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Water Quality Status of Three Different Rivers for Fadama-oriented Irrigated Agriculture in Ogbomoso, Southwest Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors involved in the design of the study and literature searches. Authors TPA and MAA managed the experimental process and data collection. Author GOA wrote the first draft, managed data processing and analyses. All authors read, corrected and approved the final manuscript.

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ABSTRACT

Aims: The objective of this study was to evaluate water quality status of rivers OBA, ORA and SUNSUN for irrigated agriculture in Ogbomoso, Southwest Nigeria.
Study Design: Data were analyzed using 2 x 3 factorial design, with two sampling sites and three sampling periods as treatments in three replications.
Place and Duration of Study: The experiment was conducted in six Fadama sites along three rivers (*Oba, Ora*, and *Sunsun)* in Ogbomoso located on Latitude 8° 10'N and Longitude 4° 10'E, about 342 m above the mean sea level, southwest Nigeria between December 2014 and March 2015 during the 2014/2015 irrigation (dry) season.
Methodology: Water samples were collected from two representative Fadama sites along each river and at three different periods during the 2014/2015 irrigation season for the determination of

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water quality indicators and overall water quality index (WQI).
Results: There was significant temporal variation in the water quality indicators of the three rivers. Except for permeability index (PI), other integrated water quality characteristics of SAR, KI, SSP, ESP, MI and RSC varied significantly ($p<0.05$) with respect to sampling site and period, and the average values were within permissible limits for irrigation. Of the three rivers, only River SUNSUN had salinity and sodicity classification of C3-S1 and water quality index of class III during a particular period.
Conclusion: The results from SUNSUN River showed that care must be taken in using the river for irrigation, especially at the peak of dry season, because of salinity problem. Further studies is also recommended for heavy and trace metals contamination as a result of the observed anthropogenic activities in the vicinity of the river bodies.

Keywords: Fadama-oriented irrigation; water quality characteristics; water quality index.

1. INTRODUCTION

Water quality is an important factor for the evaluation of environment changes, which are strongly associated with the social and economic development of any nation [1]. The global concern that fresh water will be scarce in the near future has forced every nation of the world into the evaluation of water qualities in recent years [2]. According to [3], water has become a global concern, not only in terms of the available quantity, but also its quality. In this context, water from a certain source may be good enough for drinking without treatment, however it may not be suitable as a coolant in an industry. Similarly, such water may be good for irrigating certain crops while it may not be suitable for certain other crop species [4].

In irrigated agriculture, salinity and sodicity hazards have been reported as constant threats, with poor irrigation water quality becoming major concern as the climate is changing [5]. This author stressed that the quality of irrigation water is directly related to its effects on both the crops and soils on which they are grown as well as its management, thus high quality crops can only be produced by using high-quality irrigation water. Water for irrigation varies greatly in quality depending upon the total quantity of dissolved salts and its ionic composition [5] in relation to the source of the water [6], its location and time of sampling [3]. [6] stated that the characteristics of irrigation water that define its quality vary with the source of the water. These authors affirmed that there are regional differences (even within a given region) in water characteristics, principally because of differences in geology and climate. In addition, soil types, industrialization, population and anthropogenic activities also contribute to the differences in water quality. Therefore, the use of water for irrigation, while contributing significantly to improving crop productivity and contributing to food security, may in certain situations lead to the accumulation of salts in the soil matrix, which reduces the osmotic potential and soil fertility; impacts soil permeability and infiltration capacity, with overall effect on crop growth and productivity.

Water resources managers and professionals generally disseminate water quality status and trends in terms of the assessment of individual water quality indicators. While this is readily understood within the water resources community, it does not readily get translated to communities who have profound influence on the water bodies and related policies, that is, the general public and policy makers [2]. Therefore, for better understanding of the status of the environment, every community expects a better and comprehensible water quality nomenclature [4]. In this context, the water quality index (WQI) has been reported to bridge the gap between water quality monitoring and reporting methods. The integrative index, which summarizes large amounts of water quality data into a single number, for instance on a rating scale from zero (0) to hundred (100) as excellent, very good, good, fair, poor, etc., which expresses the relative level of impairment of a water body and how the quality has changed over time and due to other influencing factors, has become established for communicating information to water managers, policy makers and the public in a consistent manner [4,7].

Fadama irrigated agriculture is one of the food security strategies established by World Bank sponsored through Federal Government of Nigeria with the aim of meeting the food challenges of rapidly growing human population [8]. For the Ogbomoso Fadama irrigation Project, three major rivers, Oba, Ora and Sunsun, are being used for water supply to the field on yearly basis, either by natural flooding, with the residual moisture content utilized for planting and crop establishment or by manual lifting of water and application to the field. Despite the success of the project in terms of employment and income generation for the rural populace, one critical aspect remains unattended to since the inception of this project over twenty years ago, which is the lack of any documentation on the quality status of the water sources to ascertain their level of suitability for irrigation considering certain anthropogenic activities occurring within the vicinities of these rivers, which make them prone to contamination. Thus, there is the need to generate a database on the quality status of the rivers so that strategies for mitigation could quickly be put in place. Therefore, the objective of this study was to evaluate the water quality status of three different rivers for Fadama-oriented irrigated agriculture in Ogbomoso, Southwest Nigeria.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted in six Fadama sites along three rivers (*Oba, Ora*, and *Sunsun)* in Ogbomoso located on Latitude 8° 10' N and Longitude 4° 10' E, about 342 m above the mean sea level, southwest Nigeria between December 2014 and March 2015 during the 2014/2015 irrigation (dry) season. The study area has a bimodal rainfall pattern, with rainfall peaks in the months of June and September and break in August, with mean annual rainfall of approximately 1200 mm while the mean maximum temperature was not above 33°C and minimum temperature 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 [9]. According to SSS [10], the soil of the study sites is classified as Hapludalf.

The respective FADAMA sites are *Ikose* along Ogbomoso-Igbeti road and *Ojaoba* along Ogbomoso-Oyo road for *Oba* stream; *Baaki* within Ogbomoso township and *Ora garage* along old Ogbomoso-Osogbo road for *Ora* stream and *Obadare* within Ogbomoso township and *Sunsun* along Ogbomoso-*Ajawa* road for *Sunsun* stream (Fig. 1). Two of the FADAMA sites are located along the bank of each of the rivers.

2.2 Sample Collection and Analysis

The six sites selected for the work were visited as early as 8:00 am to collect samples for analyses. Sampling was conducted in December 2014, February 2015 and March 2015. During each sampling campaign, three replicates of water samples were collected in sterilized bottles. After sampling, the bottles were marked, sealed and taken to the laboratory in ice-packed container, where they were stored in a refrigerator until they were taken for further analyses. The water quality indicators analyzed included: pH, Electrical conductivity (EC), Ca^{2+}, Mg^{2+}, K^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}, CO_3^{-}, HCO_3^{-}, PO_4^{-} and NO_3 - N. All analyses were done according to [11] standard method. The concentrations of Na^{+}, Ca^{2+} and Mg^{2+} were used to quantify the sodium adsorption ratio (SAR) according to the equation:

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

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

2.3 Water Quality Index

To calculate the water quality index, reference water samples with electrical conductivity (EC) ≤ 0.7 dS m^{-1} were used [12]. According to [13], the samples with this EC range can be used without any restriction with regard to salinity.

The irrigation water quality index ($IWQI_i$) was therefore computed for each river sample following the equation proposed by [12]:

$$IWQI = \frac{1}{n}\sum_{i=1}^{n} WQI_i$$

where n is the total number of variables evaluated.

For WQI_i and $IWQI$, four irrigation water quality index classes (I, II, III and IV) were used [12]. According to these authors, the classification was based on the range of values from -1.96 to 1.96 as class I, indicating 95% probability that the WQI_i value is statistically equal to the reference population; or in other words, the values of the indices contained in the determined interval do not present any level of restriction. These classes and their interpretations are presented in Table 1.

