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Full Length Research Article

EFFECTS OF SOIL SALINITY ON SUSTAINABILITY OF CROP PRODUCTION IN GUSAU LOCAL GOVERNMENT AREA, ZAMFARA STATE, NIGERIA

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ABSTRACT
The sustainability of agricultural production on the soils in the Sudano-Sahelian agroecological zone needs current information on the salinity status for appropriate management practices. This paper assessed the effects of soil salinity on the sustainability of crop production in Gusau, Local Government Area, Zamfara State. Soils were sampled from a polygon layer of grid stratification map of Gusau LGA at 0 - 20cm depth, a total of 8 polygon layers with over 50% proportion were selected for the collection of samples. Three soil samples were collected purposively at three different locations to produce eight composite soil samples. Soil parameters that were analyzed include Electrical Conductivity (EC) and Total Dissolved Solids (TDS) which are crucial in determining salinity level. Classification chart was used to classify the soils based on various degree of salinity. The results of the soil samples were interpolated using Inverse Distant Weight (IDW) to create maps of the spatial distribution of salinity level across the study area. Modis 13Q1 NDVI data of the study area from 2000 to 2020 were acquired from LP DAAC. The Area of Interest (AOI) and data attributes were selected. The data was used to show the vegetation responsive changes from salinity, which serves as an indirect method of detecting salinity. The EC values shows non salinity (0 to 2 dS/m), low salinity (2 to 4 dS/m) and mild salinity (4 to 5.7 dS/m). TDS ranged from non-hazard (140 ppm) to high hazard (465 ppm). Non-hazard class ranged (< 150 ppm), low hazard (150 to 250 ppm), medium hazard TDS (250 to 300 ppm) and high hazard (300 to 500 ppm) were found spatially distributed in different parts of the study area. A sustainability map of the study area from the severity of soil salinity which determined different management practices shows three sustainability classes of soils, very sustainable soils, sustainable soils and less sustainable soil. The study concludes that soils in Gusau ranges from moderate salinity towards the North and Central part of the study area and low in the Southern part. By implication, the soils in the North and Central areas can only sustain crops that are not sensitive to salinity. It is recommended that farmers should review their farm management strategies on soils with risk of salinity in order to reduce the rate and implications in the area.

Keywords: Gusau, Total Dissolved Solids, Electrical Conductivity, Sustainability, Salinity

INTRODUCTION
Salinization is the process by which dissolved soluble salts accumulate in the soil. The accumulation of salts in the soils may influence the soil water balance. National Soil Survey Center (NSSC, 2008) attributed the salinization processes to involve hydrological processes, changing climate, irrigation, drainage, plant cover and to a large extent farming practices.

Page et al. (2023) stressed that soil salinization is one among many environmental issues in many areas of the world. Zewdu (2012) stressed that salt affected areas stretched on all continents of the world, statistics about the extent of world salt affected areas vary with a general estimate close to 1 billion ha, which represent about 7 percent of the earth's continental extent. More than 120 countries are confronted, to a smaller or to a greater degree with the problem of soil salinity (Musa et al., 2022). In addition, Pozza and Field (2020) asserted that naturally salt-affected soils of 77 million ha became salinized as a result of human activities. These areas on average represent 20 percent of the world's agricultural lands, whereas the figure in arid and semi-arid countries exceeds about 30 percent (Zewdu et al., 2017 and Musa et al., 2022). Nigeria is not exceptional when it comes to the issue of soil salinity. Soil salinity problems in Nigeria has probably been due to the extensive agricultural activities, coupled with increase in population and the use of drawing underground water for irrigation of agricultural lands. In addition, Page et al. (2020) stated that the nature of harsh climate featuring low amount of rainfall duration and high temperatures also contributes to the soil salinity problems. Excessive soil salinity reduces productivity of many agricultural crops, especially vegetables that are particularly sensitive throughout the ontogeny of the plant, but does not result to immediate treats, and its effects on soil only become apparent on crops after a period of time (Nwankwoala, 2011). Muzammil (2018) asserted that land areas with salinity problems have witnessed desertification and consequent land degradation. Generally, salinity like any other related problem in Northern part of Nigeria have the propensity to reduce crop production at different levels, posing so much threats including soil erosion. It is a major limiting factor for crop yield in poorly drained soils (Musa, 2017).

