Salinity Status of Osere River for Irrigation: Long Term Use Implication in Selected Farmers' Field in Ilorin, Nigeria.

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Abstract

Osere River is one of the important rivers that serves as a cheaper and easier disposal alternative to industries and at the same time a less expensive and dependable water supply to farmers for dry season vegetable production in Ilorin, the capital city of Kwara State, Nigeria. The edaphic aftermath of the use of its water for irrigation was investigated using a Randomized Complete Block Design (RCBD) in a two way factorial experiment. Factors comprised of fifty meter distance intervals (50 and 100 m) downstream and a control (50 m upstream) of a soap industry effluent discharge point and irrigation duration (0, 10, 20 and 30 years). River water samples indicated that the activities of the soap industry did not lead to its increased electrical conductivity (which signifies presence of dissolved salts and/or impurities), however soils under prolonged irrigation (up to 10 years) showed signs of salt induced structural deterioration (MWD). Farm soils 50 m downstream showed the lowest structural stability (MWD = 0.77 mm)and highest % silt of 21.2 whereas those located 100 m downstream indicated highest MWD of 1.10 mm. The consequent soil structural degradation was tied to elevated values of sodium adsorption ratio (SAR) following prolonged irrigation.

Keywords: Osere River, salinity, soil structural stability and soil chemical properties

Introduction

Water is essential for the sustenance of human, plant and animal life and constitutes about 70% of the Earth's surface. Water pollution is a major problem in the global context. Polluted water has been found to be a leading cause of diseases and deaths worldwide, accounting for the deaths of more than 14,000 people daily (Pink, 2006). In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well. In a recent national report on water quality in the United States, 45 percent of assessed stream miles, 47 percent of assessed lake acres, and 32 percent of assessed bay and estuarine square miles were classified as polluted (Pink, 2006). Water body contaminations have also been reported in Nigeria, for instance in Ogun River, where industrial effluents from Lagos and Abeokuta is discharged (Jaji, et al., 2007). The river was reported to have high level of turbidity, fecal coliform, iron, oil and grease (Jaji, et al, 2007). The valleys which convey this water are also prone to pollution from human activities such as road/bridge constructions which are major yardsticks for good governance in Nigeria. Polluted water consists of Industrial effluents, sewage water, and rain water. The use of this type of water is a common practice in agriculture. Estimation indicates that more than fifty countries of the world with an area of twenty million hectares are supplied with polluted or partially treated polluted water (Mahmood, 2006). In poor countries of the world more than 80% polluted water has been used for irrigation (Mara and Cairncross, 1989). Farmers use polluted water to save their expenses (Ibrahim and Salmon, 1992). With the recent trends of unpredictable rainfall patterns and climate change, these polluted water bodies and valleys are often used in augmenting inland agricultural production (the cultivation of valley bottom called Fadama in Nigeria). Polluted irrigation water may completely render agricultural soils unproductive through salt build-up. It is as a result of such accumulation that extensive areas in the arid and semi-arid region of Nigeria have gone out of cultivation (Zata, et al., 2008). It is well recognized that the salinity of an irrigation water and the sodium adsorption ratio (SAR) have an interactive effect on soil physical properties (Frenkel, 1984). Elevated values of SAR result in decreased hydraulic conductivity decreased aggregate stability, clay dispersion, swelling of expandable clays, surface crusting and reduced workability (Frenkel et al., 1978). On very salty sites a complete loss of groundcover and visible salt crystals often occur on the soil surface making it vulnerable to erosion (Greenway, 1980). As salts accumulate in soils they can reach levels that affect the environment through loss of productive species and dominance of salt-tolerant species (Tenison, 2009), decline of native vegetation, loss of habitat, loss of nesting sites and decline in bird populations, decline in wildlife fauna other than birds, reduced food for wildlife populations, increased soil and wind erosion, reduced, decline in fish and aquatic populations, reduced aesthetic value, reduced recreational and tourism values, reduced biodiversity in stream fauna, riparian vegetation and wetlands, increases in weeds and undesirable changes in plant populations and damage to state/national parks and wildlife sanctuaries.

