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SPATIO-TEMPORAL VARIATIONS OF SOIL SALINITY IN GUSAU LOCAL GOVERNMENT AREA, ZAMFARA STATE, NIGERIA

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ABSTRACT

This paper assessed the spatio-temporal variations of soil salinity in Gusau Local Government Area of Zamfara State. Modis and Landsat images of three epochs were used to examine the effective area from 2000 to 2020. The study employed an index-based approach of RS and GIS to monitor the variations and changes in salinity. NDVI from Modis data with a threshold of -1 to 1 was used to measure salinity based on crop response to various degrees of salinity, while NDSI was used to measure salinity directly from the surface salt reflectance using Landsat images. The NDVI was classified into three classes; bare surfaces from (– 0.46 to 0.2), sparse vegetation (0.2 to 0.5) and dense vegetation (0.5 to 0.7). The result revealed that shows three salinity classes low (0.3 to 0.5), moderate (0.5 to 0.7) and high salinity (0.7 to 1). In addition, it showed a positive trend (an increase of 0.0013) in the vegetation of the study period, while that of the salinity has a negative trend (decrease of – 0.0014) over the study period. The result revealed that the area with a bare surface has high salinity compared to the other classes in the study area. The study recommends the enhancements of models in the prediction and monitoring of further salinity implications.

Keywords: Spatio-temporal, Salinity, Remote Sensing, GIS, NDVI, NDSI, Gusau

INTRODUCTION

The accumulation of dissolved, soluble salts in the soil is known as salinization. This 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 large extent farming practices (A.-H. Babati et al., 2022). Food and Agriculture Organization (FAO, 2013) stressed that soil salinization is one among many environmental issues in many areas of the world. According to Zewdu (2012) it is important to note that salt-affected areas are widespread across all continents of the world; statistics on their extent vary, but a general estimate of close to 1 billion hectare, or around 7% of the continental area of Earth, has been made. The issue of soil salinity affects more than 120 countries significantly (Al-Khaier, 2003). In addition, Zurqani et al. (2012) claimed that 77 million ha of naturally salt-affected soils got salinized as a result of human activity. These regions account for 20 percent of the world's agricultural fields on average, compared to over 30 percent in arid and semi-arid regions (Zewdu et al., 2017). Regarding the problem of soil salinity, Nigeria is not unique.

Soil salinity issues in Nigeria are most likely the result of extensive agricultural activities, population growth, and the use of underground water for irrigation of agricultural lands (Zaharaddeen et al., 2017). In addition, Mahmoud (2005) stressed that the nature of harsh climate featuring low amounts of rainfall duration and high temperatures also contributes to soil salinity problems. Excessive soil salinity affects the production of many crops, especially vegetables, which are particularly susceptible throughout the plant's ontogeny. However, its effects on the soil take time to manifest (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 the Northern part of Nigeria has the propensity to reduce crop production at different levels, posing so many threats including soil erosion. It is a major limiting factor for crop yield in poorly drained soils (Musa, 2017).

Thus, it is imperative to continuously monitor agricultural lands with the sole purpose of identifying saline agricultural lands for the sustenance of soil fertility, (Baba et al., 2022) reduction in soil degradation and resultant high crop production (Zewdu et al., 2017). Geographic information systems (GIS) and remote sensing techniques (RS) have become tools for identifying and classifying saline soils (Zurqani et al., 2012) and are very useful for monitoring and controlling salinity problems, especially in arid and semi-arid environments with sparse vegetation cover (Babati et al., 2021; Bashariya et al., 2022; Zaharaddeen et al., 2016). Similarly, it has been widely applied in many studies in the field of agricultural farming using a different approaches with different methods and applications in recent years (Zaman et al., 2018). Therefore, mapping and monitoring of salinity start with the identification of areas where salts concentration is prioritized and then detecting the temporal and spatial changes in this occurrence (Zinck, 2001). Several studies (Abbas & Khan, 2007; Dutkiewics & Lewis, 2008; Shahid, & Othman, 2010; Zurqani et al., 2012; Allbed & Kumar, 2013; Abebe, Alamirew, & Abegaz, 2015) demonstrated the value of employing Geographic Information System (GIS) indices and remote sensing to measure soil salinity. Therefore, this paper assessed the change in salt-affected areas from 2000 to 2020 in Gusau Local Government Area, Zamfara State.

