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Appraisal and Mapping of Soil Salinity and Sodicity Problems In Sector One of Watari Irrigation Scheme, Kano State.

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ABSTRACT

One of the main reasons for the loss of productive land in irrigated fields is the buildup of salinity in the soil. In the watari irrigation Scheme, no systematic appraisal and mapping have been made before within the sector. The study area was selected after a reconnaissance survey based on the farmer's complaint about the low production. Global positioning system (GPS) was used to record the coordinate, and delineate the boundary of the study site. The coordinates of the delineated boundary were Geo tagged on Google Image to obtain the image of the study site. Grids of 100 x 100m were superimposed on the Geo tagged image and were used as sampling points. A total of 234 samples were obtained from 160 ha of land for the study; within each grid, four soil samples were collected at a depth of 0 – 20cm, and mixed them into one sample from each grid. The collected samples were processed and analyzed using standard laboratory procedures for salinity and sodicity evaluation. Standard methods were followed to measure pH, electrical conductivity (EC), and soluble cations. Arc GIS 10.3 was used to map out the varying degree of salinity and sodicity. The extent of the area of the classes and percentage coverage indicated that the non-saline area covers about 28.80% (46 ha) of the total land size. But 25.50% (40 ha) of the sector were slightly saline, moderate salinization problem within the sector occupied 34.10% (54.6 ha) of the land area. Only 11.6% (18.6 ha) of the total land size had both salinity and sodicity hazards of the sector with ECe dSm^{-1} and SAR values greater than 4 dSm^{-1} and 13, respectively. Based on the findings, the extent of soil salinity and sodicity of the study area revealed that substantial parts were consistently and continuously affected by salinity problem 71.2% (114 ha). Specific proportions of the irrigated land need special attention so as to prevent and control secondary salinization. The sodic soil should be controlled at the earliest before the soil structure is entirely destroyed since only 28.80% (46 ha) is free. The water table control by rehabilitating the subsurface drainage system seems to be the only feasible way to improve the sustainability of the scheme.

1.0. Introduction

Global food production will need to increase by 38% by2025 and by 57% by 2050 (Wild, 2003) if food supply to the growing world population is to be maintained at current levels. Akinwumi (2018) reported that Nigeria increased food production by 21 million tonnes within four years. Most of the suitable land has been cultivated, and expansion into new areas to increase food production is rarely possible or desirable. The aim, therefore, should be an increase in yield per unit of land rather than in the area cultivated. More efforts are needed to improve productivity as more lands are becoming degraded. It is estimated that about 15% of the total land area of the world has been degraded by soil erosion and physical and chemical degradation, including soil salinization (Wild, 2003). According to a report published by Food and Agricultural Organization (FAO) in 2000, the total global area of salt-affected soils including saline and sodic soils was 831 million hectares (Martinez-Beltran and Manzur, 2005), extending over all the continents including Africa, Asia, Australasia, and the Americas FAO (1988).In some places, the very sustainability of irrigated agriculture is threatened by this degradation (Rhoades *et al.* 1999). Soil salinity and sodicity problems are common in arid and semi-arid regions where rainfall is insufficient to leach salts and excess sodium ions out of the rhizosphere, more than 80 million ha of such soils are found in Africa (Global Harvestchoice, 2010).

Soil salinization is the process of enrichment of soil with soluble salt that results in the information of salt-affected soil. Soil salinity in irrigated areas is becoming a severe problem for agriculture. Saline soil conditions have resulted in a reduction of the value and productivity of considerable areas of land throughout the world (Asfaw, 2016). Information on the extent and magnitude of soil salinity is needed for better planning and implementation of effective soil reclamation programs. A soil is considered saline if the electrical conductivity of its saturation extract (ECe) is above 4 dSm^1 (US Salinity Laboratory Staff, 1954). The processes by which soluble salts cause salinity and sodicity in soils include, the application of waters containing salts; weathering of primary and secondary minerals in soils; organic matter decay and water-table instability, excess soluble salts increase the osmotic pressure of the soil solution, thus, causing plant cells in early stages of the growth (particularly at the seedling emergence) to dehydrate, as they are unable to extract water from solutions that have higher osmotic pressure than plant cells (Brady and Weil, 2002).