OSERE River in Ilorin which serves as a source of irrigation water to many farmers was reported as polluted (with slightly alkaline pH) by Adeyemi-ale et al.(2014). The pollution of this river can be traced to the untreated effluent discharged into the river by the industries situated along the river course. Some (soap and detergent) effluents discharged by these industries are known to contain salts such as sodium and magnesium which causes water salinity (Ogundiran et al., 2014) and consequently soil salinity when used for irrigation. The long term use of this water for irrigation may bring about increased soil exchangeable sodium percentage and sodium adsorption ratio which may result in poor soil quality (soil crusting, reduced total porosity, aeration, water penetration and water redistribution). Against this backdrop, there is therefore need to assess the extent of the pollution of Osere River and also the extent of soil degradation occasioned by the use of the water for irrigation.

Materials and Methods

Description of Experimental Location

Ilorin is the capital of Kwara state, Nigeria. It lies by latitude 80 35' E and longitude 40 35' N (Jimoh, 1999) with a total land area of about 100 km^2 (Kwara State Government, 2007). For administrative purposes, it is divided into Ilorin West, Ilorin East, Ilorin South and Moro Local Government Areas (Oyebanji, 1993). The climate of Ilorin is the humid tropic type and characterized by both the wet and dry seasons with mean annual temperature that ranges from 25 - 28.9 0C. The annual mean rainfall is about 1150 mm, exhibiting the bimodal pattern between April and October of every year. Days are very hot during the dry season from November to February, temperature typically ranges from 33 - 34 0C while from February to April, values are frequently between 34.6 and 37 0C. Essentially, Ilorin is located in the transition zone between the deciduous forest (rainforest) of the southwest and the savannah grasslands of the north (Oyegun, 1982).

The vegetation of Ilorin is composed of species of plants such as locust bean trees, shea butter trees, acacia trees, baobab trees, elephant grasses, shrubs and herbaceous plants among others (Jimoh, 1999). Jimoh (1999) reported that Ilorin city is underlain by basement complex parent material which is composed largely of metamorphic rocks especially gneiss and resistant quartzite. The soil of Ilorin is formed from the Precambrian basement complex rocks and it is under the grassland savannah forest cover and belong to the soil group called “Ferruginous soil” which are reddish-brown in color with a proportion of clay content. The dominant clay type is the kaolinite clay and illite group.

The study area covers selected portions of Osere River and its bank, located at Ilorin west local government. According to Adeyemi-ale et al., (2014) Osere River lies between latitude 8049/ N and longitude 4054/ E. The River is not the main river in Ilorin and flows in North-south direction (Oyebanji, 1993). This research was carried out along the river banks where farmers use the water for irrigation. Various types and forms of effluents drain into this river from various sources leading to its pollution. Some identified effluents include sewage, industrial wastes and agricultural chemicals as corroborated by Adeyemi-ale et al., (2014) and Ogundiran et al., (2014).

Experimental Design

The experiment was a Randomized Complete Block Design (RCBD) in a two (2) way factorial.

Factor A was distance between sources of irrigation water. The sources of irrigation water were 50 m upstream (control), 50 and 100 m downstream with approximate GPS locations of 80 46’37’’55 E, 40 53’88’’92 N; 80 46’40’’95 E, 40 53’89’’78 N and 80 46’34’’97 E, 40 53’87’’03 N respectively; whereas Factor B was the duration/history (years) of irrigation (10, 20 and 30 years) which was obtained by interviewing the farmers and nearby residents. Three (3) plots with the same irrigation history at each farm site were selected to serve as replicates. The selected farmers belonged to the same social class and shared similar practices [cultivated Amaranthus Spp., planted on beds, applied NPK (15:15:15), manual weeding and sprinkler irrigation]. Factor A was aimed at determining the effect of the effluent water discharged by a soap/detergent industry at a point between control and 50 m downstream of Osere River.