MATERIALS AND METHODS

Study Area

Location: 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, 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).

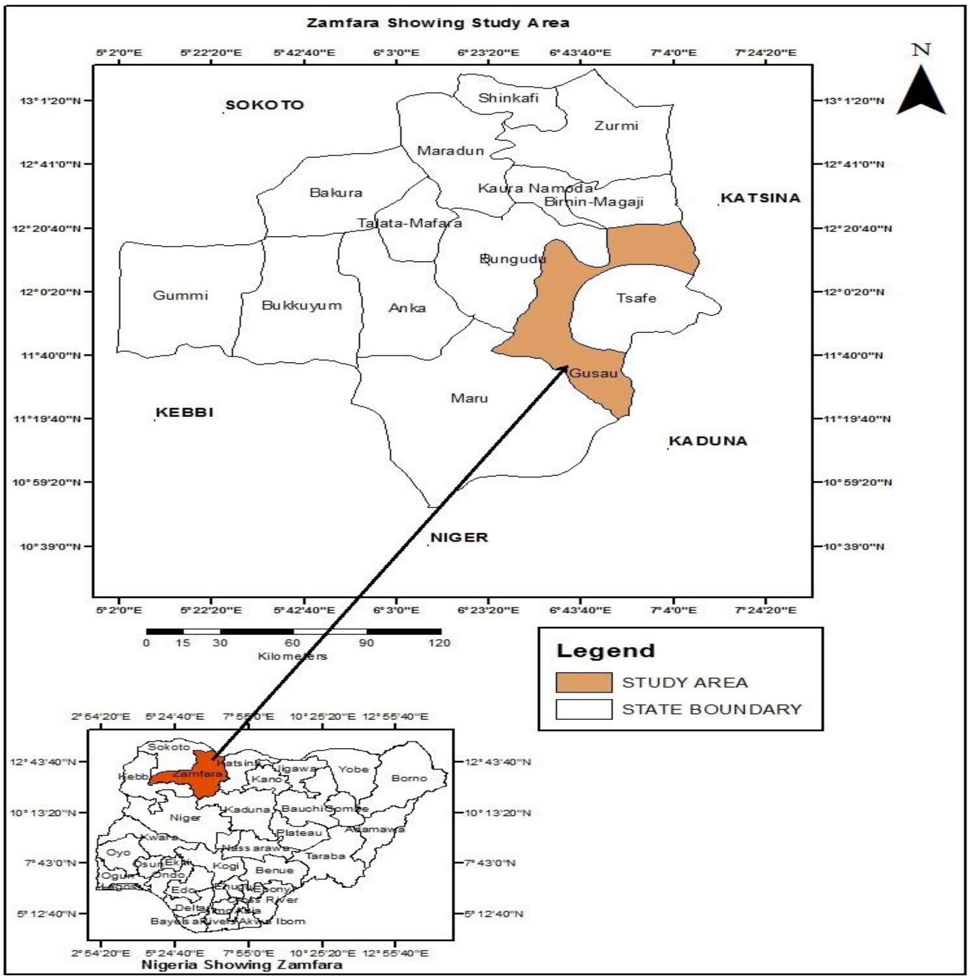

Figure 1: Zamfara State Showing the Study Area and an Inset Map of Nigeria
Source: Adopted from Zamfara State Ministry of Land and Survey, (2021)

Climate: 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). The temperature rises to 38°C during the rainy season than the approximately 30°C monthly means. 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.

Soils and drainage: The majority of the soils of Gusau are wind-blown Sahara desert silt that is overlaid with leached ferruginous tropical soils that were produced on weathered regolith (Aminu, 2014). Since rainwater can easily wash away the topsoil from the soils, especially if the vegetation cover is lost, the soils are vulnerable to erosion (Dalhatu, 2009). The majority of the soils are sandy loam (Jaiyeoba, 1995). According to Dalhatu and Garba (2012), Gusau LGA is similarly heavily influenced and drained by the River Sokoto, and the uplands are traversed by minor streams and rivers that meet and refuel Gusau Dam. From the Gusau region, these Sokoto Rima and River Niger tributaries flow west and south.

