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Effluents in irrigation water: a case study of Asa River on farmlands in Ilorin, Nigeria

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Abstract

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Asa River is the most important river in Ilorin, serving, among other uses as source of water for irrigation of farmlands. On the other hand, wastes (likely containing salts) from industrial, domestic and agricultural origins are dumped into this river; therefore, the need arises to determine its salinity status and long term use implications on soil structural stability. During late rainy season (late October) of 2014 a study which comprised of two (2) factors laid out in a Randomised Complete Block Design (RCBD) was conducted. Factors were source of irrigation water in Asa River and irrigation history (duration) of plots. Four (4) locations were selected. The irrigation history was 0, 10, 20 and 30 years. In each location four farmers plots with same irrigation history were selected and each replicated thrice. Results indicated that the electrical conductivity of the water used by various farmers for irrigation (0.069 – 0.20 dS/m) was significantly lower ($P < 0.05$) only at point 600 m downstream with value of 0.069 dS/m which falls within the non-saline range for river water. Varying the source of irrigation water resulted in significantly higher soil chemical (electrical conductivity, sodium absorption ratio and exchangeable sodium percentage) and structural (mean weight diameter, total porosity, bulk density and saturated hydraulic conductivity) degradation in locations 200 m and 400 m downstream. Soil chemical and structural properties were significantly affected by irrigation history, its deterioration been higher in plots with irrigation history from 10-20 years. The results therefore suggest that the observed chemical and structural degradation is due to prolonged usage, especially during drier seasons when dilution effect is reduced.

Keywords: Asa River, irrigation, salinity, soil chemical and physical properties

Introduction

Water is one of the most important substances for plants and human existence. It is a very important input required for plant growth in agricultural production. Hess (2005) reported that water needed for plant growth is provided by soil water storage in the plant root zone. Under rain-fed conditions, soil water is continuously replenished with natural rainfall but in cases of irregular distribution or low rainfall like in the arid and semi-arid climates, artificial supplementation (irrigation) is essential to maintain soil water storage at an optimum level for high crop yield (Punial & Pande, 1997). The current world population of 7.5 billion (The World Bank, 2018) is sustained in a large part by irrigated agriculture. Freshwater rivers, lakes, and groundwater are used to irrigate crops, to provide drinking water and to act as a sanitation system (Zewdie, 1994).

Good quality water for irrigation is becoming scarcer on a global basis due to expanding urbanization and industrialization (Catley-Carlson, 2000). Zewdie (1994) reported that water sources used for irrigated agriculture have increasingly become polluted with municipal sewage, industrial toxic effluents, heavy metals, fertilizer chemicals, radioactive substances, land sediment and oil. Poor quality water in many parts of Nigeria are disposed into wells, ponds, streams, and rivers which serve as a source of irrigation water, as well as for drinking purposes (Alemtshaye, 2002). The use of polluted water for irrigation is a common practice especially among peasant farmers which represents a large percentage of the farming population in Nigeria. Farmers use polluted water to save their expenses (Ibrahim & Salmon, 1992). Harmful effects can last for several years due to extensive irrigation with polluted water; with negative effects on groundwater quality (Smith, 1992). The FAO (1992) reported that water quality for agricultural purposes is determined on the basis of the effect of such water on the quality and yield of the crops, as well as the effect on the characteristic changes in the soil and human health when the crops are consumed. According to Richardson (1994), the most commonly encountered soil-water problems used as a basis to evaluate water quality are those related to salinity, infiltration rate, toxicity (heavy metals) and a group of other miscellaneous problems. Poor quality water may affect irrigated crops by causing accumulation of salts in the root zone and loss of permeability of the soil due to excess sodium or calcium leaching (FAO, 1985; FEPA, 1991). Salt accumulates and concentrates in soil when water evaporates from the soil surface, when plants use water, when leaching is not adequate to remove salts beyond the root zone and/or when precipitation does not wash salts off the land surface (Podmore, 2009).

According to Ayres & Westcot (1976) and Hoffman et al. (1980), soil scientists use the following categories to describe irrigation water effects on crop production and soil quality: salinity hazard – total soluble salt content, sodium hazard – relative proportion of sodium to calcium and magnesium ions, pH – acid or basic, specific ions – chloride, sulphates, boron and nitrate; alkalinity – carbonate and bicarbonate.

