Residual sodium bicarbonate ranged from 2.48 to 3.53 and -15.2 to -11.52 respectively. Base on Electrical conductivity, Total dissolved solid, Total

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hardness, Sodium adsorption ratio, Soluble sodium percentage and Residual sodium bicarbonate, Galma river was considered suitable for irrigation.

Keywords: Irrigation water; sodicity; nutrient availability; Galma river; salinity.

ABBREVIATIONS

Adj.SAR : Adjusted SAR
EC : Electrical conductivity
HT : Total hardness
RSC : Residual sodium bicarbonate
SAR : Sodium adsorption ratio
SSP : Soluble Sodium Percentage
TDS : Total dissolved salt
USDA : United State Department of Agriculture

1. INTRODUCTION

Surface water basins all over the world are very crucial in irrigation schemes. Irrigation schemes are particularly crucial in the agricultural economies due largely to the fact that global climate change has led to drastic changes in rainfall patterns [1]. As a result, rain-fed agriculture alone is no more sustainable and irrigation schemes are being encouraged as poverty reduction/eradication strategies in the developing countries. The quality of water for irrigation is often affected by natural factors (e.g., rocks, soils and surface through which it flows) and anthropogenic factors (e.g., industrial, agricultural and mining) activities [2,3]. The quality of irrigation water is assessed based on heavy metals and salt inducing contents, the presence and abundance of micro and macro nutrients, alkalinity, acidity, hardness and the amount of suspended solids [4,5]. Regardless of its source, Irrigation water contains some dissolved salts [6].

The amount and characteristics of these dissolved salts depend on the source and chemical composition. History has shown that early civilization whose rise was supported by productivity of irrigated agriculture, were thought to fall as a result of problems caused by irrigation water quality [7]. The most common reasons for failure of irrigation projects are associated with waterlogging, salinization, and alkalization. Salinization and sodification could limit the soil's productivity, leading to fertility reduction [8]. If the level of Na^+ in the soil is high, the colloidal fraction behavior will be affected. The level of Na^+ in soil is usually quantified by the exchangeable sodium percentage (ESP), the sodium adsorption ratio (SAR). When SAR increases, then the rate of the soil sodification process also increases [9].

The most ordinarily, dissolved ions in water are sodium, magnesium, calcium (Ca^{2+}), sulphate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), boron (B), carbonate (CO_3^{2-}) and bicarbonates (HCO_3^-) [10]. The concentration and proportion of these dissolved ions among other things determine the suitability of water for irrigation [5,10]. Water quality has a direct impact on crop production and also on soil properties. Soil properties, crop yield and quality will deteriorate if low quality water is used for irrigation [11,12]. The objective of the study was to examine the concentration of dissolved ions to evaluate the suitability of surface water from Galma River for irrigation.

2. MATERIALS AND METHODS

2.1 Study Area

The study area lies within Zaria, Kaduna State, Nigeria. Zaria is situated on a plateau at a height of about 570.56 m above the sea level in the center of northern Nigeria, and more than 644 km away from the sea, on a latitudes 11° 05' N and longitudes 7° 44'E. Hazell et al. [13] confirmed that Zaria has tropical continental climate, which is most prominent in the dry seasons around December and January. 13 confirmed the mean daily temperature of 31℃ with maximum value of about 36℃ which usually occurs around April and a mean annual rainfall of 108.8 mm in Zaria. Galma basin is drained by river Galma and its numerous tributaries. These tributaries include among others river Kubanni, Saye, Shika, Likarbu, Baki, Anchau, and Danwata [14]. Olowu [15] in a regional study revealed that with the exception of Galma River all streams in the area are seasonal and that the depth to water-table increased progressively away from the banks of the river during the dry season. The soil type is highly leached ferruginous tropical soils, developed on weathered regolith overlain by a thin deposit of windblown silt from the Sahara desert during many decades of the propagation of the tropical continental air mass into the area [16,17]. The vegetation of the Galma basin is of the northern Guinea Savanna type, characterized

Table 1. Equations used for computing irrigation water quality criteria

Formulae	References
TDS = ECe X 640	Dregne, 1976
$SAR = Na/[(\sqrt{Ca+Mg})/2]$	Todd, 1980
$Adj.SAR = \left(\frac{Na}{\frac{\sqrt{Ca+Mg}}{2}}\right)(1+8.4-pHc)$	
RSC= (CO_3+HCO_3)- (Ca+Mg)	Eaton, 1950
SSP = SSP = Soluble Na [meqL^{-1}]x 100/Total cation [meqL^{-1}]	Wilcox, 1955
HT (mg L -1)=Ca^{2+}X2.5 + Mg^{2+}X4.l	Sawyer and McCarty, 1967

by patches of woodland, herbs and grasses with few widely scattered deciduous trees, although continuous cultivation, bush burning and grazing activities have greatly modified the natural vegetation cover and composition. Agriculture is the most prevalent land use in the study area. Farming system is mixed livestock and crop production. In the floodplain, land use was dominated by the cultivation of crops such maize and rice in the rainy season while varieties of crops such as Cereal, roots and tuber such are grown during the dry season.