METHODS

Data Required: **The data used for this research include the following:**

i. Landsat images (ETM, ETM+ and OLI/TIRS)
ii. Modis 13Q1 NDVI data from 2000 to 2020

Soil Salinity Detection Using Remote Sensing and GIS: Multi–temporal Landsat images (ETM, ETM+, and OLI/TIRS) and Modis data from 2000 to 2020 were used to identify the salt-affected areas. Geometric and radiometric corrections were conducted on the multi–temporal Landsat images. For the accuracy of the analysis, a visual interpretation of the processed satellite image data was carried out to delineate the boundaries of the saline areas. Furthermore, the GIS and RS indices were computed and used. Specifically, the remote sensing salinity indexes used for this study were NDSI and NDVI, as applied by Zewdu et al. (2017) and Zurqani et al. (2012). These indices were derived by rationing the different bands of the satellite images. The mathematical formulation for NDSI is as follows:

$$NDSI = [(Red + NIR) / (NIR – Red)]$$

Similarly, Zurqani et al. (2012) also emphasized the effectiveness of using plant cover in salinity monitoring, which functioned as an indirect indicator of soils affected by salt. As a result, it was emphasized that vegetation might be an indirect indication of the presence of salt in the soils. The analysis's included vegetation index is then calculated 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 NDSI and 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.

RESULTS AND DISCUSSION

Spatio-Temporal Detection of Variations and Changes in Vegetation

Figure 2 shows the spatial variation of the vegetation in the study area from 2000 to 2020 and detects the temporal changes from 5 years of interval. This comprises the vegetation cover of different densities. Based on the NDVI classification threshold, three vegetation types (bare surfaces, sparse vegetation and dense vegetation) were identified in the study area.

