

Geospatial analysis of coastal flooding effect on soil and vegetation in Ilaje local government area of Ondo State, Nigeria

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Abstract

Soil salinity is believed to be mainly responsible for low land use as well as agricultural productivity in coastal regions of the world. The entire coastal areas of Ondo State is affected by coastal flooding which causes salt water to inundate the top and impregnates them with soluble salts, thereby rendering the soils and subsoils water saline. This study applied a Geo-information technique not only to identify and analyze floodable areas but also to access the salinity of soil and vegetation changes for a period of twenty six years (26yrs). Random sampling method was used for soil samples. The data were integrated in a digitally Geo-referenced framework that enabled better understanding and knowledge of the problem. The result of the soil analysis shows elevated concentrations of the salt which exceeded the normal plant tolerant levels. The result of the salinity indicates that 63.34% of the study area is strongly affected by saline waters while 36.5% shows slight salinity. Soil salt levels in the coastal areas range from 8.0 to 48 ds/m. From 1986 to 2012 the vegetation index has dropped from +1 to less than -1 which indicates that the health of the vegetation is seriously stressed and depreciating.

Keywords: Coastal Flooding, Coastal Intrusion, Salinity, Remote Sensing, Geographic Information Systems

Resume

La salinité du sol est considéré comme le principal responsable de l'utilisation des terres à faible ainsi que la productivité agricole dans les régions côtières du monde. Les zones côtières de l'État d'Ondo sont enierement affectées par les inondations côtières qui causent l'eau salée d'inonder le haut et les imprègne de sels solubles, ce qui rend le sol et le sous-sol de l'eau saline. Cette étude a appliqué une technique de géo-information non seulement à identifier et analyser les zones

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inondables, mais aussi d'accéder à la salinité des sols et des changements de la végétation pour une période de vingt-six ans (26yrs). Méthode d'échantillonnage aléatoire a été utilisée pour des échantillons de sol. Les données ont été intégrées dans un cadre numérique géoréférencée qui a permis une meilleure compréhension et connaissance du problème. Le résultat de l'analyse du sol présente des concentrations élevées de sel qui a dépassé le niveau de tolérance des plantes normales. Le résultat de la salinité indique que 63,34% de la zone d'étude est fortement influencée par les eaux salines tandis que 36,5% indique une salinité légère. La teneur en sel des sols dans les zones côtières vont de 8,0 à 48 ds / m. De 1986 à 2012 l'indice de végétation est passé de 1 à moins de -1, ce qui indique que la santé de la végétation est sérieusement stressé et déprécié.

Mots clés : Les inondations côtières, systèmes d'information géographique intrusion côtière, de la salinité, de la télédétection,

Introduction

Coastal lowlands throughout the world are under increasing development pressures as evidenced by continued clearing of mangroves and draining of wetlands (White *et al.*, 1999). Globally, coastal wetlands and ecosystems are increasingly threatened by increased flooding, erosion and associated degradation of the coastal environment. Inundation arising from the rise in sea level will increase the intensity of coastal flooding which will affect rural communities' livelihood in the creeks, lagoon, estuaries and freshwater banks. The intrusion of salt-water into fresh water sources and ecosystems, due to sea level rise will destroy stabilizing systems as mangroves, and affect other sectors like agriculture, fisheries among others (Okali and Eleri, 2004). This prolonged inundation of seawater after flooding can also cause salination of agriculturally productive soils thus resulting in loss of productivity for long periods of time (Benavente *et al.*, 2006). Nicholls (2002) pointed out that food crops and forests can be completely killed off by salination of soils or wiped out by the movement of flood waters.

Coastal flooding is largely a natural event, however human influence on the coastal environment can exacerbate coastal flooding (Ramsay and Bell, 2008; Nicholls, 2002; Griffis, 2007), Dawson *et al.*, 2009). This flooding affects land by ocean waters or river catchment and this is referred to as coastal inundation (DPCD, 2012). It is caused by a

combination of high water levels, due to tides and storm surges and waves which can lead to overtopping of coastal defences and inundation of low-lying areas, thereby causing damage to life and property. Waves and storm surges are caused by storm events with high winds blowing over the adjacent sea. In some areas like deltas and estuaries, heavy precipitations leads to river flow and also contribute to coastal flooding. Tsunamis, landslides, volcanic eruptions and meteorites are also important causal factors in coastal flooding in some parts of the world, notably the islands of the Pacific Rim (Abe, 1979). The frequency, extent and magnitude of coastal and river inundation is likely to be altered by climate change over time and through the combined interactions with sea level rise, tide ranges, storm surges and other coastal processes (DPCD, 2012).