However, Shahid et al. (2010) and Wang et al. (2023) stressed that site-specific integrated reclamation and management plan that require the implementation of strategy to transform marginal soils to good quality for crop production should include proper irrigation systems (surface, flood, basin, drip, sprinkler, subsurface irrigation, leaching and drainage), bio-saline agriculture (salt tolerant crops), physical (leveling, salt scraping, tillage, sub-soiling and sanding) chemical (use of soil amendments such as acids, gypsum among others), and salinity monitoring and mapping program. Similarly, Musa et al. (2022) are of the opinion that certain programs can also be implemented that can help in avoiding further spread of soil salinity to new regions and that if prove successful, will prevent negative impacts on national economies through reduction in the degrading of a nation's soil resources.

Thus, it is imperative to continuously monitor agricultural lands with the sole purpose of identifying saline agricultural lands for the

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sustenance of soil fertility, reduction in soil degradation and resultant high crop production (Zewdu et al., 2017). Geographic Information Systems (GIS) have likewise become tools for identifying and classifying saline soils (Liu et al., 2020). These techniques have been very useful in mapping saline areas. Similarly, it has been widely applied in many studies in the field of agricultural farming using different approach with different methods and applications in recent years (Zaman et al., 2018). Several studies Wang et al., 2023; Pozza & Field, 2020; Page et al., 2020; Liu et al., 2020) have been conducted but are limited in the study area especially those that experienced scarcity of data like the northern part of Nigeria. Therefore, this paper evaluated the effects of soil salinity on the sustainability of crop production in Gusau Local Government Area, Zamfara State using both the remote sensing and laboratory method of monitoring and assessing salinity.

MATERIALS AND METHODS

Study Area

Gusau Local Government Area is the capital town of Zamfara State, located in North-Western Nigeria with an area coverage of about 3,364 km^2. It lies between Latitude 12° 09' 51'' and 12° 10' 12'' North of the equator, and between Longitude 6° 39' 84'' and 6° 66' 41'' East of the Greenwich Meridian. It bordered Birnin Magaji and Kaura Namoda Local Government Area to the North (Figure 1), Bungudu LGA to the West, Tsafe, Kankara, Danmusa, and Safana LGA to the East, and Faskari, Birnin Gwari, Sabuwa and Maru LGA to the South.

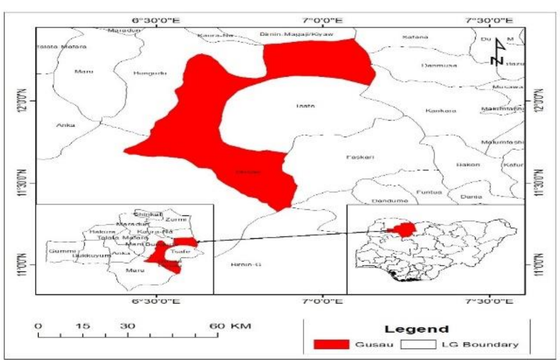

Figure 1: Zamfara State Showing the Study Area and an Inset Map of Nigeria
Source: Adopted and Modified from Ministry of Land and Survey, Zamfara State, 2021

The climatic condition in Gusau is tropically warm (Aw) with distinct wet and dry seasons, rainfall in Gusau is seasonal and the mean annual rainfall ranges from 800mm to 1,000mm (Ojo, 1982). Temperature rises up to 38°C during the rainy season than the approximately 30°C monthly mean. It is as low as 19°C between December and February (Ojo, 1982). Humidity reaches 80% at the peak of the rainy season around May to September.

Generally, the soils in Gusau falls under the leached ferruginous tropical soils developed on weathered regolith overlain by a thin deposit of wind-blown silt from the Sahara desert (Aminu, 2014). The soils are susceptible to erosion since the top soil is easily washed off by rain water, especially if the vegetation cover is removed (Dalhatu, 2009). Most of the soils have a sandy loam texture (Jaiyeoba, 1995). Similarly, Dalhatu and Garba (2012) reported that Gusau LGA is largely drained and influenced by River Sokoto and the uplands are traversed by small streams and rivers, which make confluence and recharge Gusau Dam. These tributaries of the Sokoto Rima and River Niger flows westwards and southwards along the regional landscape of the Gusau area.