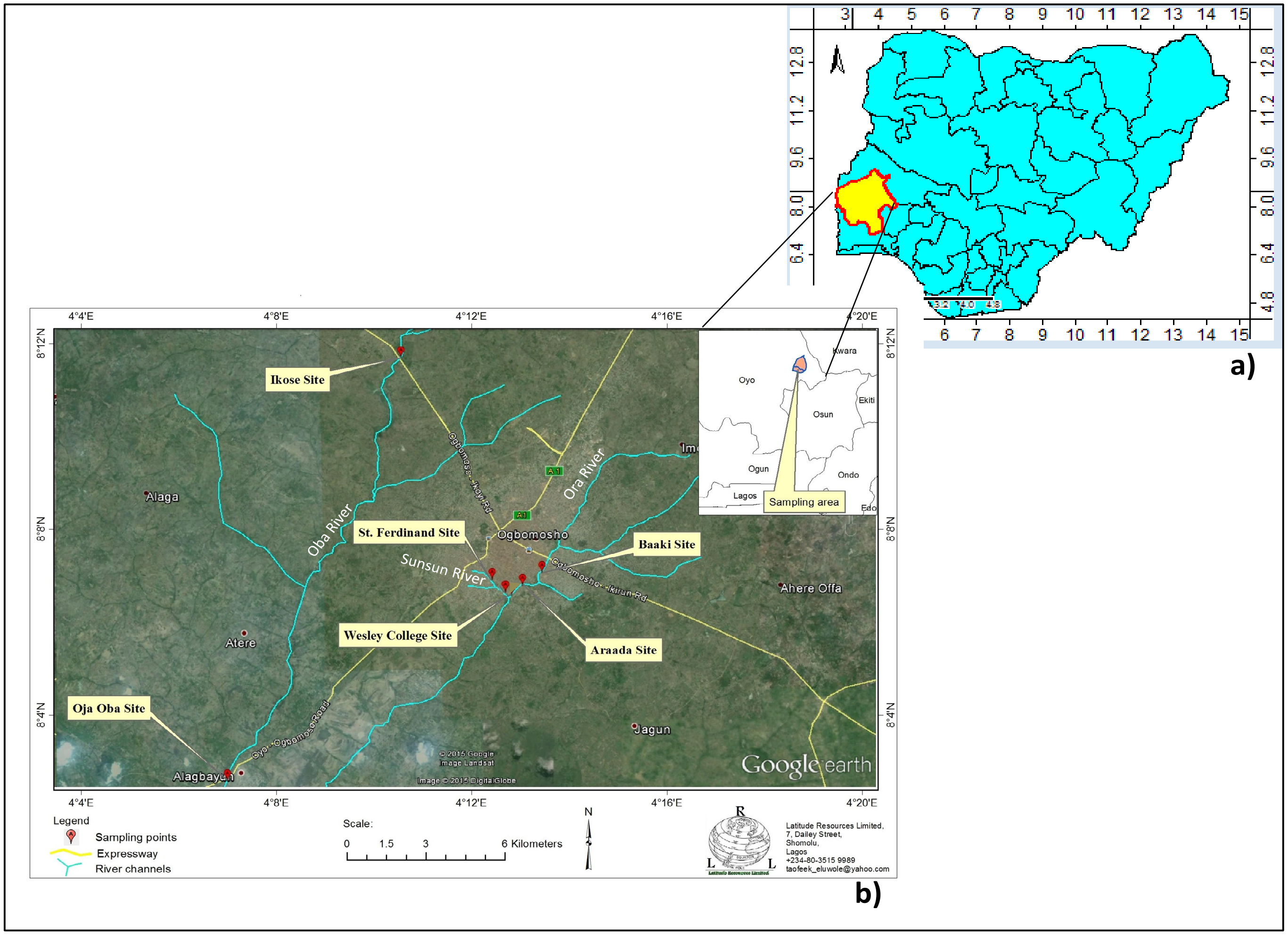

Fig. 1. Map of (a) Nigeria and (b) Oyo State showing the three rivers and the FADAMA sites at Ogbomoso

Table 1. Classification, boundary and interpretation of water quality index for each variable evaluated (WQI_i) and for the irrigation water quality index ($IWQI$)

Class	Boundary	Interpretation
I	WQI_i or $IWQI$ ≤ 1.96	Excellent
II	1.96 ≤ WQI_i or $IWQI$ ≤ 5.88	Good
III	5.88 ≤ WQI_i or $IWQI$ ≤ 9.80	Average
IV	WQI_i or $IWQI$ ≥ 9.80	Poor

Source: Maia and Rodrigues [12]

2.4 Statistical Analysis

The results obtained were subjected to descriptive statistics to determine the minimum, maximum, mean, standard deviation and coefficient of variation of the pooled data, irrespective of sampling location and sampling period. 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 5% level of probability. The relationship of SAR versus electrical conductivity (EC) and pH as well as between irrigation water quality index (*IWQI*) and EC was determined by linear regression. All analyses were performed using SPSS (v. 20) and Grapher (version 10.0) software.

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics of Water Quality Indicators

The results of the range, mean, standard deviation and coefficient of variation of the water quality indicators evaluated, irrespective of sampling location and period, for the three rivers used for FADAMA Irrigation Scheme during the 2014/2015 drying season are presented in Table 2.

The pH values ranged between 6.68 and 9.03, 7.56 and 8.67, 7.86 and 8.83, with mean values of 8.02, 8.22 and 8.41 for OBA, ORA and SUNSUN Rivers, respectively. The mean pH values indicated that the rivers were slightly alkaline. A comparison of the pH values with the normal range of 6.5-8.4 by [14] showed that some samples were outside this range. According to [15], application of irrigation water with pH outside the threshold could cause nutritional disparity or lead to toxic ion build up in the soil. Irrigating with this slightly alkaline water indicates a generally low tendency for availability of trace elements and heavy metals, thus reduces the risk of heavy metal uptake by plants [16].

Electrical conductivity (EC) is one of the major parameters for determining the acceptability of water for irrigation, being a good indicator of salinity hazard to crops as well as reflecting the total dissolved solids (TDS) in water [17]. While the TDS is a direct measurement of dissolved ions (salts and minerals) that cannot be removed by conventional filtration [18], the EC is a direct measurement of dissolved ions using electrode. The EC value of irrigation water ranges between 57.1 and 172.09 µS cm^{-1} (mean = 108.22 µS cm^{-1}) for OBA River, from 65.4 to 344.96 µS cm^{-1} (mean = 163.28 µS cm^{-1}) for ORA River; between 85.3 and 832.0 µS cm^{-1} (mean = 333.07 µS cm^{-1}) for SUNSUN River (Table 2), which in comparison to [19] are in the range of irrigation water quality classification of ‘excellent to fair’. Considering the ‘degree of restriction to use’, an EC value < 700 µS cm^{-1} refers the water of ‘no restriction’; 700-3000 µS cm^{-1} classified as ‘slight to moderate restriction to use’ and > 3000 µS cm^{-1} as ‘severe restriction to use’ [15]. Except for SUNSUN River with some EC values falling within 700-3000 µS cm^{-1} considered slight to moderate restriction to use, the waters of the rivers are suitable for irrigation as they falls under the category ‘no restriction to use’. The TDS values of the irrigation waters ranged between 36.54 and 110.14 mg L^{-1} (average value = 69.26 mg L^{-1}) for OBA River, from 41.86 to 220.77 mgL^{-1} (average value = 104.50 mg L^{-1}) for ORA River, between 54.59 and 532.48 mg L^{-1} (average value = 213.17 mg L^{-1}) for SUNSUN river. According to irrigation water quality classification by [15], Both OBA and ORA rivers had no restriction (< 450 mgL^{-1}) to use for irrigation, whereas SUNSUN River had slight to moderate restriction (450 mg L^{-1} < TDS < 2000 mg L^{-1}) to use. The slight to moderate restriction to use of both the EC and TDS obtained from SUNSUN River is an indication of the accumulation of salts in the soil, which could adversely affect plant growth [15]. High concentration of total dissolved solids (TDS) may arise through weathering of some rocks or arising from anthropogenic activities, including domestic and industrial effluents [20]. Both the EC and TDS are directly associated, thus either could be an index of saline water when non-ionic dissolved elements are absent [21]. TDS is an important parameter to monitor in irrigation water, because many of the dangerous elements which are harmful to crops may be firmly attached to the water [22]. Alobaidy et al. [17] stated that using saline water for irrigation will add salt to the soil, leading to increase in salt concentration, posing threat to both the soil and crop, for instance, reduction in osmotic process and inhibiting water and nutrients uptake from the soil matrix [23].

