FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 1, February, 2023, pp 193 - 200
DOI: https://doi.org/10.33003/fjs-2023-0701-1280

APPLICATION OF MULTITEMPORAL LANDSAT DATA IN MAPPING OF SALINE SOIL IN KANO RIVER IRRIGATION SCHEME (KRIS)

***[1]Mohammed D., [2]M. M. Maina, [2]I. Audu, [4]I. Y. Tudunwada, [5]N. K. Nasiru, [2]Nasidi N. M., & [1]S. E. Umar**

[1]Department of Agricultural and Bio-Environmental Engineering, Kaduna Polytechnic, Kaduna, Nigeria
[2]Department of Agricultural and Environmental Engineering, Bayero University, Kano, Nigeria
[3]Department of Agricultural and Bio-Resource Engineering, University of Maiduguri, Nigeria
[4]Advance Space Technology Laboratory, Bayero University, Kano, Nigeria
[5]National Space Research and Development, Bayero University, Kano, Nigeria

*Corresponding authors' email: wadata4all@yahoo.com

ABSTRACT

Soil salinization is becoming a more serious issue threatening agricultural production and the sustainable use of land resources. Crop roots are unable to absorb water from the soil when exposed to saline conditions. This study explored the potential of Landsat imagery in detecting and mapping saline soil in the Kano River Irrigation Scheme (KRIS). Samples of soil were collected from thirty-nine (39) sectors of the KRIS for ground truthing on 20th – 25th April, 2020. Electrical Conductivity (EC) of field samples were correlated with band values of satellite images and salinity indices in order to determine their relationship and assess their effectiveness in predicting soil salinity. Using a geospatial approach, the data was analyzed and maps of salt-affected areas were generated. ArcGIS 10.6 was used as the primary package for modeling and running functions. The result has shown that the EC values over the entire study area are greater than 1.3 dS/m. However, the mean value of EC is approximately 1.91 dS/m. The implication is that, most of the vegetables such as Onion, Carrot, and Beans grown in the KRIS will experience yield reduction without appropriate management practice as their threshold value has been exceeded.

Keywords: Irrigation, Landsat, Mapping, Saline, Soil

INTRODUCTION

The physical and chemical properties of determine its suitability for crop growth. Excess salts in the soil cause high osmotic pressure, which prevents crops from absorbing water (Ardahanlioglu, *et al*., 2003). Therefore, soil salinization is a condition that results in a reduction of crop growth due to the presence of soluble salts in the soil which holds water more tightly than the plants can absorb from the soil (Bannari *et al*., 2013). The roots of plants are unable to draw water from the surrounding soil when exposed to saline conditions. This reduces the amount of water available to the plant, irrespective of the amount of water present in the root zone (Rashidi *et al.*, 2008).

Many irrigation projects around the world experience land deterioration due salinity and sodicity accumulation in soils which poses threat to crop production due to yield reduction and total failure in some cases (Zakari *et al.*,2022). It also results in changes of soil's physic-chemical properties such as electrical conductivity, Sodium Adsorption Ratio, hydraulic conductivity, and availability of soil water. The problem manifests itself, as a result of constant addition of salts with irrigation water particularly in regions with soils that are poorly drained (Salih *et al.,* 2015). Soil degradation due to salinity and sodicity which are increasing at rapid rate are negatively impacting agricultural practices (Kaledhonkar *et al*., 2012). Excess salinity raises osmotic pressure which makes it difficult for plants to extract water from the soil. Crops can tolerate salinity to a certain extent without suffering significant yield loss (salinity threshold). When salinity exceeds the threshold value, crop yield decreases linearly as salinity increases.(Fipps, 1995).

The use of Remote Sensing (RS) technologies in the prediction of soil salinity and mapping its spatial distribution at large scales has recently become more important and simpler. Recent studies have shown that delineating saline soils with RS and Geographic Information System (GIS) is effective (Khan *et al*., 2001). At large and small scales, salinity mapping can be accomplished using a variety of techniques that integrate RS and GIS. Previously, soil salinity was determined by collecting soil samples in the area of interest and then carrying out analysis in the laboratory to determine the electrical conductivity of the soil, but the method is costly and time consuming. In contrast, RS data provide more efficient and cost-effective methods and techniques for monitoring and mapping soil salinity. Many satellites and sensors are available to detect and monitor saline soil. These sensors only scan the surface of the soil, whereas the entire soil profile is involved and should be considered. This limitation emphasizes the importance of combining RS with other data and techniques (Farifteh, 2006). Therefore, this study explored the capability of Landsat imagery in detecting and mapping saline soil in KRIS through correlation between field measurements and Landsat imagery.