Data required

Normalized Difference Vegetation Index (NDVI) images of Gusau from 2000 to 2020 were obtained from MODIS 13Q1 to examine the response of vegetation to soil salinity levels. This was achieved by establishing the relationship between NDVI and salinity levels determined through laboratory analysis using Pearson's correlation coefficient. The analysis was supported by a Global Positioning System (GPS), which was used to obtain accurate locations of the soil samples (Figure 2a, 2b, and 3).The data from the collected soil samples were subjected to laboratory analyses of mainly the soil chemical properties, which include the electrical conductivity and total dissolved solids. These are essential components of soil quality, which enhances the effective growth of plants. Similarly, (FAO-USDA, 1993) salinity classification chart was used to classify the soil chemical parameters into different classes.

Soil sampling techniques

A Polygon layer of stratification grid map was created from the Gusau base map to indicate the sampling points, this is considered by Jones (2001); Carter & Gregorich (2008); Soil Survey Staff (2014) to be one of the most relevant soil sampling strategies. The fishnet tool of the ArcGIS 10.5 software was used to generate a regularly spaced grid of sampling points inside the polygon layer. A total number of sixteen (16) stratified grid cells of 15 km2 covering the entire study area was demarcated. From the 16 grid cells, eight grids of cells with over fifty percent (50%) proportion in the study area were selected for the samples (Figure 2a, 2b & 3). Three soil samples were collected purposively at three different agricultural locations. The three samples from each polygon were composited to make a sample for each of the eight grid cells A - H. Similarly, the coordinates of the composited soil sampling points were recorded using a global positioning system at an accuracy of ±3 m. Subsequently, the samples were collected from the sub-surface soil at 0 - 20cm depth using a hand auger as considered by Soil Survey Staff (2014). This is because 0 - 20cm is said to be the ploughing depth in most agricultural soils, and salinity mostly affects the root zone and crop production.

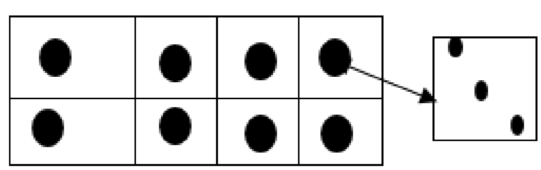

Figure 2a and 2b: Stratified Systematic Unaligned Grid (Jones, 2001; Carter & Gregorich, 2008).

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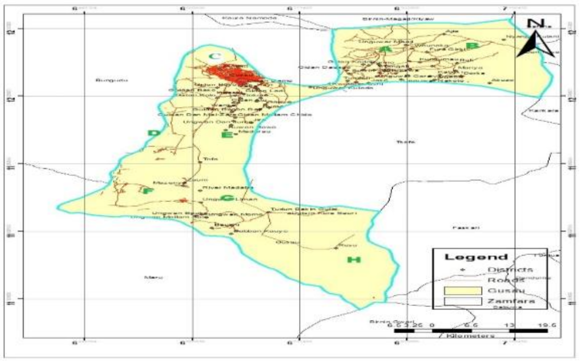

Figure 3: Stratified Systematic Unaligned Grid Sampling Map of Gusau
Source: Modified from Map of the Study Area, (2020)

Laboratory analyses of soil samples
After the collection of samples from representative fields, the soil samples were packaged in a polythene bag labelled A - H and were taken to the Laboratory for appropriate analysis. The soil samples have been air dried and sieved with a (2 mm) sieve size to remove coarse particles. Soil chemical analyses on the fine fractions carried out in the laboratory included the Electrical Conductivity EC and Total Dissolved solids TDS.

Method of data analysis
Descriptive and inferential statistics were used to present, summarize and analyze the various data used for the study. Similarly, remote sensing analysis for salinity change detection and GIS assisted spatial modelling was employed. Threshold from the FAO (USDA, 1993) salinity classification chart was used to examine the soil salinity level (Table 1). Coefficient of variation (C.V) was used to examine the degree of variation within the soil parameters. The EC data were coded base on the sample points in excel work sheet and saved as CSV file. This was exported into the ArcGIS environment, and the map of Gusau served as a base map. Subsequently, the exported data in the ArcGIS environment was plotted and displayed as X and Y which formed a point shapefile. The shapefile data of the measured EC was interpolated using inverse distance weight (IDW). And lastly, the spatial variation was determined using the interpolated map of the EC data.
Results of salinity (EC and TDS) from the analyzed soil samples, degree of crop sensitivity at various salinity level from the FAO (1993) salinity classification chart, as well as the different management practices of the various salinized soil classes was used to classify the soils into various sustainable classes.