Sodium (Na^+) content is another major indicator when evaluating irrigation water quality. When sodium concentration <100 mg L^{-1} indicates no restriction, while concentrations > 100 mg L^{-1} shows moderate to high degree of restriction especially for sensitive crops [15]. Na^+ concentrations of the three river samples varied from 6.09 to 66.01 mg L^{-1} (average value = 42.92 mg L^{-1}) for OBA River, from 17.89 to 87.43 mg L^{-1} (average value = 48.89 mg L^{-1}) for ORA River, between 46.82 and 88.36 mg L^{-1} (average value = 63.04 mg L^{-1}) for SUNSUN River which had the highest Na concentration (Table 2). The range and mean values were less than 100 mg L^{-1}, 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 [22] stated that soils saturated by sodium peptize and they lose their permeability, leading to decrease in fertility and their suitability for cultivation.

High concentrations of Ca^{2+} and Mg^{2+} ions in irrigation water will cause increase in soil pH, leading reduction in the availability of phosphorous to plants [24]. According to Khodapanah et al. [25], water containing Ca^{2+} and Mg^{2+} above 200 mg L^{-1} is not suitable for agriculture. The observed concentrations of these elements were not more than 51.09 and 48.13 mg L^{-1} for Ca^{2+} and Mg^{2+}, respectively, showing that none samples exceeded the threshold, thus no threat.

Chloride (Cl^-) is a toxic substance that requires special attention when water is abstracted for irrigation, with possible sources attributed to anthropogenic activities and natural processes. The observed Cl^- ion concentration of the river samples ranged from 48.22 to 700.23 mg L^{-1} (average value = 287.0 mg L^{-1}); 121.5 to 705.6 mg L^{-1} (average value = 426.39 mg L^{-1}); 348.57 to 1843.2 mg L^{-1} (average value = 687.0 mg L^{-1}) for OBA, ORA and SUNSUN rivers, respectively (Table 2). The classification of the rivers in terms of chloride concentration indicates safe to severe degree of restriction for irrigation [15]. Chloride is very essential to plants, however at very low concentrations. This is so because Cl^- is not tied up by the soil, but it is moved with the soil-water, being absorbed by the crop, translocate in the transpiration stream, and eventually stored in the stems, roots and leaves. For example, if the concentration of Cl^- in plant leaves exceeds the tolerance limit, symptoms such as leaf burn or drying of leaf tissue develop [17]. The severity of restriction, especially from ORA and SUNSUN rivers, may be attributed to no recharge (rainfall) and reduced water volume during the drying season, hence most of the ions may have been concentrated.

Nitrogen (N) as nitrate (NO_3^-) and phosphate (PO_4^{3-}) in irrigation water are more of fertility issue, however high levels of PO_4^{3-} in water sources is not desirable, as is it an indication of eutrophication of surface water bodies [26]. The NO_3^- ion concentration obtained from the river samples ranged from 0.05 to 2.21 mg L^{-1} (mean value = 0.66 mg L^{-1}); 0.07 to 2.81 mg L^{-1} (mean value = 0.95 mg L^{-1}); 0.09 to 2.70 mg L^{-1} (mean value = 1.02 mg L^{-1}) for OBA, ORA and SUNSUN rivers, respectively. Conversely, the total phosphate concentration of the rivers ranged from 0.06 to 15.31 mg L^{-1} (mean value = 2.95 mg L^{-1}); 0.08 to 0.98 mg L^{-1} (mean value = 0.44 mg L^{-1}); 0.20 to 4.42 mg L^{-1} (mean value = 1.13 mg L^{-1}) for OBA, ORA and SUNSUN in that order (Table 2). Although nitrates and phosphates are important plant nutrients however there could be pollution of water bodies by these compounds originating from several point and diffuse sources, particularly indiscriminate discharge of household and industrial effluents as well as runoff from agricultural activities (fertilizers, pesticides, and wastes from animal pens) as observed by the anthropogenic activities of the inhabitants of the study area. David and Koop [26] stated that when excess nitrogen and phosphorus are transported to surface water, they cause eutrophication and elevated algal, causing significant impact on the health of the aquatic ecosystem, and thus reduce the ecological and recreational values of freshwater resources. 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 [27]. According to [28], detergents, industrial effluents and fertilizers transported by surface runoff could cause increased concentrations of phosphates in surface waters.

Sulphates are naturally occurring in surface waters as SO_4^{2-}. However, discharges from industries as well as atmospheric precipitation could add significant quantities of sulphates to surface waters [2]. Sulphate had concentrations between 0.02 and 7.15 mg L^{-1} (average value = 2.63 mg L^{-1}) for OBA River, from 0.01 to 3.12 mg L^{-1} (average value = 0.87 mg L^{-1}) for ORA River, between 0.01 and 3.31 mg L^{-1} (average value = 0.92 mg L^{-1}) for SUNSUN river (Table 2). These values were within the maximum limit of 500 mg L^{-1} set by [29], indicating no threat from SO_4^{2-}.

Water having elevated levels of both CO_3^{2-} and HCO_3^- is an indication of Ca^{2+} and Mg^{2+} precipitating as carbonates [17], which could cause plugging of emitters if such water is used for drip irrigation. The HCO_3^- concentration had values ranging from 10.89 to 97.60 mg L^{-1} (mean value = 58.84 mg L^{-1}), between 17.92 and 62.33 mg L^{-1} (mean value = 39.66 mg L^{-1}), and from 35.97 to 134.31 mg L^{-1} (mean value = 61.86 mg L^{-1}) for OBA, ORA and SUNSUN rivers, respectively (Table 2). According to the water quality criteria for irrigation in terms of bicarbonate by [15], both OBA and SUNSUN rivers ranged from none to moderate restriction to use while ORA River is classified as having no restriction to use. Of the three rivers, OBA River had low concentration of CO_3^{2-}, although only during the first sampling period in December 2014.

When compared with the classification of coefficient of variation (CV) by [30], the dispersion of EC, TDS, Ca^{2+}, Mg^{2+}, K^+ and Na^+ around the mean value was generally high (CV>35%), while that of pH was low (CV<15%). For NO_3^-, SO_4^{2-}, PO_4^{3-}, data dispersion was extremely high (CV >1.0) (Table 2). The reason for the high CV values is attributed to different period of sampling, showing the heterogeneity of the water quality indices to a great extent. During the interval between sampling, a series of natural (rainfall, weathering, erosion, etc.) and human-induced (waste disposal, agricultural activities etc.) processes take place which impact water quality at different scales.

3.2 Temporal Variability of Water Quality Indicators

The temporal distribution of the water quality indicators evaluated for the three rivers are shown in Figs. 2, 3 and 4. Except for few cases, there were significant differences (p<0.05) in the water quality indicators among the three rivers for each sampling period. Except for SO_4^{2-} and PO_4^{3-}, SUNSUN River seemed having the highest concentration of the quality indicators. K^+, Na^+, NO_3^-, HCO_3^- and Cl^- increased with time (Figs. 3 and 4); pH and Ca^{2+} increased at second sampling (middle of growing period) but decreased during the third sampling (end of growing period) while the EC decreased with time (Fig. 2). The significant difference in the water quality indicators is attributed to the fact that each river originates from different sources and each river course possesses different attributes such as soil type, weathering as well as human activities, in other words, the loads received by individual river differs. The highest values from SUNSUN River may be due to its relative dimension in term of size and water volume. Thus there is tendency that it could carry higher pollutant load.

3.3 Integrated Irrigation Water Quality Characteristics

According to Alobaidy et al. [17], the concentration of salt from individual irrigation water should not be the only criteria for restriction for irrigation use. The authors stated further that waters with elevated salt concentration can still be used for irrigation without any impact on soil functioning. On this premise, we computed some established water quality characteristics. Thus, the results of analysis of variance (ANOVA) of integrated irrigation water quality characteristics of the three rivers used for the FADAMA Irrigation Project are presented in Table 3.