MATERIALS AND METHODS

Study Area

The Kano River Irrigation Scheme (KRIS) is Nigeria's largest and first irrigation project (Yakubu *et al.*, 2018). It is located in Northern Nigeria's Sudan savannah zone at an elevation of approximately 440 m above sea level between latitudes 11°32'N and 11°51'N and longitudes 8°20'E and 8°40'E. (Figure 1.). The vegetation is Sudan savanna, which includes trees, shrubs, and grassland. The area is well drained by the Kano River formation, which consists of the Hadejia, Katagum, and Jama'are rivers, which all join to form the River Yobe. (Yakubu *et al.*, 2018). KRIS mean daily maximum and minimum temperatures are 31°C and 21°C, respectively (Zakari *et al.*, 2017).

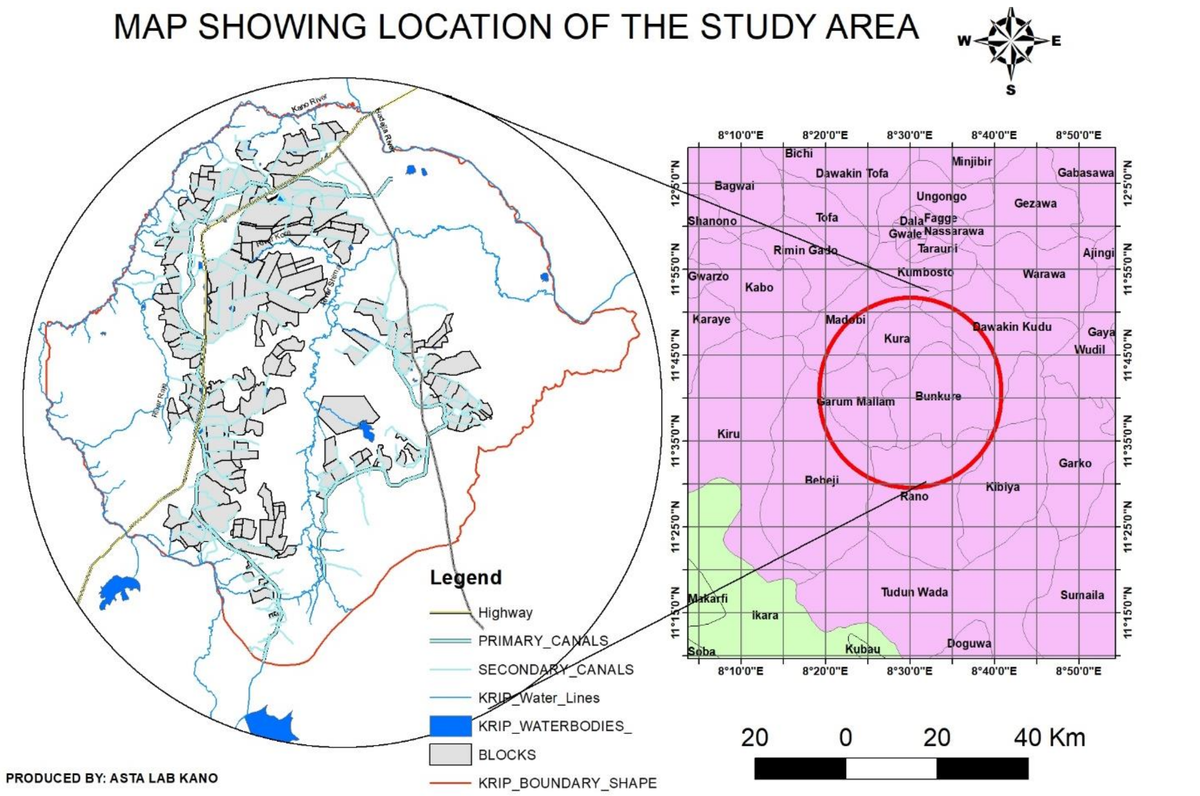

Figure 1: Map showing the location of the study area.
Source: Mohammed *et al*., 2021

The mean annual rainfall ranges from 635 to 889 mm, with maximum amounts of 214.0 mm, approximately 60% of which falls in July and August and varies greatly from year to year (Maina *et al,* 2012). The soils in the area are well drained with sandy loam texture at the surface and sandy clay loam subsoil (Jibrin *et al.*, 2008). Tomato, rice, carrot, pepper, maize, sugarcane, cabbage, lettuce, and other vegetables are grown in the study area. The Scheme was planned to be implemented in two phases with a total area of 62,000 ha (Mohammed *et al.*, 2015).