2.2 Methods

2.2.1 Water sampling

For the purposes of this study, water samples were collected from River Galma. Detailed samplings were conducted on March 2014. Nine (9) water samples were collected from Galma River by dipping a 120 mls container below the upper surface of the river. APHA (American Public Health Association) guidelines were used in collecting and preserving the samples. The samples were immediately transported to the General Laboratory of Soil Science, Ahmadu Bello University, Zaria for hydro-chemical analysis.

2.2.2 Water analysis

The water samples were analyzed for pH, EC, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), boron (B), sulphate (SO_4^{2-}), chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and nitrate (NO_3^-). The pH and electrical conductivity (EC) were determined electrometrically [18]. Calcium and Magnesium were read in a Pye Unicam Model Sp 192 atomic adsorption spectrophotometer at wave length 423 and 485 nm respectively, whereas potassium and sodium were estimated by flame emission spectrophotometer [19]. Sulphate was determined turbid metrically [18]. Carbonate and Bicarbonate was determined by titration method [18]. Chloride was estimated by $AgNO_3$ titration [18]. Nitrate and boron were determined calorimetrically. Total dissolved salt (TDS) was determined by the following formula shown in Table 1 Water under test was classified as per results obtained from chemical analyses. Sodium Adsorption Ratio (SAR), Adjusted sodium absorption ratio (Adj.SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC) and total hardness (HT) values were computed from the estimated values of Na^+, K^+, HCO_3^-, CO_3^{2-}, Ca^+, and Mg^+ ion concentrations using the formula shown in Table 1. The suitability for irrigation of the surface water tested was assessed based on the values of EC, TDS, SAR, SSP, RSC and HT obtained by chemical analysis. Mean were used to assess the data.

3. RESULTS AND DISCUSSION

Water quality criteria for irrigation generally take into account, amongst other factors, the crop tolerance to salinity, sodium concentration and phytotoxic trace elements. Hydro-chemical parameters including statistical measures, such as minimum, maximum, and average and standard deviation, are reported in Table 2.

3.1 Anionic Concentration in Irrigation Water

There was no measurable carbonate content of both the surface. The mean bicarbonate, Chloride, Nitrate, Boron and Sulphate values for all samples fell within the safe limits (20 Ayers and Westcost, 1985). The bicarbonate content ranged from 0.09-0.38 mgL^{-1}, chloride ranged from 1.4 to 5 mgL^{-1}, nitrate ranged between 0.01 to 0.03 mgL^{-1}, while boron and sulphate ranged 0.51 to 0.92 mgL^{-1} and 1.21 to 4.47 mgL^{-1} respectively. The Carbonate and Bicarbonate concentration were within the safe limit according to the classification of [20]. In waters having high concentration of bicarbonates, there is tendency for calcium and magnesium to precipitate as carbonate, resulting in the release of more sodium into the soil solution (sodicity).

It is observed that all the water samples have chlorides level lower than the permissible limit for irrigation of 10 mg L^{-1} and are therefore rated low according to [21,22]. This indicated that the water will not cause chloride toxicity problem to crops under irrigation.

Nitrate is present in negligible amounts in all the water samples. Nitrate concentrations of the water samples were well below 5 mg/L and are therefore rated low according to [21,22] ratings hence, they are not toxic to plant. This suggests that, if the water are considered safe for irrigation because no quality problem associated to nitrogen will arise.

Boron is necessary in small quantities for growth of plants, but a slight excess of boron in the irrigation water or in the soil solution can cause toxicity to a variety of crops [23]. All of the water samples analyzed were within the permissible limits for semi-sensitive crops based on McCarty et al. [24] proposed limits for boron concentration in irrigation.

Sulphate is an essential compound for plant growth. The sources of sulphate include the dissolution of sulphide minerals, gypsum ($CaSO_4.2(H_2O)$ and anhydrite $CaSO_4$), rainfall and fertilizers. It is measured in irrigation water to give an indication of possible deficiency problems. Concentrations of sulphates are beneath the acceptable limits according to irrigation water standards as proposed by 20. Base on sulphate concentration the water was safe for irrigation.