Mapping of soil salinity is an essential component of a reclamation scheme (Muhammad *et al*. 2001). Therefore, the present study was planned to assess and mapped out the salinity/sodicity problem within sector one of the Watari irrigation scheme. Because it's the single most significant problem affecting food production in irrigated areas of Nigeria, in which diversity of food production has declined severely as a result of salinity effect in recent years. It has been observed that the degree of salinity and expansion of affected areas have led to an increasing demand for growing more food to feed the booming population of Nigeria (Mohammed *et al.* 2014). However, there is clear evidence from various reports that there is an increased occurrence in soil salinity and sodicity issues within the watari scheme (Adamu, 2012, 2013, Ya,u 2014, Mohammed *et al*. 2014). Assessing and mapping salinity/ sodicity problems of sector one watari irrigation scheme could help to access the necessary management practices that can be adopted.

2.0. Materials and Methods

2.1. Description of Study Area

Watari Irrigation project is one of the public irrigation schemes developed by the Kano State government aimed at increasing crop production and livelihood of rural farmers (Shanono *et al.*, 2012). It is located in Bagwai Local Government Kano State, within Sudan Savannah belt of Northern Nigeria, between latitude 12^0 06' 54.54 to 12^0 09' 17.8N and longitudes 08^0 11 50.62 to 08^0 16 28.05E with an elevation of 490m above sea level. It is located in the valley of Watari River, a tributary of the Challawa River from the northern corner, (Karaye, 2002). The central canal is about 10km long, with 8 sectors, out of which only five sectors are now under irrigation (sector 1, 2, 3, 4 and 8) with a total land area of 690 ha. Sector one of the project has a total irrigable land of 160 ha size (KNARDA, 2014). The Project Area consists primarily of existing irrigated land being used for wetland rice cultivation in the rainy seasons, while in the dry season, it's cultivated with cash crops such as vegetables.

Figure 1: Image of the Study Area (Google Earth 2016)

2.2. Field Sampling

Sector one of the Watari irrigation project was selected after a reconnaissance survey based on the farmer's complaint about the low production within the sector. Global positioning system (GPS) was used to record the coordinates, and delineate the boundary of the study site. The coordinates of the delineated boundary were Geo tagged on Google Image to obtain the image of the study site. Grids of 100 x 100m were superimposed on the Geo tagged image and were used as sampling points. A total of 234 samples were obtained from 160 ha of land for the study (Figure 2). Within each grid, four soil samples were collected at a depth of 0-20cm from 45m (eastern part), 10m (northern part), and 5m (southern part) away from the center of the grid, respectively. The composite samples and subsamples were drawn from each of the grid.