Collection of Samples for Measurement of Ground Truths
Soil samples were collected from thirty-nine (39) sectors in the study area for measurement of ground truth on 20^{th} – 25^{th} April, 2020. Four (4) samples were collected at different points in each sector and one hundred and fifty-six (156) samples were collected from all the sectors. The collection was done with soil auger, core samplers, wooden plank and digger. Samples weighing 500 g were placed in a properly labelled polythene bag. Care was taken during sampling by ensuring that representative samples were collected and areas with clear evidence of salinity were noted. The coordinates of all the sampling points selected at random were taken with Garmin 78 GPS and recorded. The collected samples were taken to Centre for Dry Land Agriculture (CDA) of the Bayero University, Kano for the analysis.

Laboratory Analysis of Soil Samples
Laboratory analysis was carried out on the soil samples. Samples were prepared for analysis by removing stones, gravel and stumps. The samples are then air dried. The electrical conductivity was measured at 25 °C from the soil the soil saturation extract which was was prepared by missing soil and distilled water in the ratio 1:5 and agitated with mechanical shaker. One hundred and fifty grams (150 g) of air-dried soil was weighed and mixed with distilled water until saturated. The mixture was covered and allowed for 24 hours to form solution. The soil solution was then extracted using a Buchner funnel apparatus vacuum. The soil saturation extract was stored at 4^{o}C until after the analysis. Parameters determined are pH, Electrical Conductivity (EC) and concentrations of Na^+, Ca^{2+}, K^+ and Mg^{2+} ions from the extract. The electrical conductivity was measured with conductivity meter WAP cm 35 while the pH was measured by using glass electrode pH meter. Measurement of sodium, calcium and magnesium concentration were measured with Atomic Absorption Spectrometer while Potassium was measured with flame photometer.

Acquisition of Landsat Data
The Satellite image for the year 2020 was used to delineate salt-affected soil in the KRIS. Data from the Landsat with a spatial resolution of 30 m was used. Spectral data was acquired based on the dates of field work in order to ensure accuracy and compatibility. Multi-temporal satellite images of the April 2020 acquired during the dry season were used to ensure accuracy. Geo-referencing of the satellite images was done by using the World Geodetic System (WGs) of 1984 datum assigned to North Universal Transverse System zone 32.
The multi-temporal satellite images were processed by applying atmospheric and radiometric corrections techniques. This was done to reduce the influence of atmosphere, weather and to correct any geometric distortion caused by the rotation of the earth. The images were filtered, enhanced and further processed by conversion from digital to reflectance value.

Salinity Indices
Signals received in different spectral bands were used for the development of salinity indices. Salinity indices applied in

numerous studies related to soil salinity mapping were examined. The indices applied in this study were computed and analyzed iby using spatial analysis tool in ArcGIS environment. The indices formed from the combination of spectral bands are presented in Table 1.

Table1: Salinity Indices Formed from Bands Combination

S/No	Indices	Equation	Reference
1	Salinity Indices 1	$SI1 = \sqrt{(B^2 x R^2)}$	Douaoui *et al*., 2006
2	Salinity Indices 2	$\text{SI2} = \sqrt{(\text{GxR})}$	Douaoui *et al*., 2006
3	Salinity Indices 3	$\text{SI3} = \sqrt{(\text{BxR})}$	Abbas and Khan, 2001
4	Salinity Indices 4	$\text{SI4} = \frac{\text{RXNIR}}{\text{G}}$	Azabdaftari and Sunar, 2016
5	Salinity Indices 5	$\text{SI5} = \frac{\text{B}}{\text{R}}$	Abbas and Khan, 2001
8	Salinity Indices 6	$\text{SI} = \sqrt{(\text{R}^2\text{XG}^2)}$	Taghadosi *et al.*, 2019
7	Normalized Difference Salinity Index	$\text{NDSI} = \frac{\text{R} - \text{NIR}}{\text{NIR} + \text{R}}$	Taghadosi *et al.*, 2019

Correlation

Laboratory results of EC for the field samples, salinity indices and the band values of satellite images were subjected to correlation analysis to test the level of correlation between these variable so that they can be used in developing a model for predicting soil salinity in the KRIS. Prior to the development of models, data was tested and found to be normally distributed as presented in Figures 2a and 2b.