Coastal flooding causes coastal freshwater bodies including lakes, lagoons and coastal fresh water aquifers to be affected by salt intrusion (Gallien *et al.*, 2011; Hunt and Watkiss, 2011) thereby this salt water inundate the soils and impregnates them with soluble salts rendering the soils and subsoil water saline. Salinity causes unfavorable environment and hydrological situation that restricts normal crop production. In general, soil salinity is believed to be mainly responsible for low land use as well as crop intensity (Rahman and Ahsan, 2001). The freshly deposited alluvium from upstream in the coastal areas of Ondo State becomes saline as it comes in contact with the sea water and continues to be inundated during high tides and ingress of sea water through creeks. It is argued that coastal flooding associated with sea level rise will become a significant issue into the next 100 years especially as human populations continue to grow and occupy the coastal zone (Nicholls *et al.*, 2007). Various researchers have identified the problems associated with salt intrusion into the soil due to flooding but little attention has being given to know the level of intrusion and the major damages caused by this intrusion into soil and effect on vegetation for over a period of time. This paper explores and examines coastal flooding and its implications on soil and vegetal landcover. The paper maps the floodable areas and extent of saltwater incursion on the land surface in Ilaje Local Government Area (LGA), Ondo State, Nigeria, coastal areas and determines the effects of coastal flooding on vegetable land cover from 1986 to 2012.

Study area

Ilaje Local Government Area, Ondo State, Nigeria is located between latitude $4^{\circ} 34' 21''$. 339E and longitude $6^{\circ} 36' 45''$ 791N and $5^{\circ} 4' 45''$. 035E and $5^{\circ} 57' 12''$. 369N as shown in (Figure 1). It consists of over four

hundred towns and villages, covering an area of 3, 000 square kilometers. It shares boundary in the west with Ogun State, in the east with Delta State in the north with Okitipupa Local Government, bounded and with the Atlantic Ocean in the south. It is covered by undulating low land surfaces. The extreme south of the LGA is covered by silt, and mud and superficial sedimentary deposits.

There is sand formation on the western part of the Local Government extending from the Lekki peninsula in Lagos State to Araromi Seaside and Zion Lepe, Agba to Etugbo and Ipore all, Mahin and Ugbonla. Ilaje Local Government is the largest local Government in Ondo State in terms of its land mass. It has a shoreline covering about 180km thereby making it the LGA with the longest coastline in Nigeria which favors fishing activities in the coastal areas.

Ilaje Local Government is predominantly an agrarian community with over 60% of its labour force deriving their income from farming. The LGA is richly blessed with varied and favorable ecological and climatological conditions with vegetation ranging from mangrove swamps of the southern coastal riverine areas through the rainforest of the midlands, thus making it suitable to support the cultivation of a large variety of crops.

Data and Methodology

Data

Primary and secondary data used for this study are as discussed below.

The primary data includes the field points, soil samples, field observations

Secondary Data includes the satellite imageries (Landsat and Shuttle Radar Topography Mission (SRTM)) and topographic maps.

Soil Sample

An 18km by 12km grid was generated over the study area; and using the ESRI ArcGIS package, 20 random points were generated. Soil samples from these randomly generated point locations were collected to 15 centimetre depth using a soil auger and a ruler to check the depth. In the laboratory, the soil samples were tested for salt content, water holding capacity and soil particle size was determined to gather salinity information.

Satellite Dataset and Flood Height Information

Flood height data derived from The Shuttle Radar Topography Mission (SRTM) were obtained from the Regional Centre for Training in Aerospace Surveys (RECTAS) covering majorly the month of July 2011. This is needed to show the flood level for the different years considered in the study.