Layout of the experiment

Three (3) farm sites along Osere River (downstream) were selected at a distance of 0, 50 and 100 meters from a control point. Each plot measured 12 × 10 m with eight (8) beds each measuring 5 × 2 m. A plot 50m away (upstream) from an effluent discharge point was used as control. The effluent source was soap industry.

Data Collection

Water Sampling

Nine (9) river water samples which comprised of six (6) Osere River water samples collected 50 and 100 m downstream and (3) control sample (fifty meters upstream of effluent discharge point) referred to as 0 m sample, were taken to the laboratory for analysis.

Soil Sampling

Twelve (12) auger top soil samples were collected at each site (0 – 15 cm soil depth) and bulked accordingly (0, 10, 20 and 30 years irrigation duration) and a composite of four samples taken to represent each of the irrigation durations. Twelve undisturbed core soil samples were also collected from each site. All the samples were bagged in polyethylene plastic bags and taken to the laboratory analyses.

Preparation of soil for physical and chemical analyses

The soil samples were air dried and sieved with a 4.75mm mesh sieve size to remove stones, plant roots and have the soil of uniform particle size before carrying out physical analyses whereas 2mm sieve size was used to prepare samples for chemical analyses in the laboratory.

Laboratory Analyses

Physical Analyses

Soil texture

Soil textural class determination was done using hydrometer method according to Bouyoucos (1936) and calculated thus:

%Silt + Clay = 40seconds corrected hydrometer reading x 100
Weight of sample

%Clay = 2hours corrected hydrometer reading x 100
Weight of sample

%Sand = 100 – (%silt + clay)

%Silt = %Silt + Clay - % Clay

Soil bulk density

Soil bulk density was determined according to Blake and Hartage (1986), and calculated thus:

Dry bulk density = Mass of oven dried soil/Total volume of soil

Total Porosity

The total porosity (TP) was estimated from the bulk density (BD) and an assumed particle density (PD) of 2.65g/cm³ thus:

$$TP = 100\left(1 - \frac{BD}{PD}\right)$$

Macro porosity (MaP) was calculated thus:

MaP = Volume of water drained at 60cm tension
Volume of bulk soil

Micro porosity (Mip) calculated thus:

MiP = Total Porosity – Macro porosity

Saturated hydraulic conductivity (Ksat)

Saturated hydraulic conductivity (Ksat) was determined by the constant head permeameter method (Klute and Dirksen, 1986).

The transposed Darcy's equation was used to calculate Ksat thus:

$$Ksat = \frac{Q}{At} \cdot \frac{L}{\Delta H}$$

Where:

Ksat = hydraulic conductivity (cm/hr)

Q = volume of percolate (cm³)

L = height of core (cm)

ΔH = hydraulic head difference (cm)

A = cross sectional area of core (cm^2)

t = time required to collect percolate (hours)

Mean weight diameter

The distribution of aggregates was determined by the wet sieving technique described by Kemper and Rosenau (1986). In this procedure 25g of the less than 4.75mm air dried soil samples was emptied into the topmost of a nest of sieves of diameter 2, 1, 0.5, 0.25mm and pre-soaked in distilled water for 5minutes before oscillating in water 20 times (along a 4cm amplitude) at the rate of 1 oscillation per second. After wet sieving, the resistant aggregates on each sieve were transferred into beakers, oven dried at 105ºC for 24 hours and then re-weighed. The percentage ratio of the aggregate in each sieve was calculated and thus represents the water stable aggregate of size classes; 4.75 – 2.00, 2.00 – 1.00, 1.00 – 0.05, 0.05 – 0.25 and less than 0.25mm. The method of Van Bavel (1950), as modified by Kemper and Rosenau (1986), was used to determine mean weight diameter of water stable aggregate thus:

$$\mathrm{MWD} = \sum_{i=1}^{n} \mathrm{XiWi}$$

Where MWD = mean weight diameter of water stable aggregate.