In the light of the foregoing it is therefore imperative to determine the quality of water used by farmers for irrigation and its effects on soil quality for sustainable crop production. The Asa River is one of the two major rivers in llorin, Kwara State, Nigeria. It receives effluents from a beverage, soap and detergent, metal fabricating industries, and domestic wastes amongst others (Eniola & Olayemi, 1999). The Asa River is used for various purposes: domestic, industrial, farming and swimming both within and outside llorin town. Therefore, the objective of this study is to determine the water quality for irrigation purposes and the effect of its long term use on soil structural stability

Materials and Methods

Description of Experiment Location

Ilorin is the capital of Kwara State, Nigeria (Fig. 1). It lies between latitude 8º 30’N and 8º 50’N and longitude 4º 20’E and 4º 35’E of the equator (Kwara State Government, 2017) with a total land area of about 100 km² (Kwara State

Government, 2007). Ilorin has a humid tropical climate characterized by both the wet and dry seasons with a mean annual temperature of 27° C. The annual mean rainfall is about 1150 mm, exhibiting bimodal pattern between April and October of every year. Days are very hot during the dry season from November to February (when temperature typically ranges from 33-34° C). 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, shear butter trees, acacia trees, baobab trees, elephant grasses, shrubs and herbaceous plants among others (Jimoh, 2011). Jimoh (2011) also reported that Ilorin city is underlain by basement complex rocks 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. The soil belongs to the USDA order- Alfisol, falls in the Odowa series, of a sandy loam texture and generally low in organic carbon (Onwualu & Ahaneku, 2001; Eifediyi et al., 2017). The dominant clay minerals are kaolinite and illite. The study area covers selected portions along the bank of the Asa River where vegetable farming is practiced with the river serving as the source of irrigation water. The Asa River is located in Ilorin West Local Government Area and is the main river in Ilorin, flowing in a South-North direction. It divides Ilorin into two parts: a western part representing the core or indigenous area and the eastern part where the Government Reservation Area is situated (Oyebanji, 1993). The Asa River has a surface area of 302 ha with a maximum depth of 14 m and is located approximately 4 km south of Ilorin Township (Adekeye, 2004). The river lies between latitude 8° 28' and 8° 52'N and longitude 4° 35' and 4° 45'E. The tributaries of Asa River are Agba, Aluko, Atikeke, Mitile, Odota, Okun, and Osere Rivers.

Design and Layout of the Survey

The survey which was carried out in late rainy season of October, 2014 was of a two factor factorial in a Randomized Complete Block Design (RCBD). The factors were comprised of Factor A: distance between irrigation water sources and Factor B: irrigation history (irrigation duration in years). There were four farming locations which corresponded to 200 m upstream (control); and 200, 400 and 600 m downstream. At each location four farmers with different irrigation history were selected. The irrigation history was 0, 10, 20 and 30 years of irrigation with Asa river water (Fig. 2).

Three farmers were selected for each irrigation history to serve as replicates. The selected farmers belonged to the same social class and shared similar practices which included cultivation of Fluted pumpkin (*Telferia occidentalis*) planted on ridges, NPK (15:15:15) application, manual weeding and sprinkler irrigation. Information on the irrigation history and farming practices were obtained by interviewing the farmers and local residents. A total of 4 × 4 × 3 (48) plots of size 3.5 m^2 (7.0 m × 0.5 m) on ridges of dimension 15 m by 1.0 m with furrows measuring 0.5 m were sampled. The first farm site (control) was located 200 m (upstream) before a metal and steel industry (subsequently designated – 200 m), with coordinates 8° 27'5.5"N, 4° 35'33.6"E. The second farm location (200 m downstream) was situated after the metal and steel industry with coordinates 8° 28'3.1"N, 4° 33'29.7"E while the third farm(400 m downstream) was situated behind two major soft drink bottling industries (after point of effluent discharge) which is also the point where the Osere River (with suspended effluents discharged from a soap and pharmaceutical industry) flows into the Asa River with coordinate 8° 28'41.8"N, 4° 33'34.4"E and the fourth farm(600 m downstream) is situated downstream of all the previous locations, receiving effluents from domestic sources such as sewage etc. with coordinates 8° 29'56.6"N, 4° 34'08.5"E.