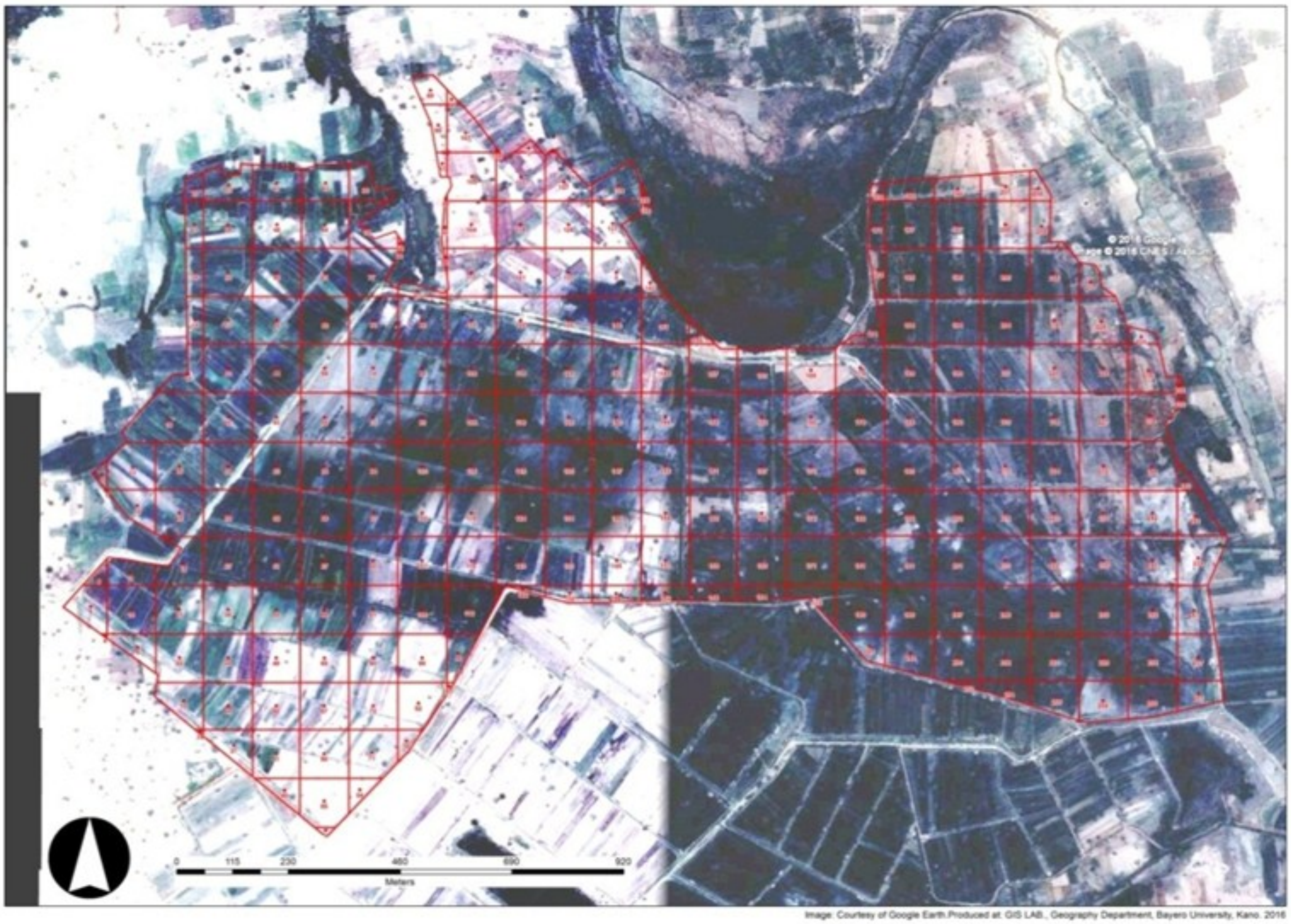

Figure 2: Image of a study site with superimposed grids.

2.3. Sample Preparation and Laboratory Analysis

A total of 234 representative soil samples were air-dried, gently crush with pestle and mortar and sieved with 2 mm mesh. The fine earth separate (<2mm) were well labeled and stored in the plastic bottles for detailed laboratory analysis. Standard laboratory procedures were used to analyze the soil samples collected for the following parameters;

Soil pH was determined in water using a 1:2.5 soil to water ratio (IITA1989). The soil pH was read with a glass electrode on a pH meter (JENWEY 3520 MODEL). Electrical conductivity (EC) of the soil was determined from soil to water ratio of 1:2.5. Soil samples were soaked for 24 hours to allow for the proper settling of the electrolytes. The EC was then measured by an electrical conductivity meter (DDS-307 MODEL) as described by Bower and Wilcox (1965), and the values obtained were converted to saturated paste extract based on soil texture as documented by Slavich and Petterson (1993). Exchangeable acidity was determined by leaching the soil with (1M KCl) solution. The Al^{3+} and H^+ ions in the 1M KCl extract were determined by titrating with sodium hydroxide (0.05M NaOH) solution as described by (Anderson and Ingram 1998). The exchangeable bases (Ca, Mg, K, and Na) of the soil were extracted with 1M ammonium acetate (1M NH_4OAC) solution (Anderson and Ingram 1998). Calcium and Magnesium were read on Atomic Absorption Spectrophotometer (AAS, 210 VGP MODEL), while Na and K in the extract were read on a flame photometer (JENWEY PFP7 MODEL).