X = diameter of each size fraction in (mm) and

W = proportion of the total samples weight in the corresponding size fraction.

Chemical Analyses:

Soil pH

Soil pH was determined according to Chofield and Taylor (1995) in which a combination electrode was immersed into the soil - water suspension and the soil pH was read.

Determination of electrical conductivity in soil and water samples

Electrical conductivity was determined in 1:2.5 soil/aqueous extract at 25ºC as described by Black et al., (1995).

Determination of Calcium (Ca), Magnesium (Mg) and Sodium(Na)

Soil samples were extracted with an excess of 1N ammonium acetate ($NH4OAC$). The amounts of exchangeable sodium (Na), calcium (Ca) and Magnesium (Mg) in the extract were determined by Atomic Absorption Spectrophotometer (AAS).

Salinity hazard determination

Salinity hazard was calculated as:

$$SAR = Na / (0.5 \times (Ca + Mg)1/2$$

Exchangeable sodium percentage (ESP) as:

ESP= (Exch. Na/CEC) 100

Data Analysis

Data collected was analyzed statistically using analysis of variance (ANOVA) with Genstat, and significant means separated using least significant difference (LSD).

Results and Discussion

Data on the electrical conductivity of Osere River which is an indicator of the concentration of dissolved electrolyte ions in the water is shown in Table 1. The result indicated that distance between irrigation water sources did not have significant effect on the electrical conductivity of the irrigation water. Implying that the electrical conductivity of the water the farmers use for the irrigation of the three farm sites sampled were the same. It could also be further interpreted to mean that the human activities (including the activities of the soap and detergent industry) between the sampling points were not introducing significant level of impurities into the river. It has been reported that the normal range of electrical conductivity of most streams and rivers (depending on geology) range between 50 – 150 microsiemens per centimeter (Sharon, 1997). The highest average value recorded in this work (0.022dSm^{-1}) translates to 22 microsiemens per centimeter, which was observed 50 m downstream.

Table 2 shows that distance between irrigation water sources along Osere River significantly affected the pH of the irrigated soils. Soils collected 50 m (downstream) away from control (50 m upstream) showed significantly higher pH than soils at control and at 100 m distance away from control. The observation may be attributable to the long term effect of effluent water discharge into the river by a soap industry just before 50 m sampling point. It is thought that the effluent water is alkaline, as buttressed by the report of Adeyemi-ale, (2014). This condition of the effluent water may have accounted for the increased salinity (slightly alkaline) of: 1.soils in farms irrigated with water sourced close to (downstream) the effluent discharges point and 2.soils under irrigation durations up to 20 years. Furthermore, the effect of irrigation duration on the pH of the irrigated soils also significantly increased as the duration increased from 10–20 years, though generally no particular trend was observed. The interaction showed that soils irrigated with water from 50 m distance (downstream) away from control had the highest pH after 20 years. The result suggests a gradual build-up of saline salts from a poorly concentrated or irregularly distributed background of natural or industrial origin around the 50 m location. Soil pH is known to influence nutrient availability. According to Pratt and Suarez (1990) elevated pH also has an adverse impact on soil stability.

Table 1: *Effect of distance between irrigation water sources on the Electrical conductivity (dSm^{-1}) of Osere River water*

	Distance of water source in meters (Factor A)		
	Control	50	100
	0.017	0.017	0.017
	0.017	0.022	0.019
	0.017	0.025	0.025
	0.017	0.022	0.020
MEAN	0.017	0.022	0.020

LSD 0.05 for Factor A = Ns, Ns = non-significant

Table 2. *Effect of distance between water sources and irrigation duration on pH of selected irrigated farmlands along Osere River bank*

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)			
	Control	50	100	Mean
0	7.3	7.3	7.3	7.3
10	7.3	7.3	7.3	7.2
20	7.3	7.5	7.4	7.4
30	7.3	7.4	7.3	7.4
Mean	7.3	7.4	7.3	

LSD 0.05 for Factor A = 0.1, Factor B = 0.1, $A \times B = *$

Table 3 shows that distance between irrigation water sources had no significant effect on the bulk density of the irrigated soils. The results also showed that the use of Osere River for irrigation for a period up to 30 years did not significantly ($P < 0.05$) affect the bulk density of the irrigated soils. The interaction between irrigation water source and irrigation duration was not significant.