Sample Collection

Water sampling procedure

Four (4) river water samples (0-20 cm deep) were randomly collected in plastic bottles from each location and taken to the laboratory for analyses.

Soil sampling procedure

Since the study sites are mainly used for vegetable production (shallow rooted) for the metropolis, bulk soil samples were collected from the top soil (0-15 cm depth) using a stainless steel soil auger at each farm location and a composite sample (2 kg) was collected in polyethylene plastic bags and taken to the laboratory for analyses. Undisturbed soil samples were also collected using cylindrical metal cores.

Preparation of soil for physical and chemical analyses

The soil samples were air-dried and sieved with a 4.75 mm sieve to remove stones, plant roots and to have the soil of a uniform particle size before physical analyses: whereas, a 2 mm sieve was used to prepare samples for chemical analyses in the laboratory. The core samples did not undergo preliminary preparations.

Laboratory Analyses

Physical Analyses

Soil bulk density

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

$$\text{Dry bulk density} = \frac{\text{Mass of oven dried soil}}{\text{Total volume of soil}}$$

Total Porosity

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

$$TP = 100\,(1 - BD/PD)$$

Saturated hydraulic conductivity (K_{sat})

Saturated hydraulic conductivity (K_{sat}) was determined by the constant head permeameter method (Klute & Dirksen, 1986).

The transposed Darcy's equation was used to calculate K_{sat} thus:

where:

$$K_{sat} = Q/At \;.\; L/\Delta H$$

where:

K_{sat} = hydraulic conductivity (cm.h^{-1})

Q = volume of percolate (cm^3)

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 & Rosenau (1986). In this procedure 25 g of the less than < 4.75 mm air-dried soil samples was emptied into the topmost of a nest of sieves of diameter 2, 1, 0.5, and 0.25 mm; and pre-soaked in distilled water for 5 minutes 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 was transferred into beakers, oven dried at 105° C for 24 h and then re-weighed. The percentage ratio of the aggregate in each sieve was calculated and thus represented the water-stable aggregate of size classes 4.75 – 2.00, 2.00 – 1.00, 1.00 – 0.05, 0.05 – 0.25 and < 0.25 mm. The method of Kemper & Rosenau (1986) was used to determine mean weight diameter of water-stable aggregates thus:

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

where

MWD = mean weight diameter of water stable aggregate.

X = diameter of each size fraction in (mm)

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

Chemical Analyses

Determination of electrical conductivity in soil and water samples

Electrical conductivity (E.C) of water samples and soil samples (1:2.5 soil/aqueous extract) were determined at 25º C by using E.C meter model-4070, after calibrating with 0.05 N KCL solution (Page et al., 1982).

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

Soil samples were extracted with an excess of 1N Ammonium Acetate (NH_4OAC). The amounts of exchangeable calcium (Ca), magnesium (Mg) and sodium (Na) in the extract were determined by Atomic Absorption Spectrophotometer (AAS).

Salinity hazard determination

Salinity hazard was calculated as:

Sodium Absorption Ratio (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 17 statistical software and significant means separated using least significant difference at the 5% probability level.