Effective CEC was determined from the summation of the exchangeable bases by 1M NH_4OAC extraction while the exchange acidity by 1M KCl extraction (Anderson and

Ingram, 1998), as indicated by the following relationship:

$$ECEC\ (cmol\ kg^{-1}) = \sum (K^{+} + Ca^{++} + Mg^{++} + Na^{+} + Acidity)$$

The Exchangeable sodium percentage was calculated as the proportion of the CEC (NH_4OAC) occupied by the exchangeable sodium as follow;

$$ESP = \frac{\text{Exchangeable Sodium}}{ECEC} \times 100$$

Sodium adsorption ratio was calculated as the proportion of Na^+ to Ca^{2+} and Mg^{2+} as shown by the relationship below;

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

2.4. Soil Salinity Assessment

Soil salinity assessment and mapping were created using ArcGIS software version 10.3, and the data were fitted to theoretical models (ordinary and straightforward kriging). Taking the Electrical conductivity of saturated paste extract Ece values of collected soil samples, a soil salinity raster map was created, interpolation method was also selected based on the smallest errors resulted from the method used when compared to each other. The raster layer was reclassified using reclassify tools in the spatial analysis as salinity classes, using different Ece ranges and layout, were prepared from the developed raster layer.

2.5. Soil Sodicity Assessment

Sodium Absorption Ratio (SAR) is widely used to measure sodicity status. The SAR was interpolated using the interpolation technique to create a potential soil sodicity raster map. The Generated raster layers using reclassify tools were classified to show the soil sodicity hazard of the study area; a layout for soil sodicity raster was also developed.

Moreover, to develop the extent of salt-affected soil, the raster layer was developed for soil salinity and sodicity. The raster layer was combined to generate a single layer. The combined raster layer was reclassified for soil salinity/sodicity analysis. Also, a layout was prepared for the developed raster layer using ArcGIS software version 10.3.

The Fuzzy overlay tool was used to determine the salinity and sodicity hazards using multiple sets of variables (ECe, pH, ESP, and SAR) in multicriteria overlay analysis (Figure 3). Fuzzy overlay analysis reclassifies or transforms the data values to a standard scale. The transformed values represent the probability of belonging to a specified set of data. The combining analysis step in fuzzy overlay analysis quantifies each location's possibility of belonging to specified sets from various input raster's. The spatial overlay result revealed four classes of salinity and sodicity using (Ece and SAR) that has a high coefficient of variation.