Vegetation Change Detection Using Remote Sensing and GIS
Multi-temporal images spanning 20 years from MODIS were extensively used to identify and map salt-affected areas impacting vegetation by correlating them with laboratory-extracted data, such as electrical conductivity. Before the correlation, the NDVI dataset was subjected to geometric and radiometric corrections. Feature extraction and visual interpretation of the processed satellite image data was carried out to delineate boundaries of the affected areas. Furthermore, the GIS and RS index used for the study is the NDVI as applied by Zewdu et al., (2017) and Zurqani et al. (2012). Zurqani et al. (2012) also stressed the efficiency of using vegetation cover in salinity monitoring, which served as an indirect indicator of salt affected soils and hence stressed vegetation could be an indirect sign for the presence of salt in the soils. Subsequently, the vegetation index included in the analysis is computed as follows:
NDVI = [(NIR – Red) / (Red + NIR)].
The temporal changes were achieved through soil salinity change analysis using ArcGIS. The soil salinity result from the NDVI has given the soil salinity changes for the entire study period. Subsequently, change analysis was conducted using time series. The loss and gain on soil salinity was also determined for each epoch. The adoption of NDVI in soil salinity assessment in this study is attributed to its global applicability and suitability for historical assessments. It enables long-term trend analysis with consistency across studies worldwide (Wang et al., 2023).

RESULTS AND DISCUSSION
Nature and Spatial variation of Soil Salinity Level in the Study Area
This section shows the salinity level from the results of the Laboratory analysis (Table 1), as well as the spatial variations of those results through interpolated maps EC (Figure 4) and TDS (Figure 5).

Soil salinity level
Table 1: Variation in soil salinity level

Salinity level	Crop sensitivity	EC (dS/m)	Sample points	EC (dS/m)	TDS (ppm)
Non saline	Very sensitive crops	0-2	H	1.8	140
			B	2.0	170
Low salinity	Sensitive crops	2-4	E	2.8	155
			D	3	380
			G	3	180
Mild salinity	Mildly sensitive crops	4-8	F	5	350
			A	5.3	460
			C	5.7	465
High salinity	Mildly resistant crops	8-16			
Severe salinity	Resistant crops	>16			

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The results of electrical conductivity and total dissolved solids is presented in Table 1. The results shows that the electrical conductivity (EC) of the soil samples ranged between 1.8 to 5.7 dS/m with a mean value of 2.57 dS/m, which shows the variations between EC values across the surfaces of dryland and waterlogged areas in Gusau.

Findings of the analysis shows that from the sampling map (Figure 3) of grid units, polygon H have the least EC value of 1.8 dS/m, followed by B with EC value of 2.0 dS/m, all which ranged between non-saline soil class. Polygon E with EC value of 2.8 dS/m, G with EC value of 3 dS/m and D with EC value of 3 dS/m are ranged between the low salinity class. Polygon F with EC value of 5 dS/m, A with EC value of 5.3 dS/m and C with EC value of 5.7 dS/m are ranged between mild salinity class. This shows that there is salinity risk in some part of the study area since the values from the results are above 4 dS/m which is within the critical limit.

Similarly, the results of the Total dissolved solids (TDS) ranged from 140 to 465 ppm and an average of 287.5 ppm, the result shows polygon H has a TDS value of 140 ppm, E with 155 ppm, B has 170 ppm, G also has 180 ppm. These shows lesser amount of organic and inorganic salts or elements in the soils. Polygon F with 350 ppm, and D has 380 ppm which also shows a mild amount of organic and in organic salts present in the soils. Polygon A and C with the highest TDS value of 460 and 465 ppm respectively has a considerable amount of high organic elements present in the soils, which evidently show salinity risk around the floodplain areas where most agricultural activities take place in Gusau. However, the potentiality of dry land areas to become saline is less compared to that of waterlogged or floodplain areas, this is because most dry land areas are subjected to leaching which gets the salts particles down the lower soil horizons when the rain falls. Therefore, areas with greater risk of salinity require best management practices to prevent further build-up of salinity on the soils. This is in conformity with the results of Alhassan et al. (2018) on medium hazard salinity on soils which has EC range between 1.54 to 4.76 dS/m, and TDS between the range of 44.8 mmol/L to 908.8 mmol/L.