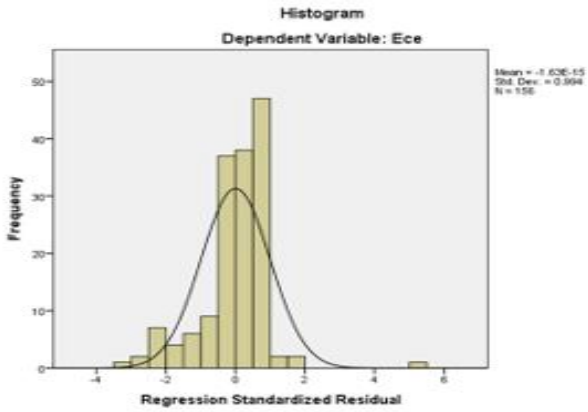

Figure 2a: Normal Probability Plot

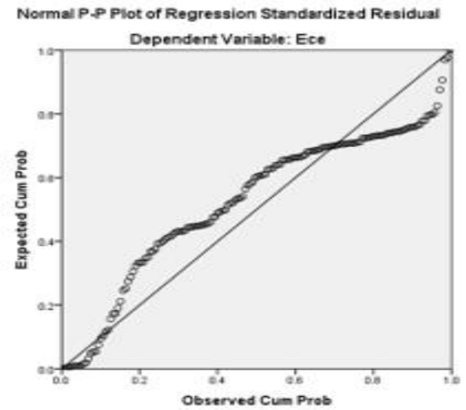

Figure 2b: Normal Distribution Plot

Stepwise Multiple Linear Regression (MLR) techniques were used to develop the models, with variables being added or removed based on the t-statistics of their estimated coefficients. This was followed by an assessment of the spatial distribution of EC in order to predict salinity levels at various KRIS locations using EC point data. These datasets were analyzed and map of salt-affected areas were generated with developed models using the geospatial approach. ArcGIS 10.6 was used as the main GIS package for modelling and running functions such as input, analysis, processing and output.

Salinity Maps for the Dry Season 2020

Based on the results, statistical analysis was made to determine the relationship between reflectance values and indices of soil salinity. The data was used to delineate salt affected soils in the KRIS in April 2020 by using the two models developed. The summary of their correlation R, R^2 and standard error of estimate is presented in Table 2. It can be seen from the Table 2. that model 1 has a correlation, R of approximately 64%, this implies that the predicted salinity value of the models and the observed value have correlation of 64%. The model can account for only 41% of the variation in salinity based on the R^2 value of 41%. The implication is that, there is 41% variance in response to the predictor variable SI 5. The salinity Index 5, is therefore a significant variable as the model is found to be significant at $P < 5\%$. Model 2 is also significant at $P < 5\%$ level and it can account for approximately 42% of the variation in salinity based on the R^2 value. The correlation between predicted value of the salinity by the models and the observed value have correlation of 66% which is a very close to the correlation of the first Model. However, the standard error of the both models are approximately 0.3 and this implies that the data in both models falls within a short distance from the regression lines.

Table 2: Summary of Adjusted R, R^2, and Standard Estimate of Error

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.643[a]	0.414	0.41	0.27608	0.414	108.792	1	154	0.000
2	.655[b]	0.429	0.422	0.27342	0.015	4.018	1	153	0.047

a. Predictors: (Constant), SI_5
b. Predictors: (Constant), SI_5, SI_1
c. Dependent Variable: Ece

Table 3 shows the coefficients used in the development of the two models, the intercepts, the t-values, the level of significance of the variables, the tolerance, and the variance Inflation Factors (VIF). The variables in the first Model are significant at P < 5%. The β value of 0.643 and t- value of 10.430 show that the Salinity Indices SI5, contributes more and has more significance in the Model. However, in the Model 2 which was formed from the combination of indices SI1 and SI5, the SI1 contributes less and is less significant in the model due to a lower β and t- values of 0.413 and 2.005 respectively (Table 4). Considering the tolerance and the VIF for the two models, Model 1 is likely to give a more reliable result of salinity in the study area due to lower VIF of 1.00 compared to Model 2 which has standardized coefficients for the predictors of SI_5 (β= 1.038, ρ < 0.05) and SI_1 (β= 0.413, ρ < 0.05) both with the same VIF value of 11.377 (which is greater than 10) and a tolerance value of 0.088 for both (which is less than 1.0).

Summary of the two models is follows:
Model 1: Salinity = $0.0013 \times \mathrm{SI}_5 + 0.48813$
Model 2: Salinity = $0.00021 \times \mathrm{SI}_5 + 2.42612 \times \mathrm{SI}_1 - 2.27038$

Table 3: Regression Model Based on Spectral Bands and Salinity Indices

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	0.488	0.138		3.546	.001					
	SI_5	0.0013	0.000	0 .643	10.430	.000	.643	.643	.643	1.000	1.000
2	(Constant)	-2.270	1.383		-1.642	.103					
	SI_5	0.0021	0.000	1.038	5.037	.000	.643	.377	.308	.088	11.377
	SI_1	2.426	1.210	0.413	2.005	.047	-.578	.160	.122	.088	11.377

The value of VIF and tolerance are indication of correlation between the predictors. The VIF values implies that the coefficients are approximately 11.4% bigger than the actual value expected if there is no issue of collinearity between the predictors. Presence of a collinearity in a model adversely affects result of regression. Multicollinearity is detected by VIF in regression analysis (Mohammed *et al*., 2021).