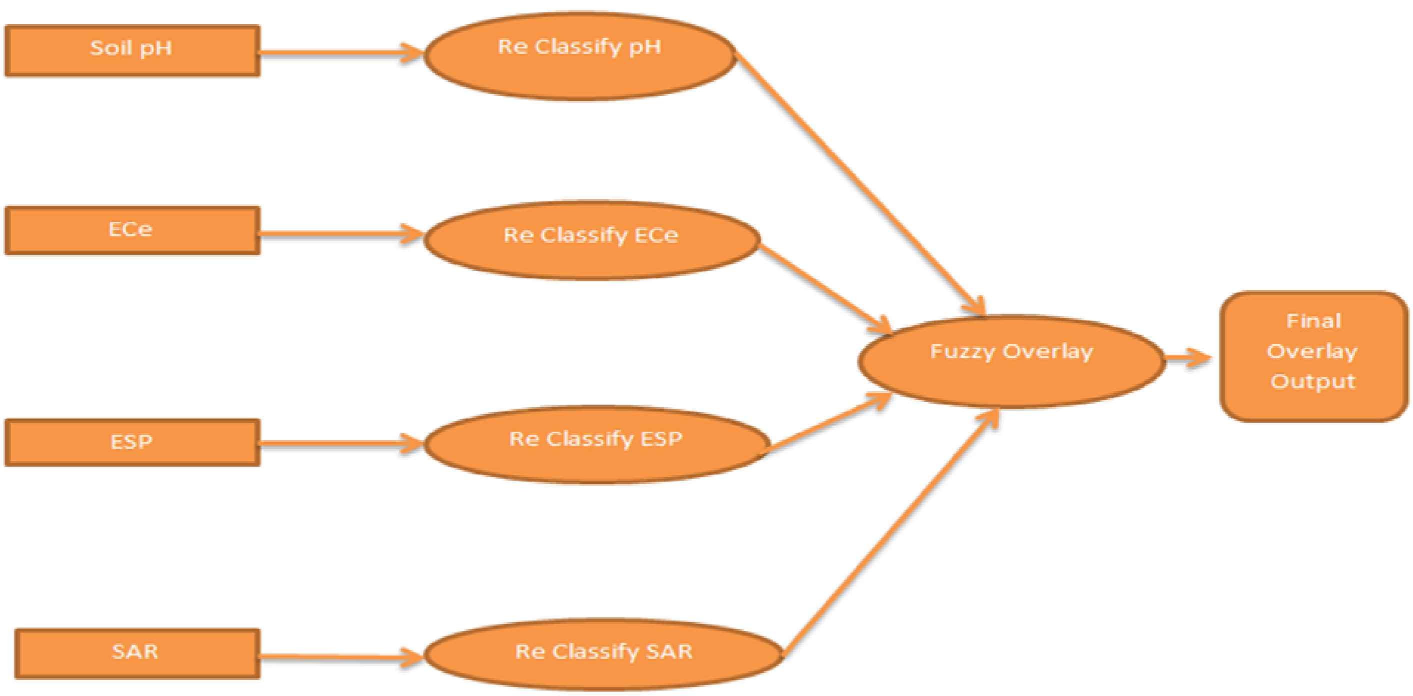

Figure 3: Flow chart of multicriteria salinity and sodicity hazards using a fuzzy overlay function.

3.0 Results and Discussion

Analytical results of electrical conductivity, pH, SAR, the concentration of essential cations of the soil solution were used as an essential parameter to explain salinity and sodicity characteristics of soils of the studied area. Four classes of soils were defined based on their chemical properties, accounting for changes in pH, ECe, and Sodium Adsorption Ratio (SAR): non-affected, saline, sodic, and saline-sodic soils, each of the last three with different degrees of salinity/sodicity. The threshold value for ECe was set at 4dS/m according to the saline or non-saline boundary in USSLS soil salinity standard analysis, and for SAR, which is an indicator of sodic or non-sodic characteristics, was set at 13.

Table 1: Descriptive analysis for soil chemical properties

Properties	Min.	Max.	Mean	CV	Sk.	Kurt.	Norm
pH (H_2O)	4.81	8.64	5.81	9.831	0.855	1.981	no
ECe (dSm^{-1})	0.163	10.67	1.189	104.5	3.878	21.68	no
Na $cmolkg^{-1}$ soil	0.0588	2.338	0.278	95.40	3.389	17.94	no
K $cmolkg^{-1}$ soil	0.0291	1.020	0.168	78.23	2.874	12.75	no
Ca $cmolkg^{-1}$ soil	1.244	20.11	5.875	32.52	3.024	17.40	no
Mg $cmolkg^{-1}$ soil	0.0976	3.535	0.846	67.14	2.349	6.131	no
EA $cmolkg^{-1}$ soil	0.167	1.002	0.486	38.41	0.233	-0.200	no
ECEC $cmolkg^{-1}$soil	2.699	23.73	7.646	29.34	2.902	15.24	no
ESP (%)	0.00532	30.66	3.635	92.89	3.558	20.22	no
SAR (%)	0.758	209.4	21.70	100.4	4.131	26.80	no