Table 4 shows that distance between irrigation water sources had no significant effect on the total porosity of irrigated soils. The effect of irrigation duration also did not have significant effect on the total porosity of the irrigated soils. There was no significant interaction between irrigation water sources and irrigation duration.

The results also indicated that distance between irrigation water sources did not lead to significant a difference in the exchangeable sodium percentage (ESP) of soils (Table 5). The effect of irrigation duration also did not have significant effect on the ESP of the irrigated soils. There was no significant interaction between irrigation water sources and irrigation duration.

The distance between irrigation water sources and irrigation duration was however found to have significant effect on the sodium absorption ratio (SAR) of the irrigated soils (Table 6). Soils located 50 m away from control showed significantly higher SAR than soils at control (50 m upstream) and 100 m distance (downstream) away from control. This observation could be attributable to the effect of effluent water discharged into the river by the soap industry located just before 50 m sampling point.

Table 3. *Effect of distance between water sources and irrigation duration on bulk density (g/cm³) of selected irrigated farmlands along Osere river bank*

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	0.663	0.663	0.663	0.663
10	0.663	0.743	0.540	0.648
20	0.663	0.757	0.557	0.648
30	0.663	0.690	0.557	0.636
MEAN	0.663	0.702	0.579	

LSD 0.05 for Factor A = Ns, Factor B = Ns, A × B = Ns, Ns = non-significant

Table 4. *Effect of distance between water sources and irrigation duration on total porosity (%) of selected irrigated farms along Osere river bank*

Irrigation History in years (FactorB)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	74.8	74.8	74.8	74.8
10	74.8	72.2	79.6	75.5
20	74.8	71.4	79.0	75.1
30	74.8	74.0	78.2	75.6
MEAN	74.8	73.1	77.9	

LSD 0.05 for Factor A = Ns, Factor B = Ns, A × B = Ns, Ns = Non-significant

It is thought that the effluent water contains Sodium (Na) ions, which in higher concentration around the discharge point leads to increased SAR of irrigated soils; however the effect appeared to be reduced downstream probably due to dilution of the effluent water into the larger water body. Sodium absorption ratio significantly increased when the duration of irrigation increased from 10 – 20 years. The interaction showed that soils irrigated for 20 years with water from 50 m downstream of control point had the highest SAR value whereas soils 100 m downstream with irrigation history of 20 years had lowest SAR value. Elevated values of SAR is known to lead to soil disaggregation and hence impeded water percolation into the soil (Frenkel, et al.,1978) and consequent signs of water stress on plants.

Table 5. *Effect of distance between water sources and irrigation duration on the exchangeable sodium percentage (%) of irrigated farmlands.*

Irrigation history in years (FactorB)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	53.4	53.4	53.4	53.4
10	53.4	46.3	49.4	49.7
20	53.4	46.1	50.5	50.3
30	53.4	54.2	33.2	46.9
MEAN	53.4	50.0	46.6	

LSD 0.05 for Factor A = Ns, Factor B = Ns, A × B = Ns, Ns = non-significant

Table 6. *Effect of distance between water sources and irrigation duration on sodium adsorption ratio (meq/l) of irrigated soil*

Irrigation History in years (Factor B)	Distance of water source in meters (FactorA)			
	Control	50	100	MEAN
0	0.13	0.13	0.13	0.13
10	0.13	0.18	0.16	0.15
20	0.13	0.24	0.12	0.16
30	0.13	0.17	0.13	0.14
MEAN	0.13	0.18	0.14	