Sodium adsorption ratio (SAR) is one of the mostly used criteria to assess sodium hazard in both soil and water bodies [31]. There were significant differences (p<0.05) in the SAR values of the river samples with respect to sampling location and period. Water having SAR<3 is considered good for irrigation [15]. It was observed that all the three rivers studied were good for irrigation, except for one case from ORA river where SAR>3. Sodium adsorption is promoted when Na^+ proportion increase in relation to Ca^{2+} and Mg^{2+}, resulting in soil dispersion [32] and the continuous use of water having elevated SAR could cause disintegration of soil aggregates. When sodium is absorbed, it becomes bonded to the soil particles, resulting into hard and compact soil when dry and impermeable to water infiltration [5].

Table 2. Descriptive statistics of water quality indicators, irrespective of sampling location and period, of the three rivers used during the 2014/2015 season at the FADAMA irrigation scheme in Ogbomoso, Nigeria

Par.	OBA river					ORA river					SUNSUN river				
	Min.	Max.	Mean	SD	CV	Min.	Max.	Mean	SD	CV	Min.	Max.	Mean	SD	CV
pH_{H2O}	6.68	9.03	8.02	0.68	0.085	7.56	8.67	8.22	0.35	0.042	7.86	8.83	8.41	0.31	0.036
EC	57.10	172.09	108.22	45.89	0.424	65.40	344.96	163.28	124.10	0.760	85.30	832.00	333.07	327.92	0.985
TDS	36.54	110.14	69.26	29.37	0.424	41.86	220.77	104.50	79.42	0.760	54.59	532.48	213.17	209.87	0.984
Ca^{2+}	2.48	38.01	22.06	14.06	0.637	20.87	48.21	32.89	10.22	0.311	27.99	51.09	40.68	8.30	0.204
Mg^{2+}	1.32	27.12	12.53	8.49	0.677	7. 95	41.21	19.06	12. 51	0.656	14.61	48.13	24.84	12.52	0.504
K^+	1.95	87.43	40.94	34.85	0.851	9.32	56.36	31.89	18.67	0.585	27.95	153.21	66.92	48.86	0.730
Na^+	6.09	66.01	42.92	24.37	0.568	17.89	87.43	48.89	25.22	0.516	46.82	88.36	63.04	17.37	0.276
NO_3^-	0.05	2.21	0.66	0.73	1.104	0.07	2.81	0.95	1.24	1.302	0.09	2.70	1.02	0.87	0.854
SO_4^{-2}	0.02	7.15	2.63	3.17	1.205	0.01	3.12	0.87	1.06	1.222	0.01	3.31	0.92	1.16	1.259
PO_4^{-3}	0.06	15.31	2.95	5.65	1.916	0.08	0.98	0.44	0.32	0.728	0.20	4.42	1.13	1.46	1.289
Cl^-	48.22	700.23	287.07	227.45	0.792	121.75	705.60	426.39	248.64	0.583	348.57	1843.20	687.80	525.47	0.764
CO_3^{2-}	1.22	1.23	1.22	0.004	0.003	nd	Nd	nd	nd	nd	nd	nd	nd	nd	nd
HCO_3^-	10.89	97.60	58.84	32.06	0.545	17.92	62.33	39.66	14.03	0.354	35.97	134.21	61.86	35.55	0.575

pH: degree of alkalinity and acidity; EC: electrical conductivity, μS cm^{-1}; TDS: total dissolved solid, mg L^{-1}; Ca^{2+}: calcium, mg L^{-1} ; Mg^{2+}: magnesium, mg L^{-1}; K^+: potassium, mg L^{-1}; Na^+: sodium, mg L^{-1}; NO_3^-: nitrate, mg L^{-1}; SO_4^{-2}: sulphate, mg L^{-1}; PO_4^{-3}: phosphate, mg L^{-1}; Cl^-: chloride, mg L^{-1}; CO_3^{2-}: carbonate, mg L^{-1}; HCO_3^-: bicarbonate, mg L^{-1}; Min.: minimum; Max.: maximum; SD: standard deviation; CV: coefficient of variation; nd: not detected

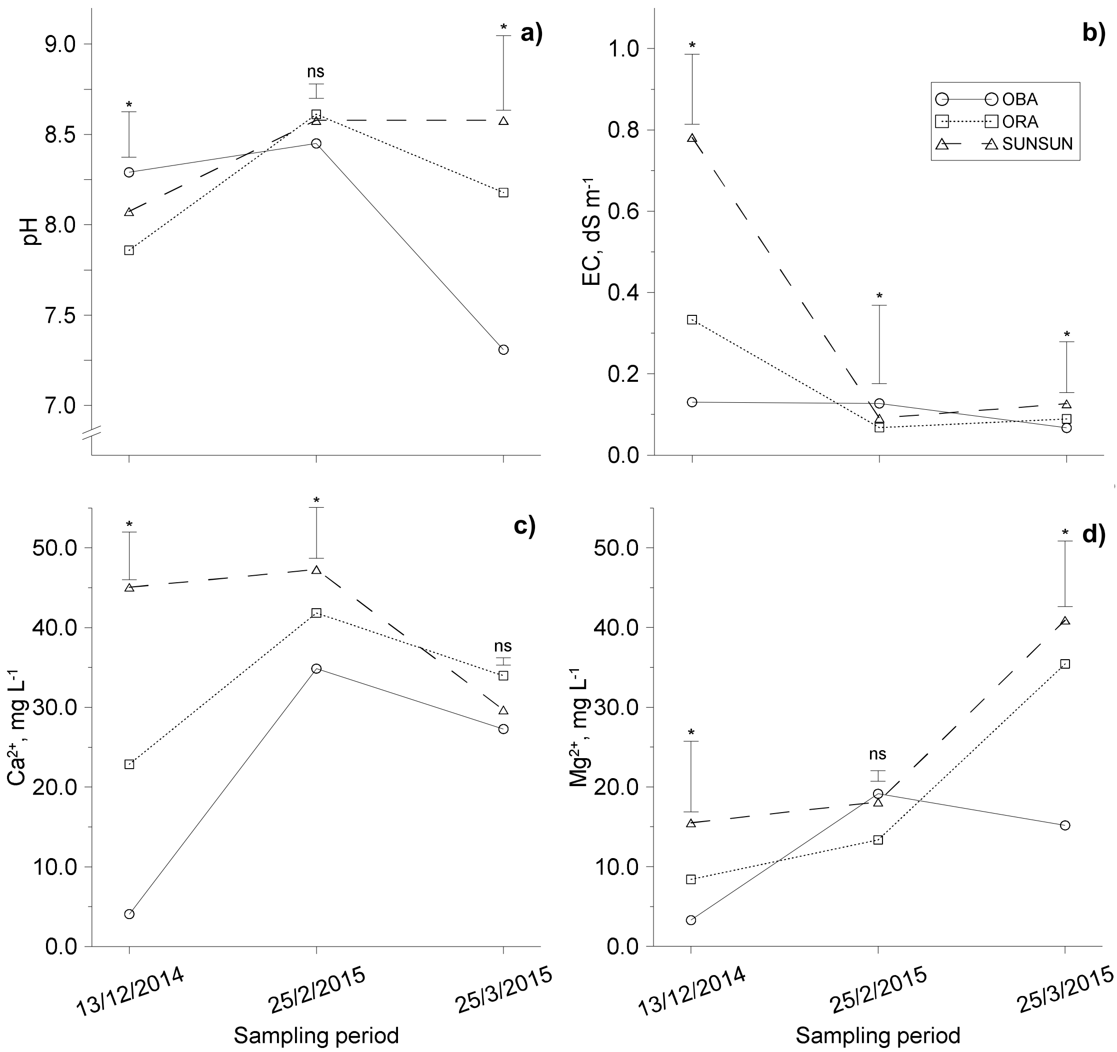

Fig. 2. Temporal distribution of the water quality indicators (a) pH, (b) EC, (c) Ca^{2+} and (d) Mg^{2+}, evaluated for the three rivers used for the FADAMA irrigation project during the 2014/2015 growing season

Kelly index (KI) has been use to classify water quality for irrigation purposes [5]. Except for the sampling location of OBA river, there were significant differences ($p<0.05$) in the KI values of the river samples due to sampling location and period. The average values of KI, irrespective of sampling location and period, ranged between 0.69 and 1.22; 0.48 and 1.29; 0.54 and 0.89 for OBA, ORA and SUNSUN rivers, respectively. According to [33] classification, values of KI < 1 is an indication of water of good water quality and > 1 indicates bad water quality for irrigation. In this study, the KI showed that all the three rivers are suitable for irrigation agriculture.