Min (minimum value); Max. (Maximum value); CV (coefficient of variation (%);) Sk (Skewness coefficient); Kurt, (Kurtosis coefficient); Norm. (Shapiro Wilk normality test), with a significance of 5 %

3.1. Extent of Salinity

Figure 4 indicates the distribution map showing the extent of salinity level was 38% (60.8 ha) of the study area are non-saline, which spread from west to east with some small patches toward the northern part. 47% (75.2 ha) is slightly saline and dominated most part of the experimental area, while 15% (24 ha) was found moderately to strongly saline and appear in some locations around the southern corner. Small patches are also observed in the northeast of the study area.

Table 2: Area coverage per salinity levels for 0-20cm depth for the Study Area, and percentage area per salinity level.

	Total Area (Ha)	Non-saline	Slightly saline	Moderately-Strongly saline
ECe dSm^{-1}		0 - 2	2 – 4	> 4
Hectare	160	60.8	75.2	24
% Area	100	38	47	15

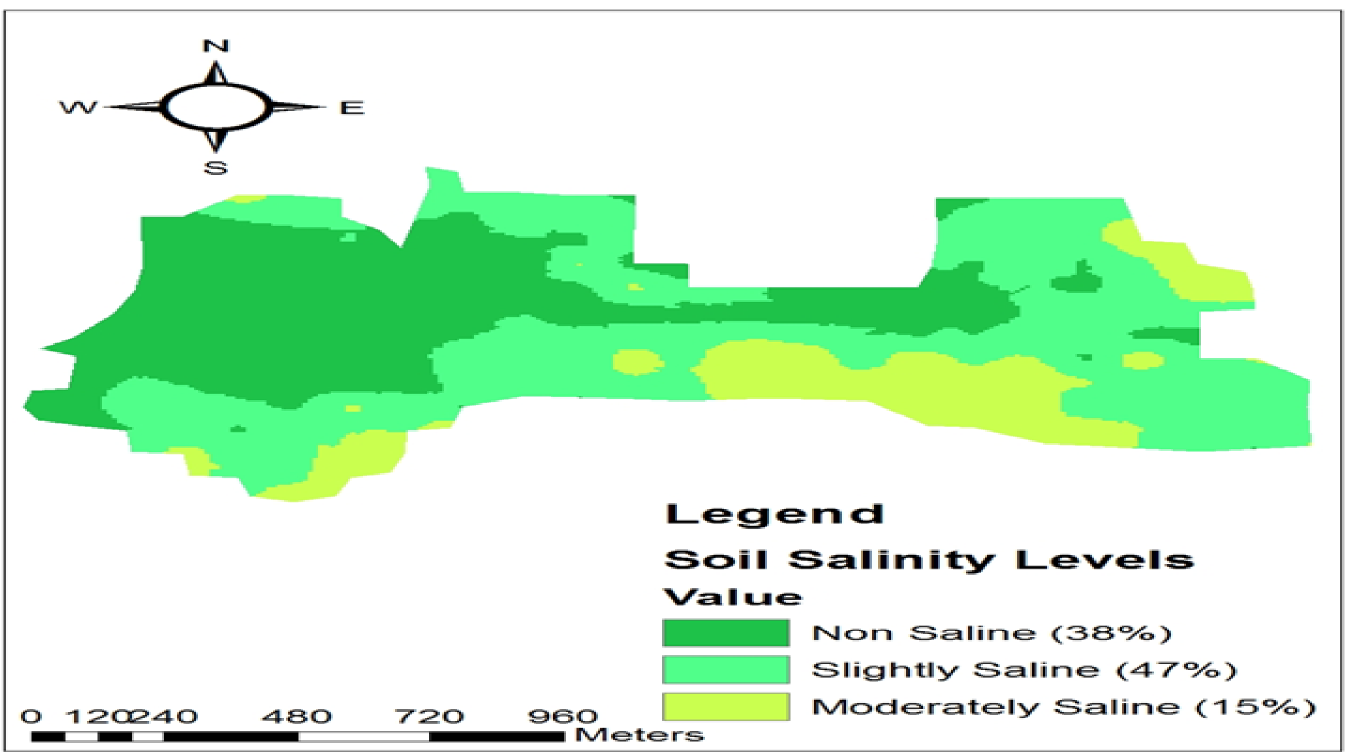

Figure 4.map showing the extent of salinity level

3.2. Extent of sodicity

The extent of sodicity level (Figure 5) shows there was no portion observed to be free from sodic in the study area. The result indicated that 2% (3.2 ha) is very slightly sodic and spread in patches at the west and northern corner, whereas 33% (52.8 ha) was slightly sodic and found in most part of the study area. Moderately sodic soil in the study area occupied 42% (67.2 ha) and distributed from south to northwestern part, 23% (36.8 ha) are strongly sodic, was found in a small portion in all the locations.