LSD 0.05 for Factor A = 0.047, Factor B = 0.057, A × B = *, * = significant at 1 % level of probability

Table 7 shows that distance between irrigation water sources and irrigation duration had significant effect on the mean weight diameter (MWD) of the irrigated soils. Higher values of MWD would indicate comparatively better soil structure and higher soil stability. Soils collected in farms located 50 m downstream showed the lowest (0.77 mm) MWD whereas soils collected at 100 m downstream of control point showed the highest (1.10 mm) MWD. This observation may be attributable to the effect of Na probably contained in the effluent discharged into the river before 50 m sampling point by a nearby soap industry. Sodium (Na) is implicated in the disaggregation (poor structure) of soil as observed in location 50 m. The MWD of the irrigated soil decreased as the duration of irrigation increased, with soils under 30 years of irrigation having the lowest (0.66 mm)

MWD compared to the highest (1.12 mm) in control soils. The interaction between both factors showed that control soils irrigated with water sourced from 100 m downstream had the highest (1.37 mm) MWD whereas soils from 50 m downstream under irrigation history of 30 years was observed to have the lowest(0.14 mm) MWD. Van de Graaff and Patterson (2001) reported that high sodicity causes excessive swelling of clay minerals which weakens soil aggregates, causing structural collapse and closing-off of soil pores. Consequently, water and air movement through sodic soils are severely restricted and affected soils are prone to erosion. The results clearly shows that though the salinity of Osere River (indicated by its water electrical conductivity values obtained at the various sampling points) is not significantly increased by the activities of the soap industry, however the prolonged use of the river water, especially close to the companies effluent discharge point for irrigation purposes could predispose the soil to adverse symptoms of soil salinity.

The silt separate of soils irrigated with water sourced from 50 m downstream of Osere River relative to control point indicated significantly ($P < 0.05$) higher content compared to 0 m (control) and 100 m downstream. Irrigated soils 100 m downstream also showed higher silt content compared with control. Values ranged between 20.0 – 21.2 %.

Table 7. *Effect of source of water and irrigation duration on mean weight diameter of selected irrigated farmlands along Osere river bank*

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	0.97	1.02	1.37	1.12
10	0.97	0.96	1.19	1.04
20	0.97	0.97	0.97	0.97
30	0.97	0.14	0.87	0.66
MEAN	0.97	0.77	1.1	

*LSD 0.05 Factor A = 0.32 Factor B = 0.39 A × B = **

This observation may likely corroborate a salty (Na) effluent discharge between control point and 50 m downstream. The dispersing action of Na may have mobilized silt fraction from the river bed and bank, resulting in a colloidal water suspension used by farmers for irrigation along the river bank. Lal (1997) reported high mobility of soil silt fraction. The results however showed significantly lower accumulation of silt in farms as the irrigation duration increased from 10–30 years with values ranging between 21.7–20.4% respectively. It is thought that silt mobility due to rainfall may have retarded the build-up of silt over the years. The interaction showed that soils irrigated for 10years at 50 m downstream had the highest % silt content.

Table 8. *Effect of distance between water sources and irrigation duration on silt content (%) of irrigated soils.*

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	20.0	20.0	20.0	20.0
10	20.0	22.7	20.3	21.7
20	20.0	21.3	21.0	20.7
30	20.0	20.8	20.3	20.4
MEAN	20.0	21.2	20.9	

*LSD 0.05 Factor A = 0.8 Factor B = 1.3 A × B = * * = significant at 1 % level of probability*

Conclusion

It could be concluded from the study that Osere river water at the points sampled was not saline, however prolonged use of the water for irrigation of farmlands on the bank led to gradual build-up of Na salt resulting in increased soil salinity (SAR) which negatively impacted on the stability of soil aggregates. The study also suggests the release of Na salt from a nearby soap/detergent industry or anthropogenic sources close to this industry.

For sustainable farming operations under irrigation from Osere River, farmers would require regular application of Calcium rich organic amendments or agricultural limes which may be applied biannually.

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