Salinity Mapping Developed from Landsat

Salt affected soils in the KRIS was delineated by using ArcGIS 10.6 with the two models developed from the stepwise regression analysis. Three (3) classes of salinity were generated with model 1 for the data obtained in dry season 2020 by taken Richards 1954 classification into cognizance as presented in Table 4.

Table 4: Areal Extent of Soil Salinity in the KRIS Derived from Model 1

Classes	EC Range dS/m	Area (ha)	Area (%)
Non-Saline (C1)	1.46 - 2.04	23106.20	32.36
Slightly Saline (C2)	2.04 - 2.36	45967.15	64.38
Moderately Saline (C3)	2.36 - 4.20	2328.98	3.26
Total		71402.32	100.00

The Non-Saline Class covers an area of 23106.2 ha representing approximately 32% of the entire area. The moderately saline class is divided into two with different ranges. The dominant classes with a range of 2.04 – 2.36 dS/m covers 45967 ha representing 64% of the entire KRIS area while the last class covers only approximately 3% of the total area of 71402.32 ha (Figure 3.). The implication is that less than 3% of the study area is saline, i.e., 69,073 ha are less affected by salinity as the EC is approximately less than 2.4 dS/m.

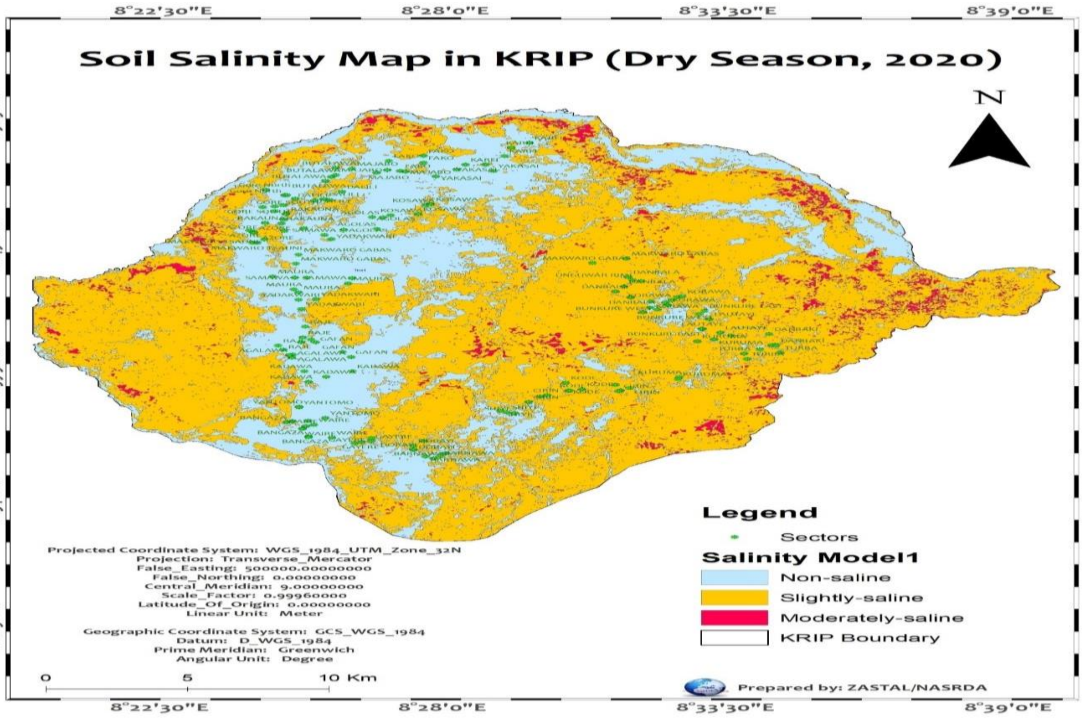

Figure 3: Soil Salinity Map Generated with Model 1

The results have shown that, the results from two models are in close agreement as the Non saline class covers 29.44% only 3% less than the value obtained from Model 1. The moderately saline which is further divided into two classes covers approximately 71% of the entire study area compared to 67% covered by the first Model (Figure 4). However, the value obtained with Model 1 are more reliable based on the value of VIF.

Table 4 shows a summary of the salinity classes, the area covered by each class, and the percentage of total area covered. The results from the two models are nearly identical, with the Non saline class covering 29.44%, which is only 3% less than the value obtained from the first Model. The moderately saline, which is further divided into two classes, covers approximately 71% of the entire study area, whereas the first Model which is more likely to give a more reliable result based on the VIF covers 67% (Figure 4). The result from the two models have shown that the EC value over the entire study area is greater than 1.3 dS/m.