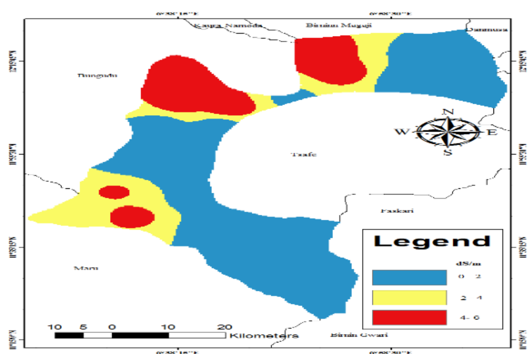

Figure 4: Spatial Variation of Electrical Conductivity in Gusau.
Source: Author's Analysis, 2021

Figure 4 shows the spatial variation of electrical conductivity of the soil saturated extract (ECe). The results was used to classify soils from EC range (Figure 4), the EC range of 0 to 6 dS/m was used to show the spatial distribution of the soil salinity level in the study area which falls under non-salinity, low salinity and mild salinity class. The southern part of the study area has the lowest EC range of 0 - 2 dS/m, which stretched towards the central part of the study area. Also, the eastern part of the study area falls under non salinity class with EC value ranging between 0 - 2 dS/m. Medium EC range (2 - 4 dS/m) is also observed in the northern and western parts of the study area. Highest EC range (4 - 6 dS/m) is observed across the northern part of the study area, although high EC value is also recorded in few spots along the western part of the study area. Thus, soils with EC range of 0 - 2 dS/m are non-saline, soils within the range of 2 - 4 dS/m are said to have low salinity. While soils within the range of 4 - 8 dS/m have mild salinity. There is a wide variation of EC values in the study area, which shows no salinity in the southern, central and north-eastern of the study area. Low salinity across the western and northern parts, and mild salinity which dominates most part of the northern part of the study area, which are mostly floodplains where rain-fed agriculture and most irrigational activities takes place.

Similarly, the TDS comprises inorganic salts and small amount of organic matter that are dissolved in the soils. This shows a wide variation across the study area (Figure 5). A very low TDS (<150 ppm) was observed in the southern part of the study area where no detrimental effects are expected on the crops and salt build up in the soils, low hazard TDS (150 - 250 ppm) was also observed across the southern and northeastern part of the study area, medium hazard (250 - 300 ppm) stretches along the east-central part of the study area with a mild impact, and a high TDS value (300 - 500 ppm) in the northern and western part of the study area was observed respectively.

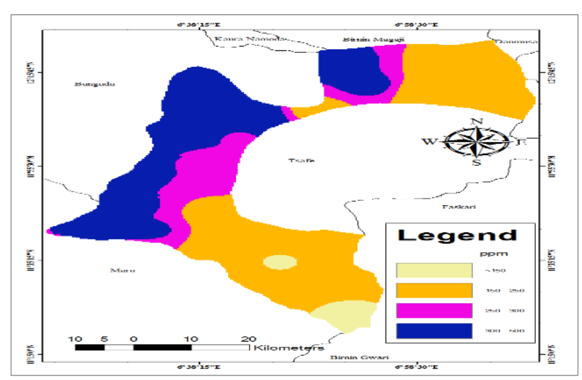

Figure 5: Spatial Variation of Total Dissolved Solids in Gusau.
Source: Author's Analysis, 2021

This shows that the study area is occupied with a very low TDS that has no detrimental effect on crops, low TDS with little effects and medium hazard TDS with adverse effects on crops. Therefore, it is eminent that Na^+, K^+, Ca^+, Mg^+ and SO^+ may likely be present in most part of the study area where TDS value is high especially in the waterlogged agricultural lands. This is in conformity with the

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assertion of Adeshina and Adamu (2011) that organic and inorganic contents or elements formed the waterlogged agricultural surfaces, and hence intensive management on these soils is likely possible to enhance the sustainability of the soils and hence improved crop production.

Spatio-Temporal Detection of Variations and Changes in Vegetation

Figure 6 shows the spatial variation of the vegetation in the study area from 2000 to 2020 and detecting the temporal changes from 5 years of interval. This comprises the vegetation cover of different density. Based on the NDVI classification threshold, three vegetation types (bare surfaces, sparse vegetation and dense vegetation) were identified in the study area.