Soil permeability is reduced when irrigating with water of high sodium concentration. Doneen [34] developed a model for classifying the suitability of water for irrigation using the permeability index (PI). Irrespective of sampling location and period, the average values of PI ranged between 63.77 and 77.97%; 42.34 and 53.83%; 47.62 and 64.73% for OBA, ORA and SUNSUN rivers, respectively. Following the Doneen [34] model, Nagaraju et al. [35] classified waters for irrigation: classes I and II as good for irrigation with 75% or more maximum permeability and class III as waters unsuitable with 25% of maximum permeability. Based on the PI values, all the three rivers studied are considered suitable for irrigation.

Another measure of a possible effect of water on soil permeability is the integration of the SAR and the corresponding EC. In this context, the US salinity monograph was developed using the combined effect of SAR (alkalinity) and EC (salinity), and has been widely used to assess the suitability of water for irrigation e.g. [17,6]. The classification of the river samples based on this nomograph is shown in Fig. 5. The two sites along OBA River had water samples falling in the class of C1-S1. ORA river water samples fall in the C1-S1 and C2-S1 class while SUNSUN river water samples fall in the C1-S1, C2-S1 and C3-S1 class. C1-S1 class indicates water of low salinity and low SAR, C2-S1 class categorizes water with medium salinity and low SAR while C3-S1 indicates high salinity but low sodium water (low SAR). Both OBA and ORA rivers can be used for irrigating almost all soil types and crops without any concern, however for ORA River, some moderate amount of leaching requirement is required. For SUNSUN River, there is very low risk of exchangeable Na^+. Thus, this type of water can be suitable for plants that tolerate elevated salts, however care is needed, especially for soils with drainage problem [36].

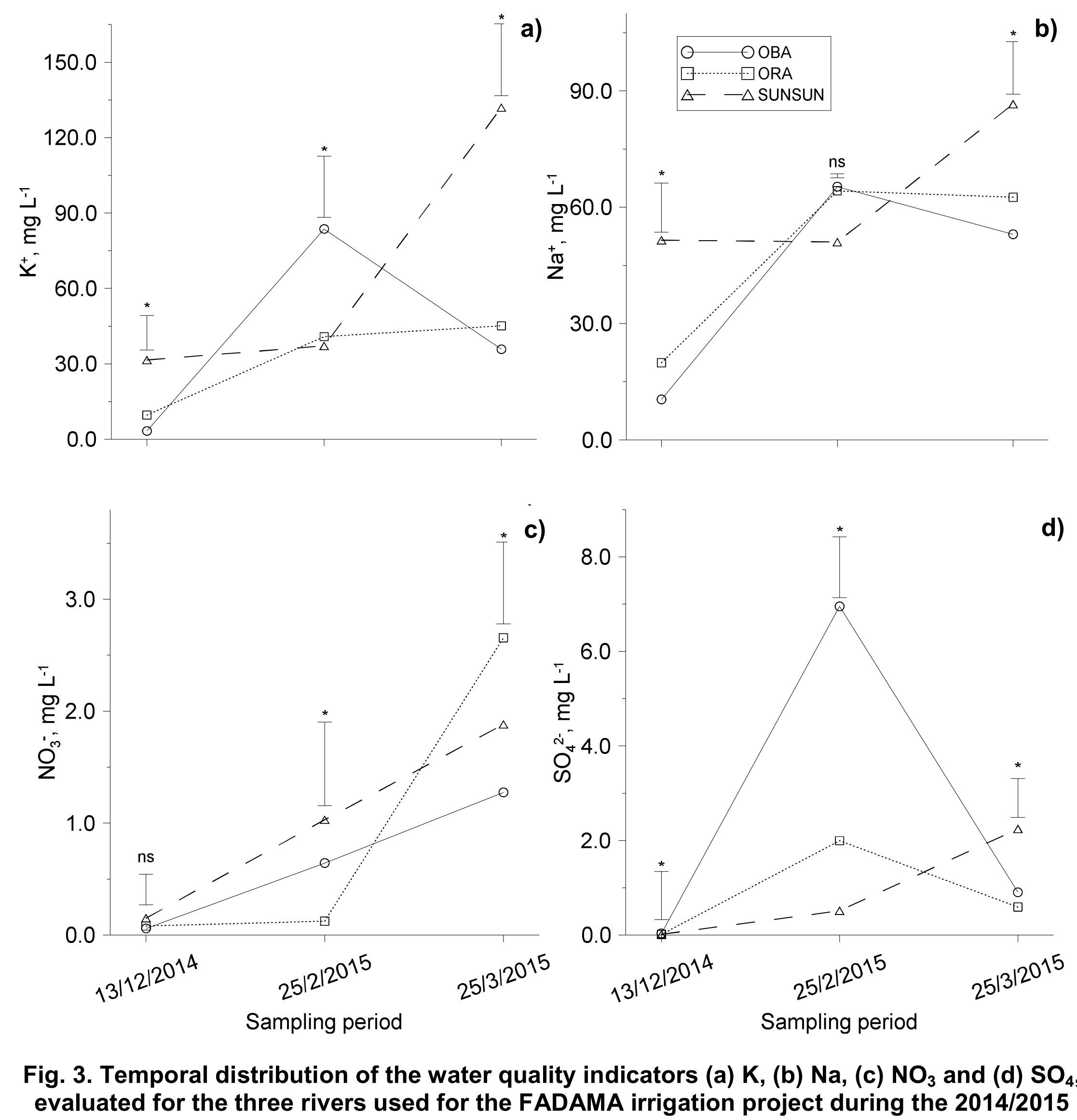

Fig. 3. Temporal distribution of the water quality indicators (a) K, (b) Na, (c) NO_3 and (d) SO_4, evaluated for the three rivers used for the FADAMA irrigation project during the 2014/2015 growing season