Results and Discussion

Water

Electrical conductivity (E.C) of water samples collected from Asa River 600 m downstream which receives effluents containing sewage from domestic sources was significantly ($P < 0.05$) lower (non-saline) than that in water samples collected at other points (slightly saline) receiving effluents from industrial sources (Table 1). Some researchers have reported significantly increased electrical conductivity of Asa River water during the dry season which they traced to the effect of effluents discharged by surrounding companies (Ogundiran et al., 2014; Olawale, 2016). In drier periods people consume more soft drinks (Baranwal et al., 2019) due to high perspiration and evaporation which will consequently lead to more production activities in the bottling companies for instance; leading to increased effluent discharge into the river. However, during rainy seasons in which this study was conducted, lower industrial activities in the bottling companies coupled with increased rainfall leading to increased volume of water in the river is expected to significantly lower E.C due to dilution of the effluent content. On the other hand, more sewage is expected to be produced in the rainy season when food supply is abundant, this is expected to lead to comparatively higher E.C in point 600 m downstream as against points upstream despite the dilution effect brought about by increased water volume but this was not the case. Crop and forage production in this region has been majorly rain fed, this result however, is suggesting a contrary pattern presently in which the *status quo* is tilting away from dependence on rain to river water supply; this may be related to high profit margins usually recorded by farmers during off (dry) season production. The E.C is an indicator of the concentration of dissolved salts in the water. Higher values could translate to higher salt contents which may negatively impact soil structural properties. Municipal development has pushed most of the farming activities in Ilorin to the stretch of land along the bank of the Asa River, as such farming activities take place on these lands both in the dry and wet seasons; however, so much of the farming activities along the bank of this river are observed to take place during the drier periods which is likely to predispose the soils to salt accumulation and consequent structural deterioration, especially over long periods.

Soil

The slightly alkaline (pH 7.1-7.9) irrigated farm soils shows that the distance between water sources and irrigation duration had no significant ($P < 0.05$) effect on the pH of farm soils irrigated with water from the Asa River (Table 2). This is an indication that the activities of industries and other entities whose effluents are channeled into the Asa River did not lead to a change in the pH of the water. The river water could therefore be of a good quality in this regard according to Ogundiran et al. (2014) who had reported a pH range of 7.13 to 7.92 and Tepe et al. (2005) who reported that most natural waters have a pH range between 6.5 and 8.5. The optimum soil pH range for most plants is between 5.5 and 7.0 (Leonard, 2013). Therefore, the observed soil pH which followed irrigation with this river water is not expected to give rise to any adverse conditions.

Results in Table 3 shows that electrical conductivity of the soils increased downstream, with farm soils located 400 m downstream (behind two major soft drink bottling companies) showing the highest E.C. values of 0.14 dS/m whereas the lowest values of 0.09 dS/m was observed in control soils (location). It was also observed that as the duration (history) of irrigation increased from 0 to 30 years, the E.C. of the irrigated soils increased in the order 30 > 20 > 10 > 0 years. The interaction indicated highest value of E.C. (0.18 dS/m) in location 400 m downstream with 30 years irrigation history. This observation shows that though the salt concentration of the Asa River is within acceptable range, its prolonged use for irrigation led to significant ($P < 0.05$) salt accumulation in farm soils. The farms are intensively cropped to vegetables during the dry periods when these produce are scarce and commands higher market price. Similarly, the massive infrastructural expansion in the city of Ilorin has led to the diminishing of agricultural lands, giving rise to intensification of the use of the scarcely available lands. The consequence as observed here is an increased accumulation of electrolytes (e.g. salts) in the farm soils. This is not without its attendant negative consequences on soil structure and plant cultivation, and by extension on man and animals.

Table 4 shows that Sodium Absorption Ratio (SAR) of farm soils irrigated with water sourced 200 and 400 m downstream, corresponding to locations behind a metal and steel works company and downstream of effluent discharge point of two major bottling companies respectively; indicated significantly ($P < 0.05$) higher values compared to control soils (-200 m) and soils 600 m downstream (effluents received from domestic sources).

The SAR values of 0.339 meq/L and 0.309 meq/L obtained in farm soils located 200 m and 400 m downstream respectively, did not differ statistically. The result also showed that as irrigation duration (history) increased from 0 to 10 years, the soil SAR values increased significantly from 0.153-0.255 meq/L, however further increments in irrigation duration to 30 years did not lead to significant differences compared to soils under 10 years irrigation duration. Arku & Musa (2014) had reported SAR values of 1.18 meq/L in effluent water from a bottling company in Maiduguri, Nigeria whereas USEPA (1992) reported sodium cyanide as one of the compounds released in metal and steel works. The SAR represents the relative proportion of Na to Ca + Mg. Sodium adsorption is stimulated when Na proportion increases as compared to Ca + Mg resulting in soil dispersion (Warrence et al., 2003). At high levels of sodium relative to divalent cations in the soil solution, clay minerals in soils tend to swell and disperse and aggregates tend to slake, especially under conditions of low total salt concentration and high pH. As a result, the permeability of the soil is reduced and the surface becomes more crusted and compacted under such conditions. The soils' ability to transmit water is severely reduced by excessive sodicity (FAO, 1992). The irrigation water containing excess of CO_3^{2-} and HCO_3^- will precipitate calcium and hence sodium will increase in the soil solution. This leads to saturation of the clay complex with sodium and consequently a decreased infiltration rate (Warrence et al., 2003). However, according to Sonon et al. (2015), SAR values less than 13 meq/L fall within the normal range for soils. Thus, the farm soils in this survey are not expected to exhibit structural abnormalities; however, this is a function of their organic matter content (Horneck et al., 2007).