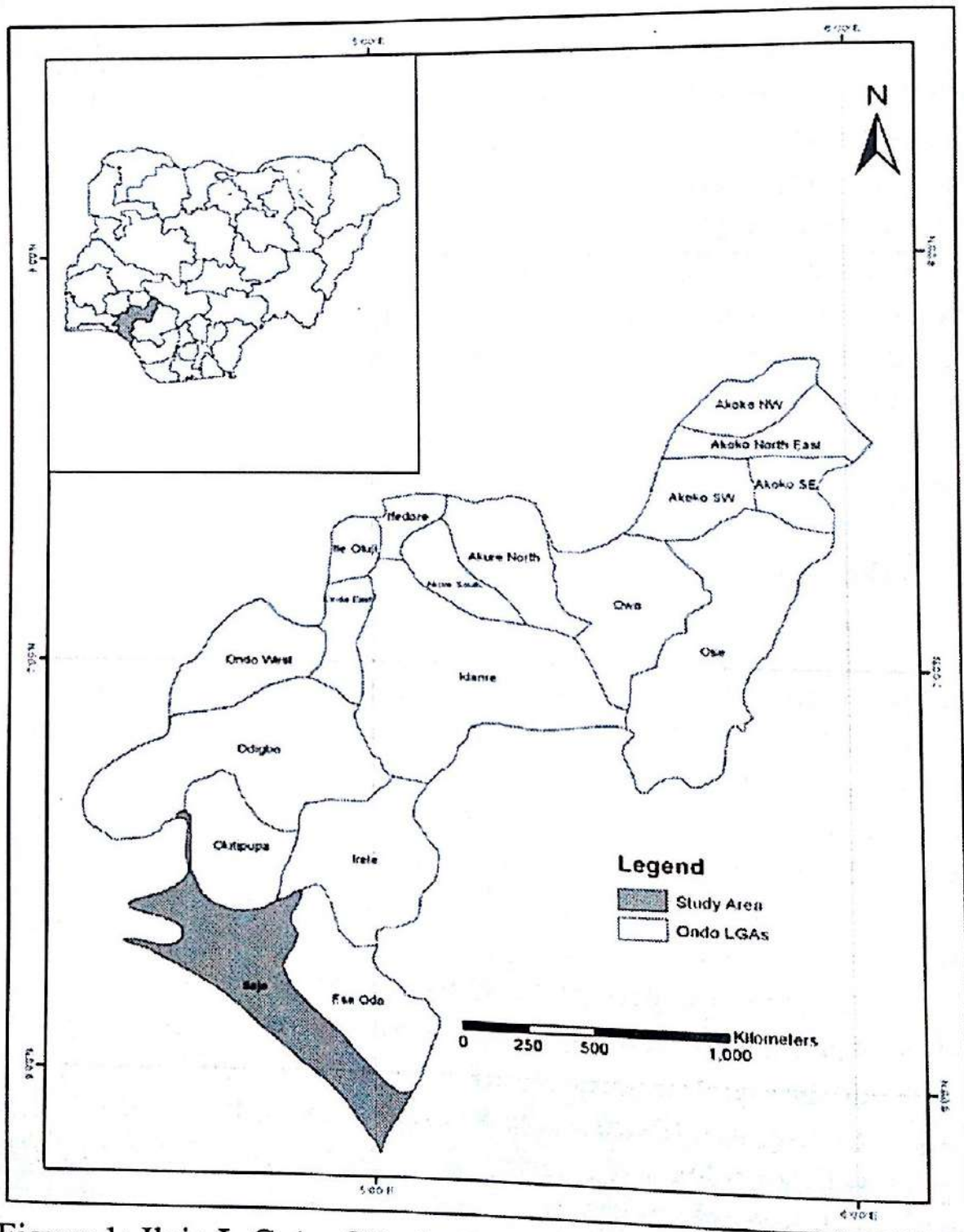


Figure 1: Ilaje L.G.A of Ondo State

Satellite imagery covering the study area were also extracted from (path/row: 190/ 56) Land sat series TM and ETM+ satellite images of 18th December 1986, 2000, 2005 and 2012 in UTM Projection Zone31, Datum WGS84 as shown in Table 1