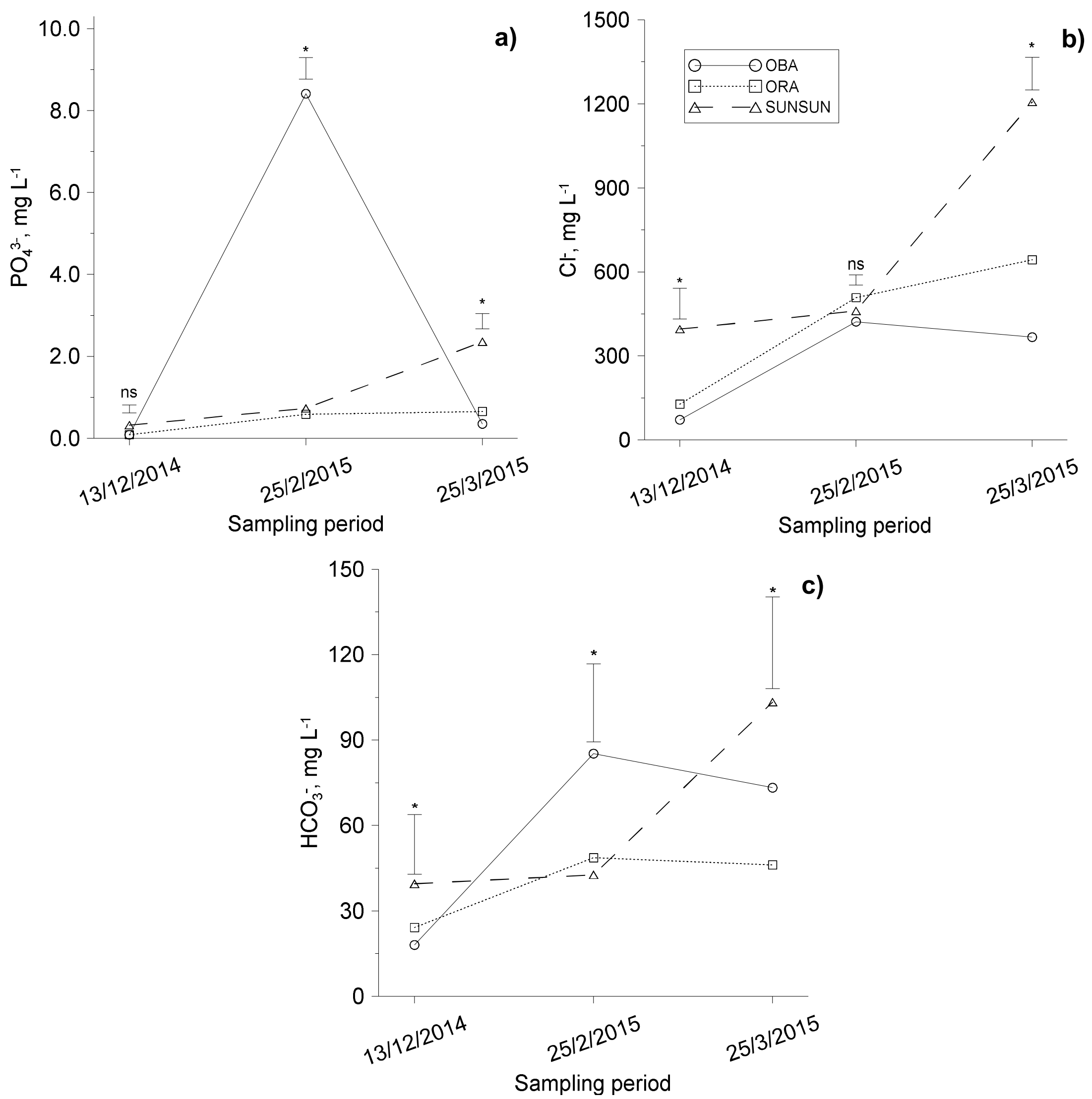

Fig. 4. Temporal distribution of the water quality indicators (a) PO_3^-, (b) Cl^- and (c) HCO_3^- evaluated for the three rivers used for the FADAMA irrigation project during the 2014/2015 growing season

Figs. 6, 7 and 8 show the fitted functions between SAR versus pH and EC. The correlation coefficient (*R*) between SAR and pH was positive, ranging between 0.0906 and 0.1717, with the highest from ORA River. Similarly, the correlation coefficient between SAR and EC was also positive, with values between 0.0121 and 0.2618, and ORA River had the highest correlation. The best relationship between SAR and pH for OBA and SUNSUN rivers was obtained using quadratic function (Figs. 6a and 8a). The lower values of *R* agree with the significant variability of the indicators with respect to sampling period. Thus, the variables are not expected to repeat their magnitude over time. [17] also reported low coefficient of correlation between SAR and EC and attributed it to high variation in the EC values.

Soluble sodium percentage (SSP) and exchangeable sodium percentage (ESP) are also used to evaluate sodium hazard and indicator of soil structural degradation. Water with SSP > 60% could result in sodium accumulations, causing soil structural degradation [37]. In this study, the SSP significantly ($p<0.05$) differed among the three rivers with respect to location and sampling period, with the average values of

SSP ranging from 30.96 to 50.01%, 29.77 to 46.44% and 28.44 to 35.13% for OBA, ORA and SUNSUN rivers, respectively. These results indicate that the rivers pose limited restriction for irrigation. According to [38], an ESP value between 10-15% is considered as critical, an ESP = 25% may pose little effect on soil structure in a sandy soil, such as the soil of this study is sandy loam in texture. Furthermore, an ESP = 5% is considered high especially for soils with 2:1 clay minerals. In this study, the average values ESP was not more than 3% for all the three rivers (Table 3), which agree with the low sodium status of the rivers as already discussed.

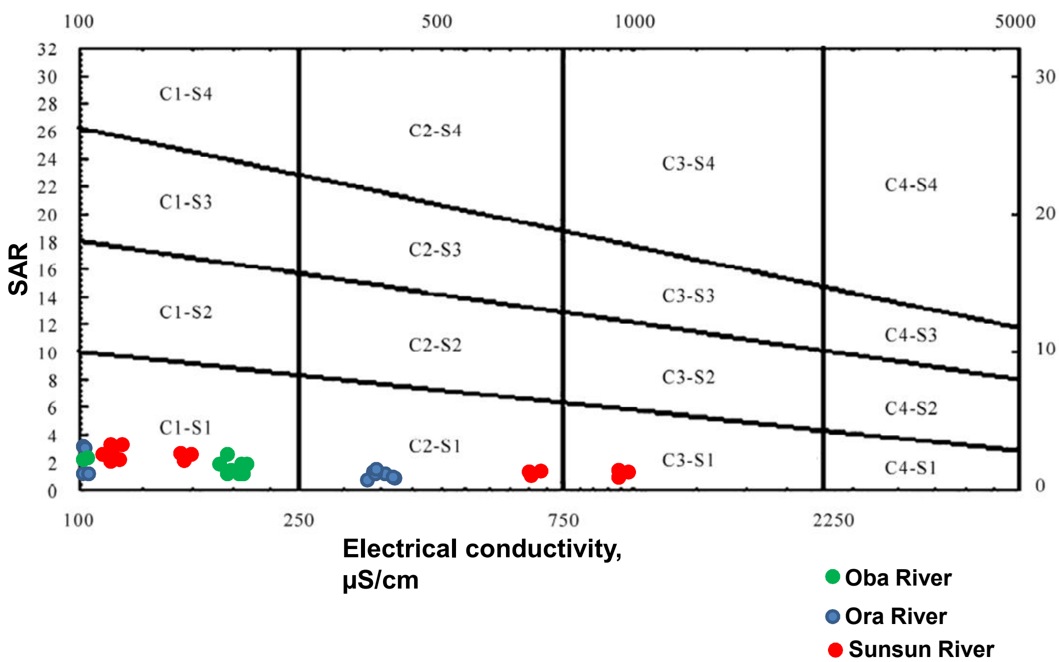

Fig. 5. US salinity nomograph showing the classification of the three river water samples with respect to sodium and salinity hazards

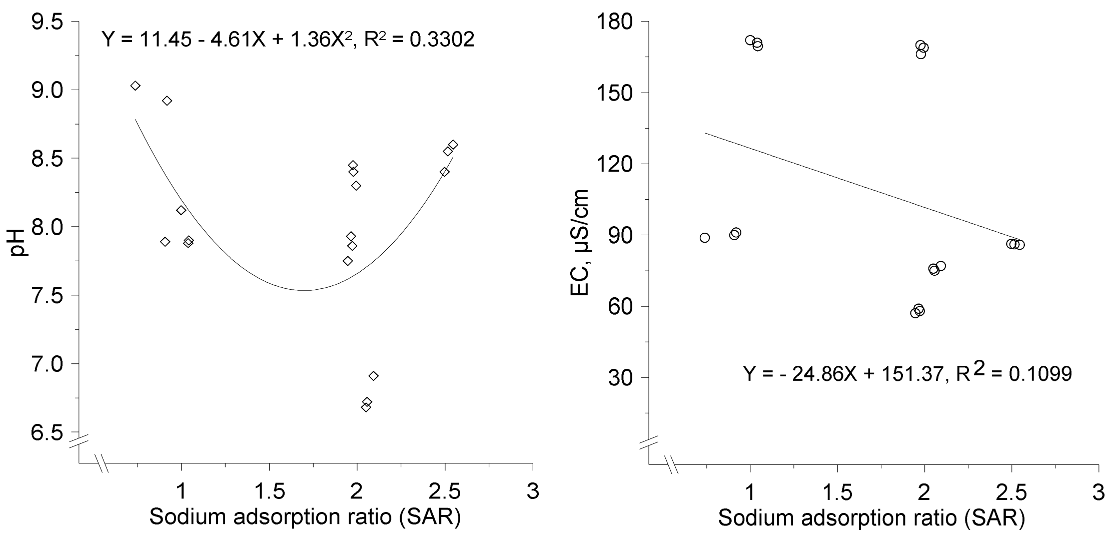

Fig. 6. Relationship between sodium adsorption ration (SAR) and (a) soil pH, and (b). Electrical conductivity, EC for OBA river