Table 2. Irrigational quality results of water samples in the study area

S/No	pH	EC	TDS	B	NO_3^-	SO_4^{2-}	Cl^-	CO_3^{2-}	HCO_3^-
		dS/m	----------------------------------			mgL^{-1}		------------------------------------	
1	7.04	0.17	108.80	0.82	0.02	4.23	3.00	ND	1.00
2	6.79	0.15	96.00	0.82	0.01	4.35	2.00	ND	0.90
3	6.94	0.16	102.40	0.89	0.01	4.47	1.40	ND	1.00
4	6.77	0.17	108.80	0.92	0.01	4.11	2.40	ND	1.10
5	6.84	0.18	115.20	0.73	0.02	2.78	2.80	ND	1.40
6	6.75	0.19	121.60	0.54	0.03	1.69	5.00	ND	3.50
7	6.93	0.24	153.60	0.66	0.03	1.21	5.00	ND	3.80
8	6.97	0.15	96.00	0.57	0.03	1.69	4.80	ND	3.80
9	6.95	0.27	172.80	0.51	0.03	1.57	4.60	ND	3.00
Mean	6.89	0.19	119.47	0.72	0.02	2.00	3.44	ND	2.17
Minimum	6.75	0.15	96.00	0.51	0.01	1.21	1.40	ND	0.90
Maximum	7.04	0.27	172.80	0.27	0.03	4.47	5.00	ND	3.80

ND = not detected

Table 2 Cont.

S/No	K	Ca	Mg	Na	HT	RSC	SSP	SAR	Adj. SAR
	----------------------------			mgL^{-1}		--------------------------	%		
1	3.4	12.8	2.48	0.58	0.02	-14.48	2.48	0.24	0.57
2	4	13.4	2.32	0.58	0.03	-14.22	2.94	0.3	0.7
3	4.2	12.6	2.8	0.5	0.03	-15.2	2.76	0.29	0.68
4	3.6	12.2	2.43	0.42	0.03	-13.93	2.61	0.26	0.61
5	4	12.4	2.58	0.58	0.03	-13.98	2.91	0.3	0.7
6	2.4	13.2	2.44	0.66	0.04	-12.14	3.53	0.33	0.98
7	1.6	12.8	2.68	0.58	0.03	-11.68	3.28	0.29	0.87
8	1.82	12.8	2.52	0.58	0.03	-11.52	3.27	0.3	0.87
9	2.15	13	2.58	0.5	0.03	-12.58	2.74	0.25	0.75
Mean	3.02	12.8	2.53	0.55	0.03	-13.3	2.95	0.28	0.74
Minimum	3.6	12.2	2.32	0.42	0.02	-15.2	2.48	0.24	0.57
Maximum	4.2	13.4	2.8	0.55	0.4	-11.52	3.53	0.33	0.98

Table 3. Suitability classification of the water samples for irrigation

S/No	EC	Grading	TDS	Grading	HT	Grading	SAR	Grading	SSP	Grading	RSC	Grading
1	0.17	suitable	108.80	suitable	0.02	excellent	0.24	excellent	2.48	suitable	-14.48	suitable
2	0.15	suitable	96.00	suitable	0.03	excellent	0.30	excellent	2.94	suitable	-14.22	suitable
3	0.16	suitable	102.40	suitable	0.03	excellent	0.29	excellent	2.76	suitable	-15.20	suitable
4	0.17	suitable	108.80	suitable	0.03	excellent	0.26	excellent	2.61	suitable	-13.93	suitable
5	0.18	suitable	115.20	suitable	0.03	excellent	0.30	excellent	2.91	suitable	-13.98	suitable
6	0.19	suitable	121.60	suitable	0.04	excellent	0.33	excellent	3.53	suitable	-12.14	suitable
7	0.24	suitable	153.60	suitable	0.03	excellent	0.29	excellent	3.28	suitable	-11.68	suitable
8	0.15	suitable	96.00	suitable	0.03	excellent	0.30	excellent	3.27	suitable	-11.52	suitable
9	0.27	suitable	172.80	suitable	0.03	excellent	0.25	excellent	2.74	suitable	-12.58	suitable

3.2 Basic Cations in Irrigation Water

The concentrations of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} in water samples varied in the ranges of 12.20-13.40, 2.32-2.80, 3.60-4.2 and 0.42-0.55 mgL^{-1} respectively (Table 2), which were far below the recommended maximum concentrations.

The concentration of $Ca^{2+,}$ Mg^{2+}, K^{+} and Na^{+} were far below the recommended maximum concentration of Ca^{2+} is 20 mg L^{-1} and that of Na^{+} is 40 mgL^{-1} [21].

3.3 pH and Salinity

The pH of the water samples ranged from 6.75 to 7.04. Salinity hazard can be deduced from the values of the electrical conductivity (EC) and total dissolved salts. Electrical conductivity levels were generally very low with mean 0.19 dS/m. Total dissolved salt content ranged from 96.00-172.80 mgL^{-1}. All the water samples were suitable for irrigation since they fall between the range of 6.5 to 8.4 which is within the normal range in irrigation water quality given by 20. When the pH is outside this range, it indicates that adequate/appropriate steps/actions will have to be taken to remedy this to avoid its negative influence in the crop performance.