Table 3: Area coverage per sodicity levels for 0-20cm depth for the Study Area, and percentage area per sodicity level.

	Total Area (Ha)	Non-Sodic	Very slightly sodic	Slightly sodic	Moderately sodic	Strongly sodic
SAR		0-2.4	2.4-8.8	8.8- 14.8	14.8-23.4	23.4->90.4
Area /Hectare	160	0	3.2	52.8	67.2	36.8
% Area	100	0	2	33	42	23

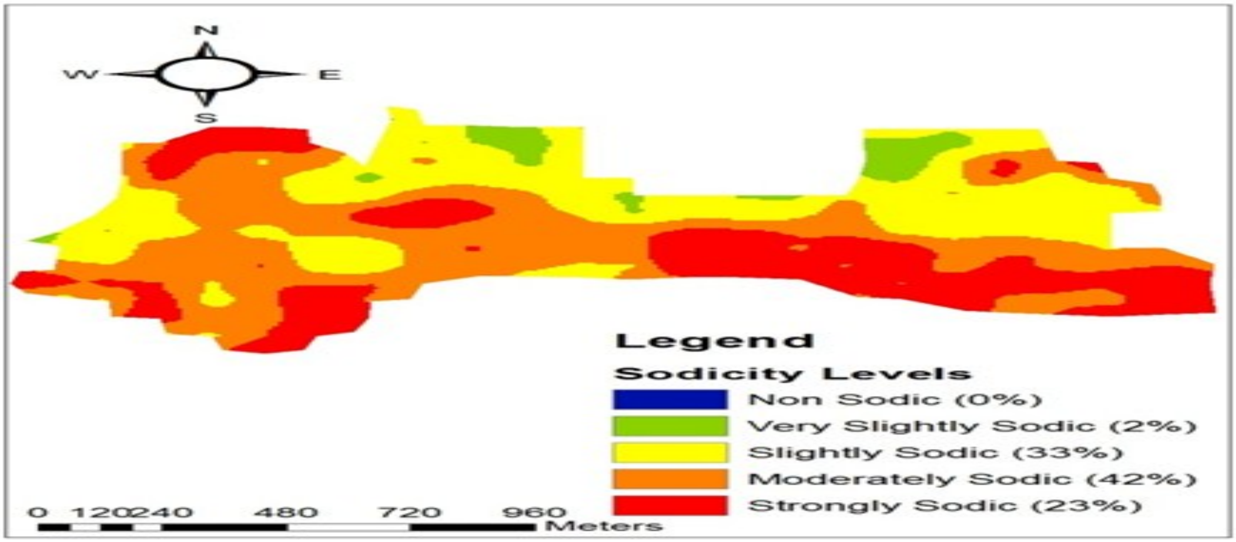

Figure 5: Map showing the extent of sodicity level

The spatial overlay result revealed four classes with varying degrees of salinity and sodicity (Fig. 6). The extent of areas of the classes and percentage coverage are presented in Table 5. Non-saline area covered about 28.80% (46 ha) of the total land size and was found around the northwest and small patches toward the east. But 25.50% (40.8 ha) of the sector had slightly saline, spreading from west to northern part and toward the east in small patches. The moderate salinization problem within the sector occupied 34.10% (54.6 ha) of the land area and was found in the southern, northern, and eastern corners. Only 11.6% (18.6 ha) of the total land size had salinity and sodicity hazards of the sector with Ece and SAR values higher than 4 dSm^{-1} and 13% respectively (Table 4) and appears in small portions in the south, north corner and some locations towards the southeast of the study area.