Varying the source of irrigation water supply led to a significant ($P < 0.05$) increase in Exchangeable Sodium Percentage (ESP) in the farm soils following the order: location 200 m > 400 m > 600 m > - 200 m. The highest value of ESP was 20.21% whereas the lowest was 7.04% as the source of water supply varied (Table 5). The result further revealed that ESP significantly increased from 13.59 – 15.51% following 10 years of irrigation but dropped to 13.66% when irrigation duration was 30 years. The interaction between the factors indicated that farm soils in location 200 m under 30 years irrigation had the highest ESP (31.60%) whereas control soils had the lowest (7.04%). Apart from sodium input suspected to emanate from company sources around 200 and 400 m downstream of this river, soil clay content may also affect the ESP. Warrence et al. (2003) had reported increased ESP and hence higher soil dispersion with increase in soil clay fraction. With ESP > 15% most soil experience poor or weak aggregation which could probably give rise to surface crusting, poor tilth and low permeability to water and air (Warrence et al., 2003). Surface crusts were typically observed in location 200 and 400 m downstream with the leaves of vegetable crops grown appearing wilted.

The result in Table 6 show that the Mean Weight Diameter (MWD) of the irrigated farm soils along the river course did not significantly ($P < 0.05$) vary, however, as the duration of irrigation increased from 0-10 years, the MWD of the soil aggregates plummeted from 0.534 to 0.390 mm. The interaction between the two factors (water source and irrigation history) showed that soil aggregates in farms located 400 and 200 m downstream irrigated for 10 years had the lowest MWD values of 0.295 and 0.356 mm respectively. The MWD of soil aggregates is an index of soil structural stability. Low values will increase the susceptibility of such soils to erosion and also result in poor tilth. The MWD (soil aggregate stability) is reduced by soil dispersion triggered by high ratio of Na^+ to $Ca^{2+} + Mg^{2+}$. The high sodium ions in the exchange sites (shown by the ESP values) of farm soils in location 400 and 200 m may have been responsible for this observation. Though the Asa River water exhibited low sodium content during the season of this investigation, the prolonged use of its water for irrigation purposes (wet and dry seasons) is responsible for the deteriorating soil structural stability observed. Passioura (1991) reported that soil structural properties such as water aggregate stability, soil porosity, bulk density and soil resilience is greatly affected by increased sodium content of irrigation water.

The bulk density of the irrigated farm soils was observed (Table 7) to have been significantly ($P < 0.05$) affected by the source of water along the river course with soils in location 200 and 400 m exhibiting the highest bulk density (1.49 g/cm^3 each) whereas control soils had the lowest (1.29 g/cm^3). The results also indicated that bulk density was significantly increased when the irrigation duration was from 10 – 30 years. Farms that have been irrigated for 10 years had the highest bulk density (1.49 g/cm^3) whereas the control soil (0 year) had the lowest (1.36 g/cm^3). The bulk density of irrigated soils did not vary between 20 and 30 years duration. The factor interactions show that farm soils located 200 and 400 m downstream which were irrigated for 10 and 20 years respectively had the highest bulk density of 1.53 and 1.55 g/cm^3 respectively. Soil crusting or sealing which accompanies sodium imposed aggregate dispersion is expected to lead to increased bulk density. This is due to the rearrangement of the soil particles achieved when such particles fall into pores big enough to accommodate them, thereby clogging or sealing such pores. As a result, the ratio of soil particles to that of the voids (pores) is increased. This resultant increase is synonymous with increased bulk density. Passioura (1991) had reported that soil structural properties like bulk density is greatly affected by increased sodium content of irrigation water.