Electrical conductivity rated low (>0.75 dS/m) according to United State Department of Agriculture (USDA) water quality rating for irrigation. This implies that the sources water was non saline and thus safe for irrigation. The result of total dissolved solid shows that the water do not contain high level of soluble salts which could affect the soils' ability to supply water and nutrients [25].

3.4 Sodicity (Permeability) Hazard

The computed values of SAR, Adjusted SAR, RSC, and HT are presented in Table 2. The SAR and Adjusted SAR values ranged from 0.24 to 0.33 and 0.57 to 0.98 respectively. RSC values ranged from -15.20 to -11.52 mg L^{-1}, while HT values ranged between 0.18 to 0.21 mgL^{-1}. The values for the soluble sodium percent (SSP) in the study area range from 2.48 to 3.53%.

The sodium adsorption ratio (SAR) parameter evaluates the sodium hazard in relation to calcium and magnesium concentrations. The sodium adsorption ratio is used to predict the potential for sodium to accumulate in the soil, which would result from continued use of sodic water. The SAR was rated low because they are far below the danger limit of > 9 considered unsafe for irrigation as proposed by Richards [26]. All the water samples were classified as excellent for crop production under irrigation. If these waters were used for irrigation purposes, sodicity hazard might not occur and crops may grow without any deleterious effect on the soil and crop yield [27].

The Adjusted SAR (Adj.SAR) is a modification of the original SAR calculation. It serves the same purposes, but is modified to include the effects of bicarbonates and carbonates, in addition to Ca and Mg [23]. It is used to predict the potential infiltration problems of high Na (or low Ca) in irrigation water [27,28]. The Adj. SAR is always greater than the SAR, thereby providing a truer index of the sodicity of the water and the risk of dispersion. All the waters sampled gave very low levels of Adj. SAR and do not pose any hazards with respect to Na build up in the soils. This might indicate that they do not pose any restrictions to their use for irrigation.

Residual sodium bicarbonate (RSC) is a measure of bicarbonate hazard, in waters having high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more saturated. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate. RSC is therefore a measure of bicarbonate hazard [29]. RSC value were graded as excellent, since the RSC is within <1.4 mgL^{-1} which is the standard for irrigation [21]. The water is safe for use because bicarbonate toxicity may not occur during irrigation. All samples showed negative values which indicated that dissolved calcium and magnesium contents were higher than carbonate and bicarbonate contents for all the samples.

Total hardness (HT) of water is a measure of dissolved Ca and Mg in water expressed as $CaCO_3$ and $MgCO_3$ [30]. Dissolved Ca^{2+} in water is responsible for water hardness since it reduces the soil acidity and replenishes Ca for crop nutrition [31]. According to Sawyer et al. [32] grading standards of HT, all the water samples were classified as soft water. Soft waters may increase the nutrient availability and decrease the micronutrient toxicity of soil, and thus keep the soil environment suitable for crop production.

Soluble sodium percentage (SSP) is an important criterion use to assess the water quality for agriculture. It reflects the potential of deterioration of the soil physical properties that affect plant growth [33]. The quality of water based on SSP was classified as Excellent (<20%), Good (20-40%), Permissible (40-60%), Doubtful (60-80%) and Unsuitable (> 80%) [34]. All the water samples belong to the category of excellent. Water belonging to the excellent category may be used for irrigation purposes.

3.5 Quality Assessment for Irrigation

The suitability of surface water for irrigation is contingent on the effects on the mineral constituents of the water on both the plant and the soil [35]. Among the criteria, EC, SAR, and SSP are the most important ones to evaluate the suitability for irrigation while TDS, RSC and HT minor criteria.

The suitability of water was determined using the classification system adopted by Bikash et al. [12]. They classified water as *suitable, moderately suitable, permissible,* and *unsuitable* on the bases of EC, SAR and SSP. The result of suitability assessment for irrigation is presented in Table 2. A sample was classified as suitable when the major criteria i.e. EC, SAR, and SSP belonged to the excellent to good class. The *moderately suitable* category comprised the samples that were excellent for SAR, good and permissible for EC and SSP.

The water was considered to be *permissible* for irrigation purposes when the samples belonged to the permissible and excellent to doubtful categories for EC and SSP irrespective of the minor criteria. When all the major criteria of water samples were doubtful to unsuitable, then the category was referred to as *unsuitable.* Base on this system of classification all the water samples are suitable for irrigation. These waters can be used for irrigation without affecting the yield and quality of crops, soil productivity and the environment.

4. CONCLUSION

The surface water in Zaria area has been assessed for its hydro-chemical constituents and suitability for irrigation. According to the findings of this study, all the parameters determined were found to be within the safe limits. The suitability assessment of Galma River for irrigation reveals that based on TDS, SAR, SSP and RSC. The water was suitable for irrigation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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