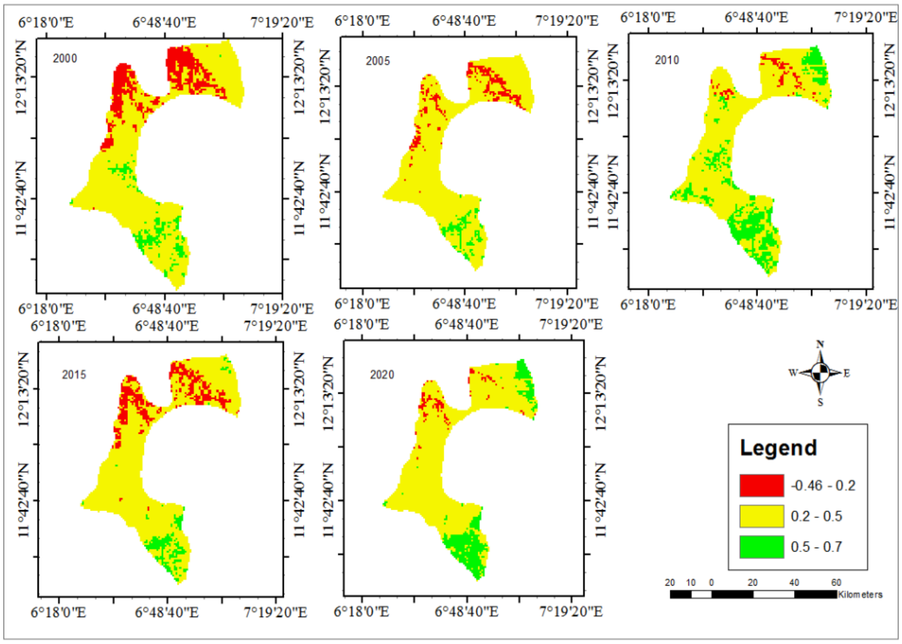

Figure 6: Vegetation cover status of Gusau
Source: Author's Analysis, 2021

In 2000, the observed results show the study area is majorly dominated with sparse vegetation which has over 60% proportion. Bare surfaces are observed with over 30% proportion in the northern part of Gusau (figure 6). The least spatial distribution is that of the dense vegetation cover across the southern part of the study area with just few proportional extent of about 10%. From 2000 to 2005, the proportion of bare surfaces have decreased to about 20%, sparse vegetation cover increases to 75% and dominated most part of the study area, dense vegetation cover also decreases to about 5%. From 2005 to 2010, the proportion of bare surfaces have reduced significantly to about 5% in the northern part of the study area, sparse vegetation cover also decreases to about 60%, proportion of dense vegetation cover increases in the south, central and north eastern part of the study area to about 35%. This shows salinity have decreased over the period, which could be as a result of flood that flushes salt particles on the soils in 2006. From 2010 to 2015, the density of the vegetation cover decreases and that of bare surfaces increases to over 25% extent in the northern part of the study area, sparse vegetation dominated most part of the study area with over 60% proportion. The vegetation density across the study area changes from 2015 to 2020, the south and north-eastern part of the study area has a dense vegetation with nearly 20% extent, sparse vegetation is greater and dominated the study area with about 70% proportion, the proportion of bare surfaces decreased to just 10% across the northern part of the study area. This shows the southern part of the study area have the healthiest and least vegetation cover and thus less salinity effects.

Sustainability of Soils on Crop Production in the Study Area

High level of soil salinity affects crop production negatively, which makes assessing, monitoring and mapping of soil salinity beforehand very paramount. This provides opportunity to delineate and categorize salinity level in order to provide effective soil reclamation procedure and substantial plan that will help to decrease the effects of soil salinity on crop yield, since no single adaptation, mitigation option or technique is applicable to all land areas. Therefore, the severity of salinity in the study area from the series of results as well as the suitability of the soils on crop production was used to delineate their sustainability for crop production.