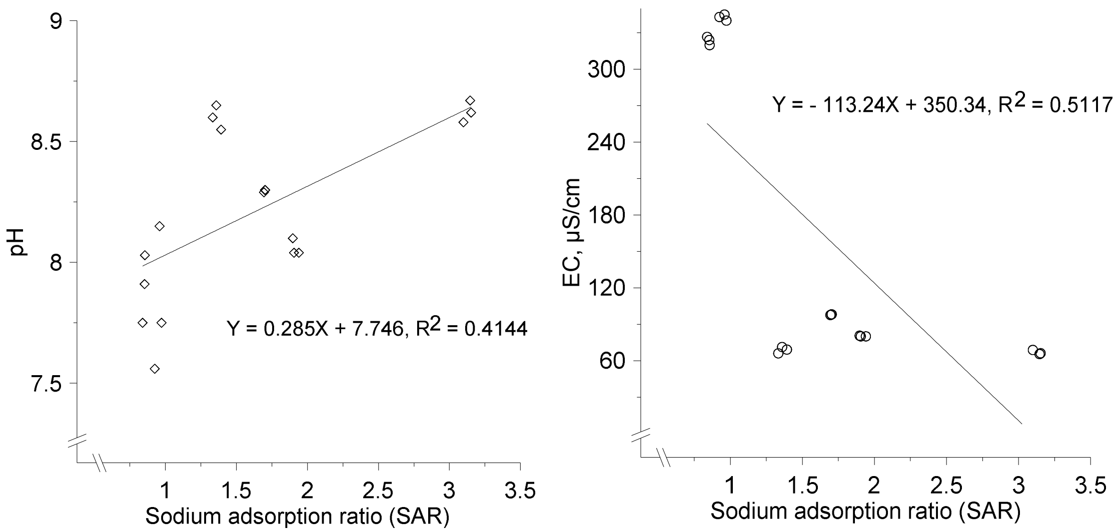

Fig. 7. Relationship between sodium adsorption ration (SAR) and (a) soil pH, and (b). Electrical conductivity, EC for ORA river

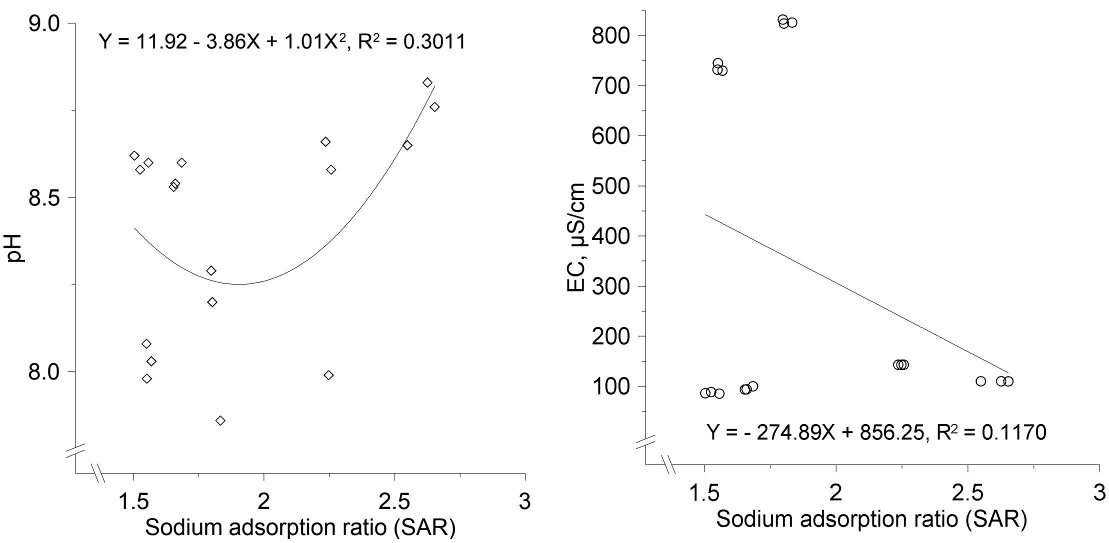

Fig. 8. Relationship between sodium adsorption ration (SAR) and (a) soil pH, and (b). Electrical conductivity, EC for SUNSUN river

The measure of the effect of magnesium (Mg^{2+}) in irrigated water is expressed as magnesium hazard (MH). Nishanthiny et al. [39] stated that waters with high concentration of Mg^{2+} will adversely affect crop yield. The average values of MH significantly ($p<0.05$) differed among the three rivers with respect to location and sampling period, with the values varying from 36.55 to 59.97%, 30.77 to 66.21% and 35.09 to 73.43% for OBA, ORA and SUNSUN rivers, respectively, with the highest values from SUNSUN River. The values of MH < 50 indicate suitable water for irrigation and >50 indicate unsuitable [15]. According to the MH values, all the three rivers showed some degree of exception in relation to magnesium hazard for irrigation, especially at third sampling from ORA and SUNSUN rivers (Table 3).

Excess concentrations of CO_3^{2-} and HCO_3^- over those of Ca^{2+} and Mg^{2+} in water influence its suitability for irrigation [17]. Eaton [40] stated that waters with high values of RSC possess elevated pH, meaning that land irrigated with such waters could have fertility problem because of accumulation of sodium carbonate, a condition known as dark soil. The average values of RSC significantly ($p<0.05$) differed with respect to both sampling location and period for OBA and ORA rivers. For SUNSUN River, RSC was significantly ($p<0.05$) differed for sampling period only. The average values of RSC varied from -2.48 to -0.06, -4.80 to -1.43 and -3.17 to -2.86 for OBA, ORA and SUNSUN rivers, respectively. According to the classification by [36], a RSC value < 1.25 meq L^{-1} is considered safe, 1.25 < RSC < 2.5 meq L^{-1} is permissible while RSC > 2.5 meq L^{-1} is unsuitable for irrigation purposes. The RSC values of the three rivers were negative showing that all the water samples had RSC < 0 and therefore are considered safe for irrigation with respect to carbonate.

Except for PI (OBA River) and RSC (SUNSUN River), there was significant ($p<0.05$) interaction between sampling location and period on the integrated water quality characteristics, which may be attributed to variability in geology and climate. In addition, anthropogenic activities at different times and the peculiarity of each region may have contributed to the significant interaction between sampling location and period on water quality.

Table 3. Results of analysis of variance (ANOVA) of computed irrigation water quality characteristics of the three rivers for the FADAMA irrigation project

		SAR	KI	PI	SSP	ESP	MH	RSC
		meq/l$^{-1/2}$	-	-------------------------	------------- % -------------		-----------------------	meq/l$^{-1/2}$
Loc.	**ST**			**OBA River**				
	ST_I	0.86	1.22	77.97	50.01	0.00	49.31	-0.06
Loc I	ST_{II}	1.98	0.69	63.77	30.96	1.64	54.34	-2.48
	ST_{III}	2.07	0.87	73.14	37.66	1.75	41.21	-1.42
	ST_I	1.03	0.87	77.28	42.63	0.25	59.97	-0.30
Loc II	ST_{II}	2.52	1.21	75.19	38.14	2.40	36.55	-1.29
	ST_{III}	1.96	0.89	69.01	41.73	1.61	55.69	-1.42
	Loc.	s	ns	Ns	ns	s	s	s
	ST	s	s	Ns	s	s	s	s
	Loc x ST	s	s	Ns	s	s	s	s
				ORA River				
	ST_I	0.95	0.48	49.67	29.98	0.14	36.80	-1.45
Loc I	ST_{II}	1.36	0.52	53.09	30.33	0.74	30.77	-2.46
	ST_{III}	1.92	0.70	53.83	34.77	1.54	66.21	-2.94
	ST_I	0.85	0.46	43.23	28.57	-0.01	38.89	-1.43
Loc II	ST_{II}	3.13	1.29	65.32	46.44	3.25	38.98	-2.33
	ST_{III}	1.70	0.51	42.34	29.77	1.23	61.31	-4.80
	Loc.	s	s	s	s	s	s	s
	ST	s	s	s	s	s	s	s
	Loc x ST	s	s	s	s	s	s	s
				SUNSUN River				
	ST_I	1.56	0.59	47.72	32.80	1.03	35.09	-2.91
Loc I	ST_{II}	1.66	0.61	47.62	32.56	1.19	41.43	-3.17
	ST_{III}	2.25	0.68	64.73	28.44	2.01	73.43	-3.21
	ST_I	1.81	0.68	52.16	35.13	1.39	37.38	-2.86
Loc II	ST_{II}	1.53	0.54	48.38	30.54	0.99	36.22	-3.15
	ST_{III}	2.61	0.89	61.60	34.73	2.52	64.56	-3.14
	Loc.	s	s	s	s	s	s	ns
	ST	s	s	s	s	s	s	s
	Loc x ST	s	s	s	s	s	s	ns