The soil E.C, SAR, ESP, MWD and bulk density have shown a threshold value in 10 years, the reason for this observation cannot be presently explained.

Farm soils irrigated with water sourced 200 and 400 m downstream had the lowest porosity (42.38 and 42.72% respectively), followed by those from 600 m downstream (48.11%), whereas control soils had the highest porosity of 51.01% (Table 8). The effect of irrigation duration (history) on the total porosity of the farm soils showed that soils irrigated for 10 years had the lowest total porosity followed by those irrigated for 20 and 30 years whereas the control (0 years) soils had the highest. The interaction between the factors was significant ($P < 0.05$) with control soils showing the highest porosity (58.47%) whereas soils located 200 m downstream with a history of 30 years irrigation duration showed the lowest (38.53%). Dullien (1992) reported that porosity which is the ratio of the pore volume of a soil to its total volume is controlled by the grain size of soil particles (MWD), among other factors like bulk and particle density. The author further reported that the porosity of surface soil typically decreases as particle size decreases due to soil aggregate breakdown. Likewise, the dispersion (breakdown) of soil aggregates arising from increased soil exchangeable sodium following prolonged (up to 10 years) irrigation with water sourced downstream of the control location (especially 200 and 400 m) led to reduced total porosity. Most field crops will generally tolerate the range of porosity values observed in this study (Ahamefule et al., 2014). Shaxson & Barber (2003) reported that plant root development is a function of pore diameter rather than total porosity, however, Smith & Mullins (2000) stated that porosity can be proportional to pore radii.

Varying the source of irrigation water along the course of Asa River significantly ($P < 0.05$) affected the Saturated Hydraulic Conductivity (Ks) of irrigated farm soils (Table 9). The Ks values with respect to the source of irrigation water followed the trend of -200 > 600 > 400 > 200 m. The highest value of 5.65 $cm.h^{-1}$ was observed in the control location (-200 m) whereas the lowest values of 1.48 $cm.h^{-1}$ was observed in location 200 m downstream. The results further showed that soils with a history of 10 years irrigation duration had the lowest Ks value of 1.72 $cm.h^{-1}$ whereas the control soils had the highest of 4.12 $cm.h^{-1}$. The interaction indicated that the control soils had the highest Ks of 10.83 $cm.h^{-1}$ whereas soils in location 200 m with irrigation history of 30 years had the lowest Ks value of 0.67 $cm.h^{-1}$. Smith & Mullins (2000) stated that porosity can be proportional to Ks as there is a positive correlation between pore radii and Ks and also between pore radii and porosity. The authors asserted that as grain size decreases the proportionality between pore radii and porosity begins to fall and so does the proportionality between porosity and Ks.

Xiao et al. (1992) observed that the higher the E.C of irrigation water, the higher the soil Ks. The authors observed that Ks doubled when the E.C of the irrigation water increased from 0.1 to 6.0 ds/m. The observed decreasing Ks values in this work are therefore a reflection of the increasing E.C values of the irrigation water.

High SAR of irrigation water would also have an unfavorable effect on soil Ks which decreases with increasing SAR (Sonon et al., 2015).

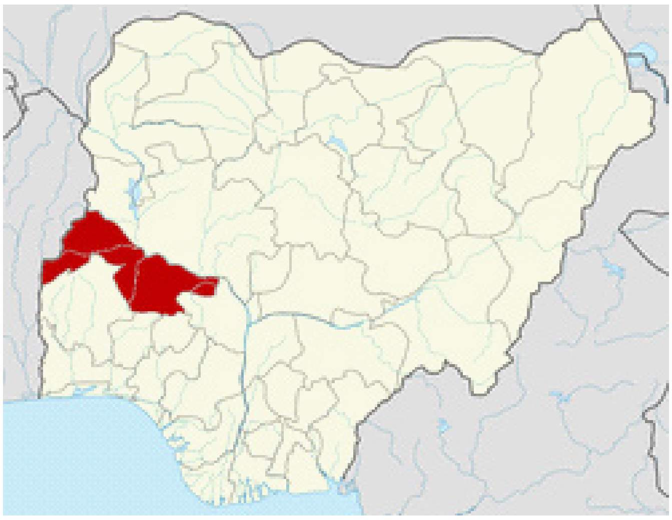

Fig. 1. Map of Nigeria showing Kwara State (Shaded area)