Table 1: Satellite Dataset

	Date acquired	No of bands	Spatial resolution (m)	Format	source	Cost
Landsat TM	12/18/1986	7	Thermal= 120m, optical =30	tiff	www.glcfa pp.glfcd.edu	free
Landsat ETM+	2/6/2000 2/6/2005 2/6/2012	9	Thermal= 60m, optical = 30 Pan = 15	tiff	www.glcfa pp.glfcd.edu	Free

Series of analysis were performed on the Landsat images, SRTM 90m DEM, interpolation of soil samples and flood data to generate salinity and flood surface maps and detection of changes in vegetal land cover in the study area. Using suitable software like Idrisi Selva software t geometric corrections, image preparations and classifications of the images were carried out. ArcGIS software was used to digitize plot GPS point locations of the soil samples, carry out geo-statistical and Spatial interpolation analysis.

Analysis

The satellite images were re-sampled using the nearest neighbor module of the Idrisi selva software. The 1986 Landsat TM 120m resolution image was re-sampled to a resolution of 30m. Bands 5, 4 and 3 were combined to create a false color composite to enhance visual image interpretation. The bands 3 and 4 were used to calculate the normalized difference vegetation index (NDVI). This was used to determine the health of the vegetation and the extent to which it has been affected by the saltwater intrusion.

Normalized Difference Vegetation Index (NDVI)

NDVI is an important factor in flood risk analysis and the technique that is used for analyzing the response of vegetation cover to flooding characteristics (Kwak and Kondoh, 2008). The NDVI is calculated from two bands in the Landsat images, the near infra-red (NIR) band (band 4) and the red band (band 3). The NDVI takes advantage of the features of these two bands, that is, the high reflectance for plant materials of the NIR band and the chlorophyll pigment absorption of the red band to produce an image that presents greenness or relative biomass (Kwak and Kondoh, 2008; ESRI, 2010). It was calculated in the raster calculator using the formula:

$$\text{NDVI} = \text{float}(\text{NIR} - \text{RED}) / \text{float}(\text{NIR} + \text{RED})$$

NDVI was calculated for 1986 Landsat TM and 2000, 2005 and 2012 Landsat 7 ETM+ images. The results of the NDVI calculation was reclassified into three categories: 'Large Change' for areas with negative NDVI values, 'No Change' for areas with positive NDVI values and 'Small Change' for very small negative and positive values. This analysis was carried out to show the changes that have occurred in the flooded areas over a period of 12 years.

The soil analysis entailed tying each soil sample collected randomly to the GPS locations; it was then integrated into the GIS environment where spatial interpolation analysis was carried out. This was to show the level of salinity. See figure 2