Table 4: Area coverage of salinity and sodicity levels derived from fuzzy overlay analysis

Salt affected soil class	Ece (dSm^{-1})	SAR	Area (ha)	% Area
Non –Saline	< 4	< 13	46	28.80
Slightly Saline	< 4	< 13	40.8	25.50
Moderately Saline	< 4	< 13	54.6	34.10
Saline- Sodic Soil	> 4	> 13	18.6	11.6
Area			160	100

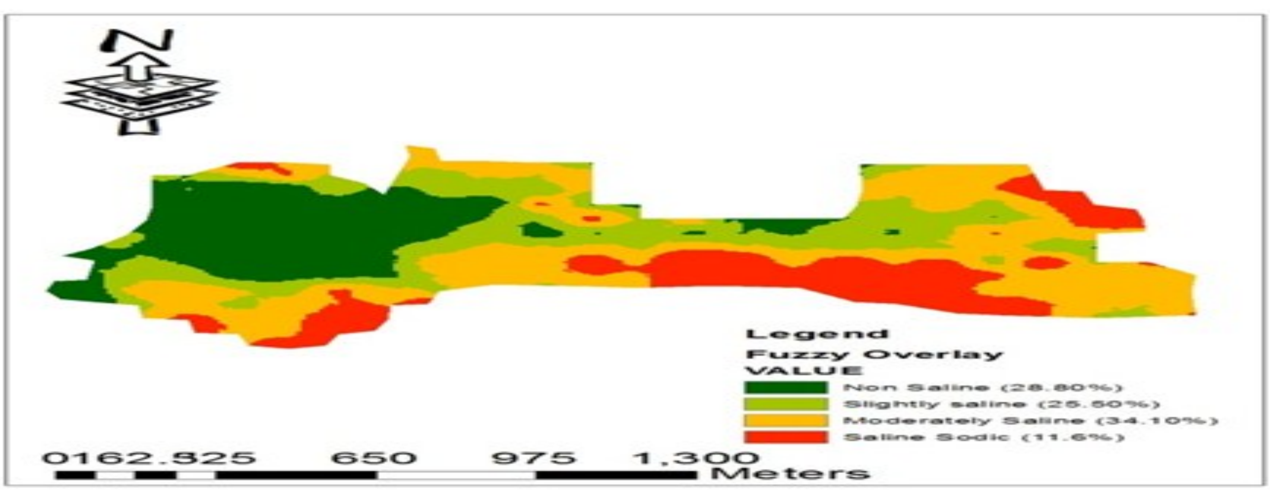

Figure 6: a map showing the extent of salinity and sodicity status

4.0. Conclusion

Based on the findings, the extent of soil salinity and sodicity of the study area revealed that substantial parts of the sector I in the Watari irrigation scheme were consistently and continuously affected by salinity problems (71.2%). A significant proportion of the irrigated land has been affected as slightly saline (25.50%), moderately saline (34.10%), and saline-sodic soil (11.6%), and soon some part will be abandoned mainly because of secondary salinization resulted from shallow saline groundwater table. Although some specific proportions of the irrigated land need special attention so as to prevent and control secondary salinization.

5.0. Recommendation

The control of the water table through rehabilitation of the existing subsurface drainage system is the only feasible way to improve the sustainability of the scheme. Furthermore, research on other alternative management options should be done, especially in areas that are nearly or slightly saline/sodic. Additionally, the sodic soil should be treated at the earliest before the soil structure is entirely destroyed since only 28.80% (64 ha) is free.

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