The result of the sustainability of soils on crop production is presented in Figure 7. The result shows that the southern and some part of central and eastern part of the study area that was classified non saline, having crops that are very sensitive to salinity, couple with EC values of less than 2 dS/m, TDS < 150 ppm, as well as high NDVI (above 0.5) are classified very sustainable for crop production. Major part of the central and the north-eastern part of the study area which were found to be low saline with moderate EC range of 3 - 5 dS/m, medium hazard TDS (250-300 ppm), and NDVI range of 0.2 - 0.5 (indicating sparse vegetation cover) that are very

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sensitive to salinity, are therefore classified sustainable. The north and some part of the western part of the study area are classified less sustainable because of mild or high salinity (having EC above 5dS/m, TDS above 500 ppm, coupled with a very low NDVI value below 0.2).

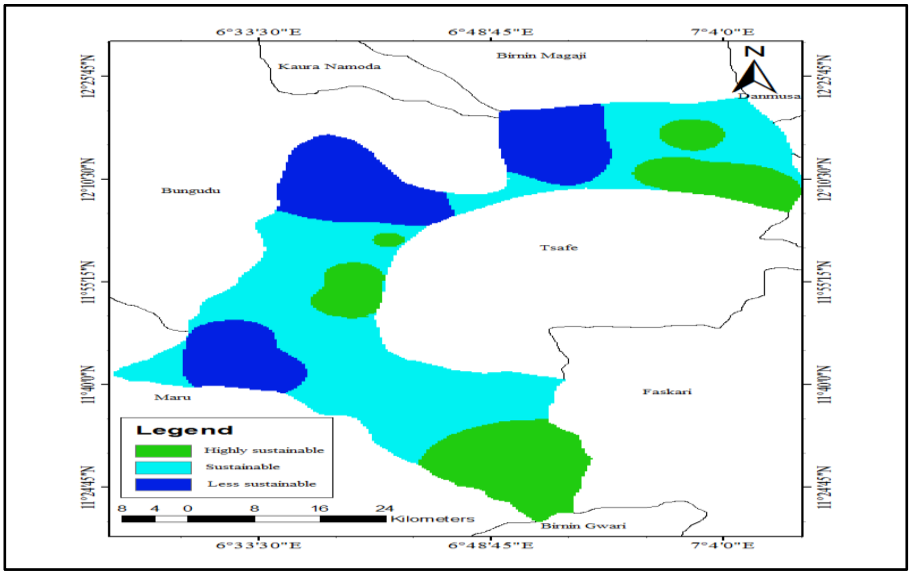

Figure 7: Sustainability of Soils on Crop Production in the Study Area
Source: Author's Analysis, 2021

Therefore, according to Musa et al. (2022), areas that are classified very sustainable require proper management practice to avoid salt build-up in the area. Areas classified sustainable supports the plantation of salt resistant crops and efficient management practice and adequate drainages to desalinize the soils and prevent further accumulation. The parts of the study area that are classified less sustainable requires the implementation of strategies that will transform marginal soils to good quality for crop production such includes; hydrological methods that will leach and drained the salts particles in the soils, biological methods such as bio-saline agriculture, physical methods which includes salt scraping, tillage, sub-soiling and sanding, and chemical that includes the use of soil amendments such as acids and gypsum among others.

Conclusion

The spatial salinity level indicates the presence of no salinity, low salinity, and moderate or mild salinity in Gusau general area. Also, non-hazard, low hazard, moderate and high hazard metals were found spatially distributed across the study area. Moderate salinity treats is intense along the waterlogged and major river channels of Sokoto Rima and tributaries of River Niger which cut across the northern and central part of the study area respectively. The variability may be connected to the shallow water table that initiated various irrigational and rain-fed farming activities across the area. However, salinity implications from the vegetation cover analysis shows a slight increase in the vegetation over the recent decades. Similarly, the vegetation of the study area showed three classes of vegetation which includes bare surfaces, sparse vegetation, and dense vegetation cover. The proportion of sparse and bare surfaces outweigh that of the dense vegetation cover in areas established to have high salinity risk. However, positive changes occurred over the recent decades, which increases the density and health of the vegetation cover.

Recommendations

The use of GIS in mapping soil salinity and its implication is very promising and researchers are urged to use this method for a clear understanding of the conditions of soils in order to adopt and enhance management practices for better productivity. There should be proper awareness on the implications of salinity locally by the State and Local Government and internationally by Non-governmental organizations. Farmers and government should review their farming management strategies on soils in order to reduce the rate and implications of salinity on soils.

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