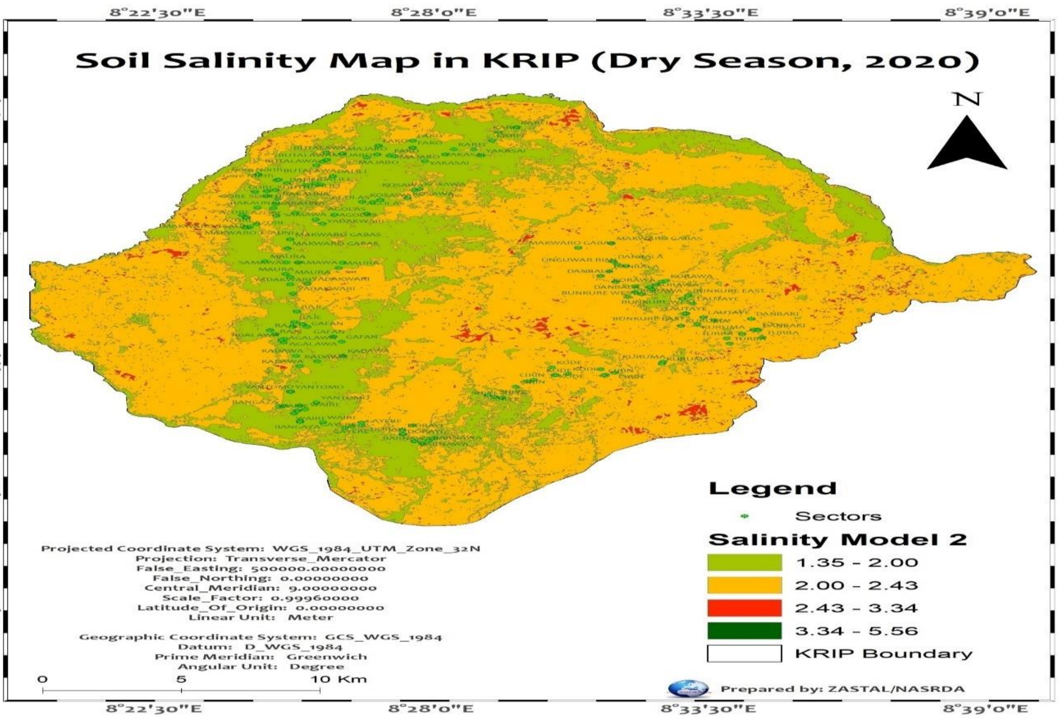

Figure 4: Soil Salinity Map Generated with Model 2

This has exceeded the threshold EC value of Carrot, Onion and Bean grown in the area. Francois, (1994) reported a threshold EC of 3.9 dS/m for Galic and it reaches 7.4 dS/m, 50% yield loss will be recorded. Crops like lettuce are moderately salt sensitive, with a salinity threshold of 1.3 dS/m (Shannon and Grieve, 1999).

Table 4: Areal Extent of Soil Salinity in the KRIS

Classes	EC Range dS/m	Area (ha)	(%) Area
Non-saline (C1)	1.35 - 2.00	21021.39	29.44
Moderately-saline (C3)	2.00 - 2.43	49378.98	69.16
Moderately-saline (C3)	2.43 - 3.34	1001.21	1.40
Saline (C4)	3.34 - 5.56	0.39	0.0005
Total		71401.97	100.00

Crops grown in KRIS and their threshold EC values are onion (1.0 dS/m), rice (3.0 dS/m), carrot (1.0 dS/m), pepper (1.5 dS/m), bean (1.0 dS/m), cucumber (2.5 dS/m), tomato (2.5 dS/m), cowpea (2.5 dS/m), wheat (6.0dS/m) and cotton (7.0 dS/m) (Mohammed *et al*., 2014).Based on the FAO standard, maximum potential of crops grown on soil with EC higher than 3.0 dS/m will not be recorded except with appropriate management practices. The implication is that only wheat and cotton can give their maximum production potential without management practices. However, only 3% of the KRIS area has an EC higher than 3.0 dS/m. Carrot and onion are salt sensitive crops (Shannon and Grieve, 1999). Studies have shown that, beyond the threshold value of 1.0 dS/m, carrot root yield reduces by 14% for every unit increase in soil salinity (Maas, 1986). The tolerance of onion to salinity was found to be higher during germination and very low during seedling growth and increases again at vegetative stage (Shannon and Grieve, 1999).

Table 5. presents the descriptive statistic of soil salinity and pixel values of salinity indices as well as spectral band values. The mean value of salinity is approximately 1.91 dS/m. The implication is that most of the vegetables such as Onion, Carrot, and Beans grown in the KRIS will be affected. This is because the threshold of value of 1.0 dS/m for such crops was exceeded and is capable of causing yield reduction in the crops.