SAR: Sodium adsorption ratio; KI: Kelly index; PI: permeability index; SSP: soluble sodium percentage; ESP: exchangeable sodium percentage; MH: magnesium hazard; RSC: residual sodium carbonate. ST_I: first sampling period; ST_{II}: second sampling period; ST_{III}: third sampling period; Loc I.: location I; Loc.II: location II. ST: sampling period. s: significant; ns: not significant at 5% level of probability by Fisher`s LSD test.

Table 4. Classification of irrigation water quality index (IWQI) of the three river water samples

River	Site	Sampling period	IWQI	Classification
		ST_I	1.14	I
	Site I	ST_{II}	0.97	I
OBA		ST_{III}	1.29	I
		ST_I	0.80	I
	Site II	ST_{II}	0.74	I
		ST_{III}	0.75	I
		ST_I	1.03	I
	Site I	ST_{II}	1.12	I
ORA		ST_{III}	0.79	I
		ST_I	1.16	I
	Site II	ST_{II}	0.67	I
		ST_{III}	0.97	I
		ST_I	8.18	III
	Site I	ST_{II}	9.33	III
SUNSUN		ST_{III}	0.67	I
		ST_I	0.87	I
	Site II	ST_{II}	1.41	I
		ST_{III}	0.68	I

ST_I: first sampling period; ST_{II}: second sampling period; ST_{III}: third sampling period; ST: sampling period

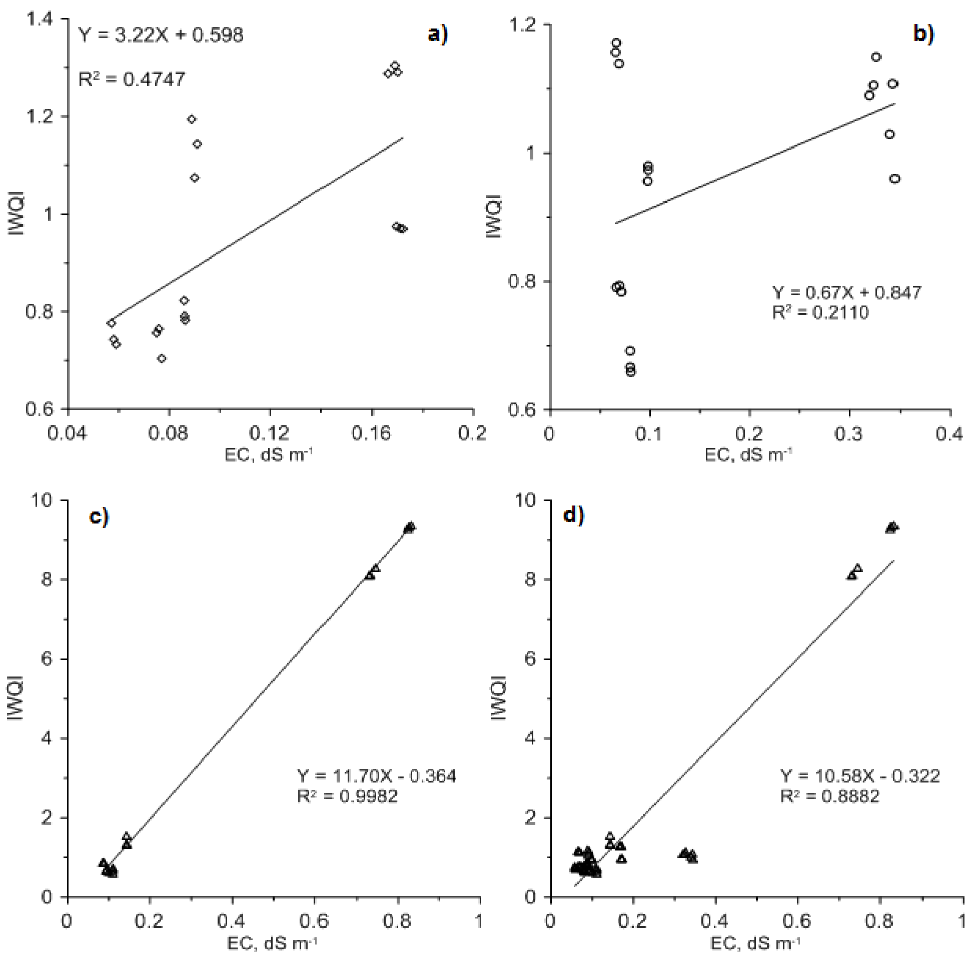

Fig. 9. Relationship between irrigation water quality index (IWQI) and (b) electrical conductivity, EC, for (a) OBA River, (b) ORA River, (c) SUNSUN River and (d) all the three rivers

3.4 Irrigation Water Quality Index (IWQI)

Irrigation water quality index (IWQI) is used to reduce large amounts of water quality indicators into simple terms (e.g., excellent, good, fair, bad, etc.) for irrigation purposes, and according to [41], this shows the quality status of water such as streams, rivers, lakes, and reservoirs. The IWQI of the three rivers are presented in Table 4. According to IWQI classification by [12], the IWQI of the rivers, irrespective of sampling location and period, fall into class I, except for SUNSUN river that had IWQI classified as class III (Table 1) at site I during the first and second sampling (ST I and II), indicating that both OBA and ORA rivers are excellent for irrigation while SUNSUN river was classified as excellent and average. The excellent water quality index classification from both OBA and ORA rivers is consistence with the grouping obtained from the US Salinity Laboratory monograph as C1-S1 and C2-S1 for each river, respectively. Conversely, the average WQI classification for SUNSUN River for site I during the first and second sampling campaign is in line with the water samples falling into C3 salinity class (Fig. 5). The relationship between IWQI and EC is shown in Fig. 9, with the coefficient of determination as 0.4747, 0.2110 and 0.9982 for OBA, ORA and SUNSUN rivers, respectively while Fig. 9d shows the relationship (R^2 = 0.882) when the results for the three rivers were combined. The IWQI can be estimated as a function of EC for SUNSUN River (R^2 > 0.90), on average for OBA River and marginally for ORA River. However, the combination of IWQI and EC for the three rivers showed that IWQI can be estimated as a function of EC using a single equation ($R^2 \approx 0.90$), which is contrary to [12] who stated that it is not possible to estimate the IWQI for their three water sources by a single equation. Also, our study did not support the hypothesis by [42] that a single regression equation might not explain the variability of ion concentration in water.

4. CONCLUSIONS

The three water bodies were not acidic and high variability was observed in the ionic composition of the three water sources and within a single water source due to different sampling periods.

Except for PI, the integrated water quality characteristics including TDS, SAR, SSP, RSC, KI, and MH differed with respect to sampling sites and periods but they were within the permissible limits for irrigation.

Although different water quality characteristics were observed, water with good quality was predominant, generally classified as IWQI I, indicating that the three rivers are considered suitable for irrigation. Nevertheless, care must be taken using water from SUNSUN River, especially at the peak of dry season for irrigation, because of salinity problem. Further studies is also recommended for heavy and trace metals contamination as a result of the observed anthropogenic activities in the vicinity of the river bodies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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