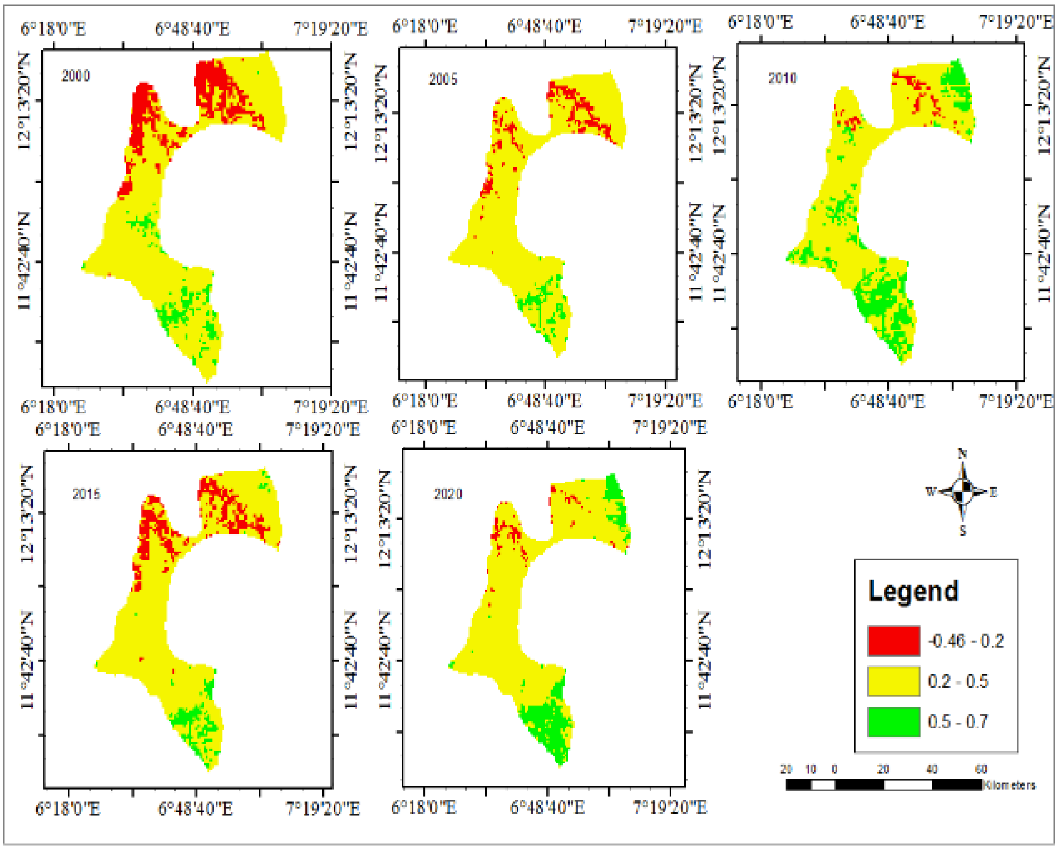

Figure 2: Status of Vegetation Cover In Gusau
Source: Author's Analysis, 2021

In 2000, the observed results show the study area is majorly dominated by sparse vegetation which has over 60% proportion. Bare surfaces are observed with over 30% proportion in the northern part of Gusau. The least spatial distribution is that of the dense vegetation cover across the southern part of the study area with just a few proportional extents of about 10%. From 2000 to 2005, the proportion of bare surfaces decreased to about 20%, sparse vegetation cover increases to 75% and dominated most parts of the study area, and 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 has decreased over the period, which could be a result of flood that flushes salt particles on the soils in 2006. From 2010 to 2015, the density of the vegetation cover decreased and that of bare surfaces increases to over 25% extent in the northern part of the study area, sparse vegetation dominated most parts 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 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 has the healthiest and least vegetation cover and thus fewer salinity effects.

Spatio-Temporal Detection of Variations and Changes in Salinity

Figure 3 shows salinity changes from the NDSI. Three classes of salinity were also identified (low salinity, moderate salinity and high salinity). Results of the spatio-temporal variations show in 2000, high salinity class was observed in the northern part of the study area with over 25% proportion, medium class salinity dominated most of the study area with about 70% extent, low salinity level was also observed across the southern part of the study area with almost 5% proportion. From 2000 to 2005, high salinity was observed in the south and central part of the study area which decreases in proportion to 3%. Moderate salinity dominated most parts of the study area to about 80% extent. Low salinity was observed in the southern part of the study area which significantly decreased in the extent to just 17%.