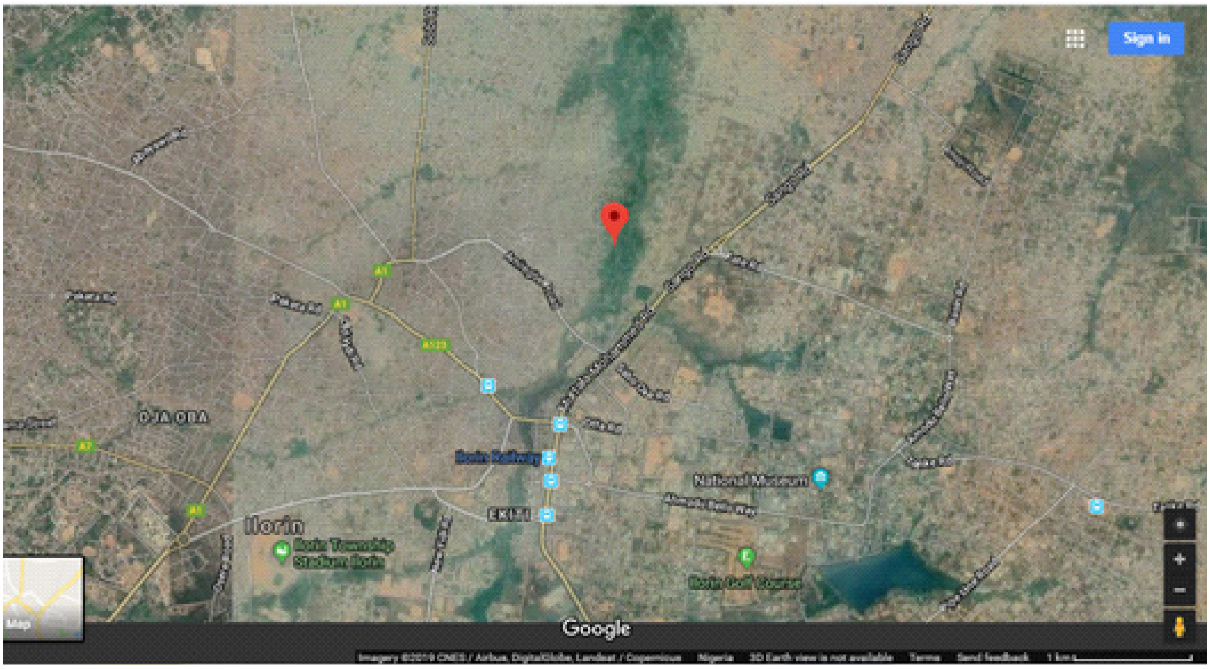

Fig. 2. Goggle earth map showing study location

Table 1. Electrical conductivity (dS/m) of Asa River at four points providing irrigation water for farmers in Ilorin, Nigeria

	Distance between water sources in meters			
	-200	200	400	600
	0.16	0.15	0.16	0.17
	0.15	0.24	0.13	0.035
	0.16	0.20	0.15	0.032
	0.17	0.21	0.16	0.038
Mean	**0.16**	**0.20**	**0.15**	**0.069**
$LSD_{0.05} = 0.06$				

Table 2. The pH of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = **n.s**
0	7.7	7.6	7.6	7.7	**7.6**
10	7.7	7.1	7.5	7.9	**7.5**
20	7.8	7.9	7.3	7.8	**7.7**
30	7.6	7.1	7.7	7.8	**7.5**
Mean	**7.6**	**7.4**	**7.5**	**7.8**	
LSD$_{0.05}$ = **n.s**					

n.s = non-significant

Table 3. The Electrical conductivity (dS/m) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = 0.012
0	0.06	0.08	0.10	0.09	**0.08**
10	0.09	0.10	0.14	0.11	**0.11**
20	0.11	0.12	0.15	0.14	**0.13**
30	0.13	0.14	0.18	0.17	**0.16**
Mean	**0.09**	**0.11**	**0.14**	**0.12**	
LSD$_{0.05}$ = 0.014					
A × B = *					