Table 5: Mean and Standard Deviation of Ece, Salinity Indices and Band Values

	Mean Values	Std. Deviation	N
Ece	1.9053	.35948	156
B2	10052.0064	1038.17060	156
B3	12064.94	1372.326	156
B4	13077.38	2263.172	156
B5	19363.53	1027.330	156
B6	19900.90	3965.882	156
B7	16856.94	3981.516	156
SI_1	.77885592	.061203501	156
SI_2	-.12562127	.038132408	156
SI 3	15710.8789	2896.38090	156
SI_4	11457.36984	1583.000751	156
SI 5	10889.14674	1777.185278	156
SI_6	20849.0597	1806.78565	156
SI_7	12554.64729	1801.221136	156
SI 10	-.03475321	.032865937	156
MSI	.57	.497	156
VSSI	-138074.68	10580.855	156
NDSI	-.19888207	.085456800	156

Major crops grown in the KRIS are rice and tomatoes with a threshold value of 3.0 and 2.5 dS/m respectively and with good management these crops will give maximum yield when planted in any sector within the KRIS. Crops like garlic, wheat and cotton require no management because their threshold values are higher compared to most vegetables grown in the scheme.

CONCLUSION

The study investigated the ability of Landsat imagery in detecting and mapping soil salinity in Kano River Irrigation Scheme (KRIS). The result has shown that the EC value over the entire area is greater than 1.3 dS/m. This has exceeded the threshold EC value of Carrot, Onion and Bean grown in the area. However, major crops grown in the KRIS are rice and tomatoes with a threshold value of 3.0 and 2.5 dS/m respectively and with good management these crops will give maximum yield when planted in any sector within the KRIS. The implication is that only wheat and cotton can give their maximum production potential without management practices.

ACKNOWLEDGMENTS
This is to acknowledge the project's funding from the Transforming Irrigation Management in Nigeria (TRIMING) under the Nigeria's Ministry of Water Resources. The support of Centre for Dryland Agriculture Laboratory at Bayero University, Kano that provided assistance with various chemical for analyses.

REFERENCES

Abbas A. and Khan S (2007) Using remote sensing techniques for appraisal of irrigated soil salinity. In: Oxley, L. and Kulasiri, D., Eds., MODSIM 2007 *International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, 2632-2638.

Azabdaftari, A., & Sunar, F. (2016). Soil salinity mapping using multitemporal landsat data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *41*(June), 3–9. https://doi.org/10.5194/isprsarchives-XLI-B7-3-2016.

Ardahanlioglu, O., Oztas, T., Evren, S., Yilmaz, H., & Yildirim, Z. N. (2003). Spatial variability of exchangeable sodium, electrical conductivity, soil pH and boron content in salt- and sodium-affected areas of the Igdir plain (Turkey). *Journal of Arid Environments*, *54*(3), 495–503. https://doi.org/10.1006/jare.2002.1073.

Bannari, A., El-Harti, A., Guedon, A. M., Cherkaoui, F. Z., El-Ghmari, A., & Saquaque, A. (2013). Slight and moderate saline and sodic soils characterization in irrigated agricultural land using multispectral remote Sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34(30), 1–6.

Dehni, A., & Lounis, M. (2012). *Remote Sensing Techniques for Salt Affected Soil Mapping : Application to the Oran Region of Algeria*. *33*, 188–198. https://doi.org/10.1016/j.proeng.2012.01.1193.

Douaoui AEK, Nicolas H, Walter C (2006) Detecting salinity hazards within a semiarid context by means of combining soil and remote-sensing data. Geoderma 134:217–230

Farifteh, J., A. Farshad and R. George (2006). "Assessing salt-affected soils using remote sensing, solute modelling, and geophysics." Geoderma 130(3): 191-206.

Francois, L.E., 1994. Yield and Quality Response of Salt-stressed Garlic. HortScience 29, 1314±1317.

Jibrin, J. M., Abubakar, S. Z., & Suleiman, A. (2008). Soil fertility status of the Kano River irrigation project area in the Sudan Savanna of Nigeria. *Journal of Applied Sciences*, *8*(4), 692–696. https://doi.org/10.3923/jas.2008.692.696.

Kaledhonkar, M. J., Sharma, D. R., Tyagi, N. K., Kumar, A., & Zee, S. E. A. T. M. Van Der. (2012). Modeling for conjunctive use irrigation planning in sodic groundwater areas. *Agricultural Water Management*, *107*, 14–22. https://doi.org/10.1016/j.agwat.2011.12.023.

Khan A. and Abbas S. (2007). Remote Sensing Based Modelling Applications in Land and Water Management: *Using Remote Sensing for Appraisal of Irrigated Soil Salinity. MODSIM 2007.* Australia and New Zealand,.