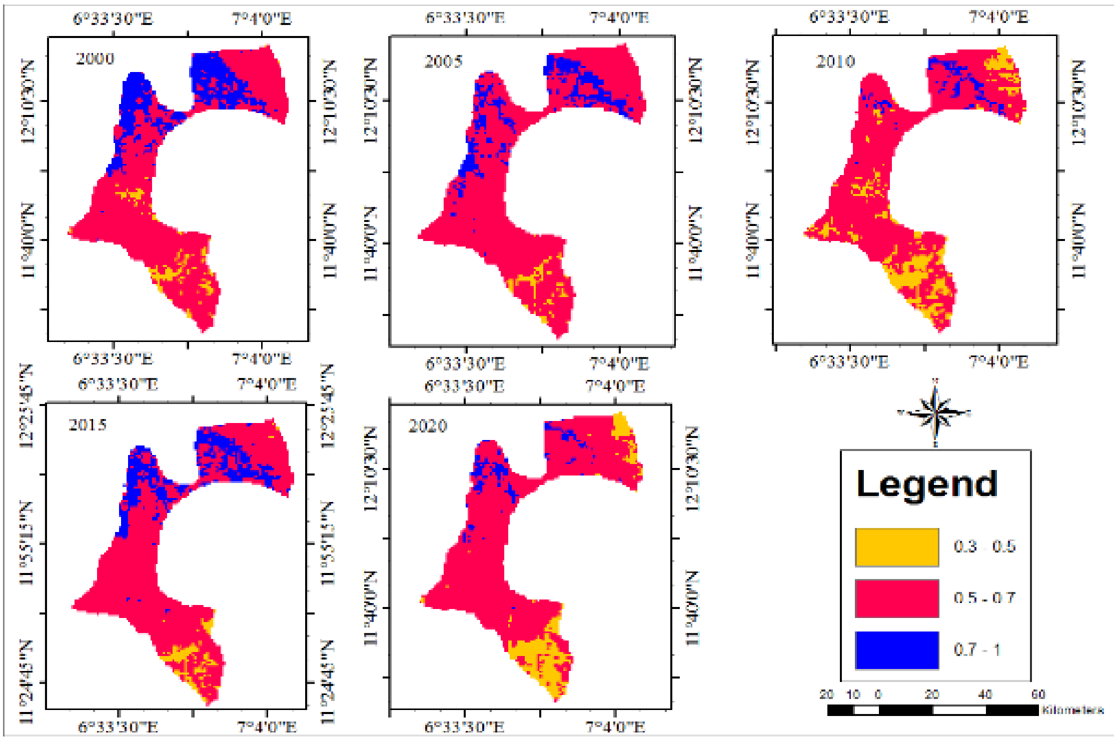

Figure 3: Salinity status of Gusau
Source: Author's Analysis, 2021

From 2005 to 2010, the proportion of high salinity class decreases across the northern part of the study area covering less than 10% proportion. The moderate salinity class decreased in proportion to almost 60%, while the low salinity class shows an increase in the proportion of 30% in the south and eastern part of the study area. This is attributed to the 2006 flood which washes up the salt particles in the study area. From 2010 to 2015, high salinity class increased in proportion to about 30% across the northern part of the study area. Moderate salinity dominated the study area at about 60% extent. The proportion of low salinity however decreased to about 10% across the southern part of the study area. From 2015 to 2020, the northern part of the study area with high salinity class decreased to about 15%. Moderate salinity however increases in proportion to about 65% across the study area. Low salinity was observed across the south and north-eastern part of the study area, covering about 20% proportion. It was observed that the spatial concentrations of salts in the study area vary, with more concentration along the riverine and waterlogged areas where most agricultural and irrigational farming activities take place than in the upland dry areas. Therefore, if rainfall or management methods do not offer adequate leaching in the waterlogged areas where salinity was reported, there will likely be increased salinity.

Trend Analysis of the Changes

Figure 4 shows the trend analysis of the mean (average) value of both NDVI and NDSI from 2000 to 2020. Results of the changes show the NDVI observed a positive trend in the vegetation with 0.0013 from 2000 to 2020. Similarly, there was a negative trend of -0.0014 in salinity over the years as observed from the NDSI.

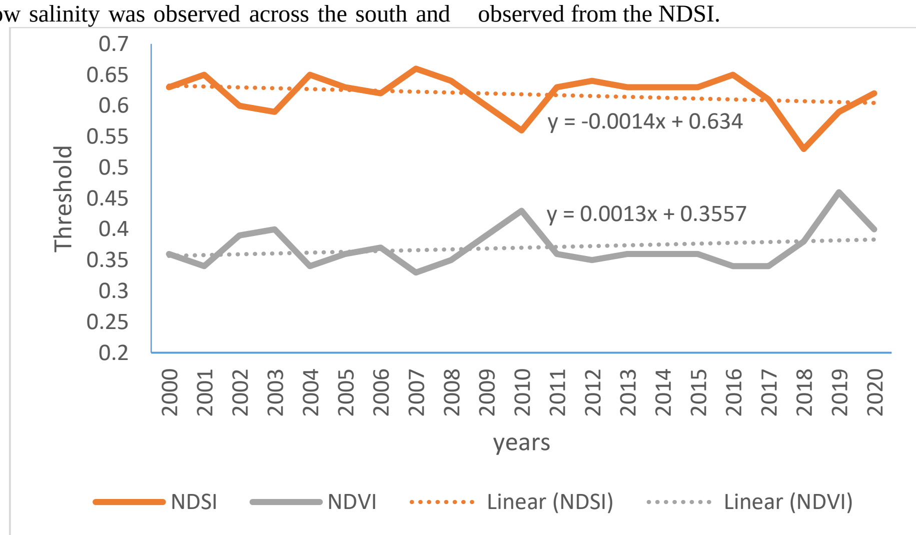

Figure 4: Time Series of Salinity Changes
Source, author's analysis, 2021

CONCLUSION

The spatial variation of salinity level indicated low salinity, moderate salinity and high salinity. Moderate and high salinity threats were found 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, trend analysis shows a decrease in salinity 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 outweighs that of the dense vegetation cover, which shows the implications of salinity on the vegetation. However, positive changes occurred over the recent decades, which increases the density and health of the vegetation cover.

RECOMMENDATIONS

More models should be developed by researchers to consider other possible factors that may trigger salinity on soils such as soil forming factors, land use and other human interventions, as well as to enhance the prediction and monitoring of further salinity implications. There should be proper awareness of 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 to reduce the rate and implications of salinity on soils.

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