A × B = Interaction between Factors A and B

Table 4. The Sodium Adsorption Ratio (meq/L) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = 0.10
0	0.153	0.157	0.143	0.160	**0.153**
10	0.157	0.117	0.660	0.087	**0.255**
20	0.143	0.437	0.357	0.087	**0.256**
30	0.160	0.647	0.067	0.057	**0.233**
Mean	**0.153**	**0.339**	**0.306**	**0.097**	
LSD$_{0.05}$ = 0.12					
A × B = *					

A × B = Interaction between Factors A and B

Table 5. The exchangeable sodium percentage (%) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = 1.30
0	7.04	17.23	16.10	14.00	**13.59**
10	7.80	8.80	30.60	14.83	**15.51**
20	6.10	23.20	15.83	14.70	**14.96**
30	7.23	31.60	3.40	12.80	**13.66**
Mean	**7.04**	**20.21**	**16.48**	**14.08**	
LSD$_{0.05}$ = 2.30					
A × B = *					

A × B = Interaction between Factors A and B

Table 6. Mean Weight Diameter (mm) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = 0.1
0	0.764	0.418	0.408	0.564	**0.534**
10	0.430	0.356	0.295	0.581	**0.390**
20	0.382	0.360	0.362	0.371	**0.369**
30	0.356	0.495	0.483	0.196	**0.383**
Mean	**0.478**	**0.382**	**0.387**	**0.430**	
LSD$_{0.05}$ = n.s					
A × B = *					

A × B = Interaction between Factors A and B

Table 7. Bulk density (g/cm³) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = 0.05
0	1.13	1.33	1.53	1.43	**1.36**
10	1.40	1.53	1.49	1.53	**1.49**
20	1.26	1.48	1.55	1.34	**1.41**
30	1.40	1.60	1.40	1.23	**1.41**
Mean	**1.29**	**1.49**	**1.49**	**1.38**	
LSD$_{0.05}$ = 0.06					
A × B = *					

A × B = Interaction between Factors A and B

Table 8. Total porosity (%) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** LSD$_{0.05}$ = 2.65
0	58.47	49.00	42.14	47.17	**49.19**
10	45.90	40.14	42.72	42.14	**42.72**
20	52.47	42.66	40.14	49.68	**46.24**
30	47.20	38.53	45.90	53.45	**46.27**
Mean	**51.01**	**42.58**	**42.72**	**48.11**	
LSD$_{0.05}$ = 3.06					
A × B = *					

A × B = Interaction between Factors A and B

Table 9. Saturated hydraulic conductivity (cm h^{-1}) of farm soils irrigated with water from four points along Asa River in Ilorin, Nigeria over varying durations

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)				
	-200	200	400	600	**Mean** $LSD_{0.05}$ = 1.12
0	10.83	0.97	3.93	0.77	**4.12**
10	3.33	1.70	1.47	0.37	**1.72**
20	5.65	2.80	3.33	2.80	**3.64**
30	2.80	0.67	1.70	9.30	**3.62**
Mean $LSD_{0.05}$ = 1.29 A × B = *	**5.65**	**1.48**	**2.60**	**3.31**	

A × B = Interaction between Factors A and B

Conclusion and Recommendation

It can be concluded from this study that Asa River showed significantly higher levels of E.C (though still within acceptable range) at all but one sampled point (600 m downstream) at the time of sampling and the prolonged use of the water for irrigation purposes led to salt build-up causing significant chemical and physical deterioration of soils irrigated with its water at the sampled points, more especially within the first 10 years of its use particularly in locations 200 and 400 m downstream.

Therefore, to ameliorate the situation and for sustainable crop production, it is recommended that organic or inorganic materials rich in calcium and magnesium (limestone, shell and dolomite) be incorporated into the soils by the farmers within the surveyed areas at least every 5 years while environmental protection agencies intensify their monitoring activities on the industries discharging their effluents into the river to ensure that standards are not compromised.

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