Khan, N. M., Rastoskuev, V. V, Shalina, E. V, & Sato, Y. (2001). *Mapping Salt-affected Soils Using Remote Sensing Indicators - A Simple Approach With the Use of GIS IDRISI -* . (November), 5–9.

Maas, E.V., 1986. Salt tolerance of plants. Appl. Agric. Res. 1, 12 - 26.

Maas, E.V., 1990. Crop salt tolerance. In: Tanji, K.K. (Ed.), Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering No. 71, ASCE, New York, pp. 262- 304.

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae*, *3*(2). https://doi.org/10.3390/horticulturae3020030

Maina, M. M., Amin, M. S. M., Aimrun, W., & Asha, T. S. (2012). Evaluation of Different ET 0 Calculation Methods : A Case Study in Kano State , Nigeria. *Philipine Agric. Scientist*, *95*(4), 378–382.

Maina, M. M., Amin, M. S. M., Aimrun, W., & Sani, I. (2012). Soil salinity assessment of Kadawa Irrigation of the Kano River Irrigation Project (KRIP). *Journal of Food, Agriculture and Environment*, *10*(3–4), 1028–1034.

Marchuk, A. G., & Rengasamy, P. (2010). *Cation ratio of soil structural stability (CROSS)*. (August), 9–11.

Mohammed D. Maina M.M., Audu I., Tudunwada I.Y and Nasiru N.K. (2021). Remote Sensing Techniques in Mapping Spatial Variability of Salinity in Kano River Irrigation Project (KRIP), Nigeria. *Nigerian Journal of Technology*, 2021, 40 (4), pp.732 –739.

Mohammed D, Hassan. A. I. and Amina. A. (2015). Variabilty of Irrigation Water Quality in Kano River Irrigation Project. *Journal of Research in National Development, Department of Maritime Management Technology, Federal University of Technology, Owerri, Nigeria.Jorind*, *12*(2), 337–343.

Mohammed D., Audu I. and Igbadun H. E (2014). Variability of Irrigation Water Quality in Jakara Irrigation Scheme, Kano, A Paper Presented at 16th National Engineering Conference, held on 9th -10th December at Mohammed Dikko LectureTheatre, Kaduna Polytechnic, Kaduna.

Mohammed D., M.M. Maina, I. Audu I. Y Tudunwada, Nasiru N.K and and Umar S. E. (2021). Response Surface Regression Model for Predicting Clay Compsosition and its relationship with Selected Properties at Kano River Irrigation Scheme, Nigeria**.** *Dutse Journal of Pure and Applied Science.* Pp 14-26.

Pitt, J. L., & Provin, T. (2001). Managing Soil Salinity. *Texas A & M Agrilife Extension*, *60*, 3–12.7(1)

Salih, S. A. R., Elsheik, M. A. M., & Aydrous, A. E. (2015). *Determination of the Effect of Gypsum and Irrigation Water in Reclamation of Sodic Soils in South Khartoum*. 55–57.

Sangari, D. U. (2006). *An Evaluation of Water and Land Uses in the Kano River Project , Phase I , Kano State*. *Volume 11*(2), 105–111.

Shahid, S. A. (2016). *Salinity Development , 2 Soil Classification , Assessment , and Management in Irrigated Agriculture*. (December 2018).

Shannon, M.C. C. and Grieve M.C. (1999). Tolerance of Vegetable Crops to Salinity, Scientia Horticulture 78 (1) 5 – 38.

Taghadosi, M. M., Hasanlou, M., & Eftekhari, K. (2019). Retrieval of soil salinity from Sentinel-2 multispectral imagery. *European Journal of Remote Sensing*, *52*(1), 138–154. https://doi.org/10.1080/22797254.2019.1571870.

Yildirim, A., Gorji, T., Hamzehpour, N., & Sertel, E. (2019). Comparison of Different Soil Salinity Indices Derived From Sentinel-2A Images. *International Symposium on Applied Geoinformatics*, (1(1)).

Zakari, M.D., Sani N.N, Sabo, A.A., Shanono, N.J., Mohammed, D.,Ahmadu S.E., Ibrahim, A.and Nasidi, N.M.(2022).Effect of Millet Chaff as Organic Ammendment on Rice Yield in Sodic Soil - A Case Study of Thomas Irrigation Scheme in Kano, Nigeria.*FUDMA Journal of Sciences*, 6(1), pp 68-80. https://doi.org/10.33003/fjs- 2022-0601-820.

Zare, M., Ordookhani, K., Emadi, A., & Azarpanah, A. (2014). Relationship Between Soil Exchangeable Sodium Percentage and Soil Sodium Adsorption Ratio in Marvdasht Plain , Iran. *2*(12), 2934–2939.