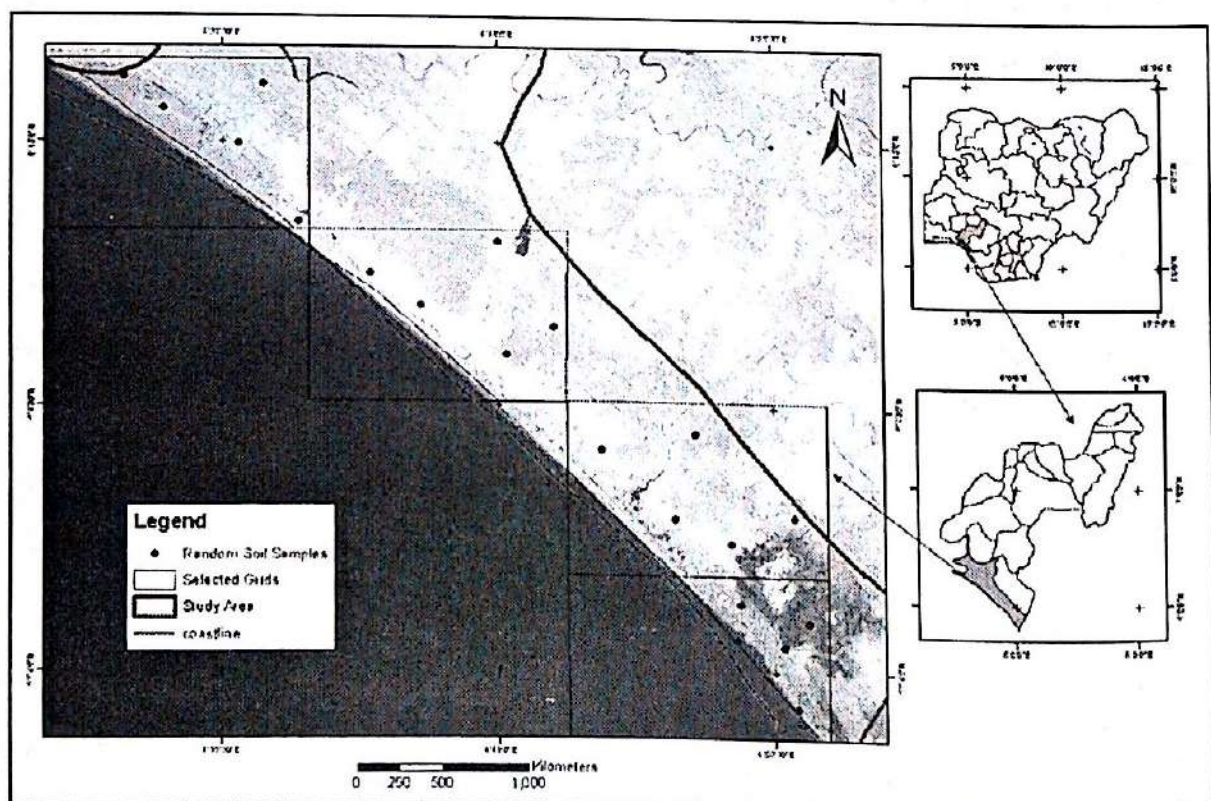


Figure 2: Soil Sample Points (Random Sampling)

Results and Discussion

Floodable Areas and the Extent of Saltwater Intrusion

Physical examination proved effective in quick elementary diagnosis of the disease as skin symptoms cannot be hidden. Table 2 show the age ranges and villages from which observed respondents came from. A total of 50 primary school students spread over 20 households from villages in the study area were chosen for the exercise. The main school in the area Baptist Day Primary school was sampled.

The first objective is to map the floodable areas and the extent of saltwater intrusion on the land in the study area. This will determine the areas that are highly floodable in relation to the surface elevation and the height of the flood. The maximum flood height reading for the month of July 2011 (see Table 2.) was used because it had the highest rainfall and highest flood height records to classify the SRTM elevation data into three classes (-3 to less than 2meters), (2meters to less than 3meters) and (>3meters), based on the maximum flood gauge readings which was 2.4meters. The Surface analysis extension was used to generate a flood surface model using the elevation data above 3meters as a barrier.

Table 2: Flood Gauge Data for the month of July 2011

Month	POINT_X	POINT_Y	Flood height
July	4.627825	6.235320	0.90
	4.546088	6.284732	0.60
	4.747665	6.124140	1.10
	4.831940	6.046781	0.70
	4.881825	5.998799	0.60
	4.978323	5.890799	1.70
	4.627825	6.235320	2.40
	4.546088	6.284732	2.30
	4.747665	6.124140	2.60
	4.831940	6.046781	2.10
	4.881825	5.998799	2.40
	4.978323	5.890799	2.00

Source: 2011 RECTAS/START project

elevation above 3metres which shows high correlate between flood elevation levels.

Saline soils contain large amounts of water soluble salts that inhibit seed germination and plant growth. The salts are white, chemically neutral, and include chlorides, sulfates, carbonates and sometimes nitrates of calcium, magnesium, sodium and potassium. Yields of most crops are not significantly affected where salt levels are 0 to 2 dS/m. Generally, a level of 2 to 4 dS/m affects some crops. Levels of 4 to 5 dS/m affect many crops and above 8 dS/m affect all but the very tolerant crops (Cardon, Davis, Bauder, & Waskom, 2007) see Table 3. The salinity of the 20 collected soil samples were interpolated using an Inverse Distance Weighted (IDW) technique To generate salinity map with different salinity classes (Figure 4). The result indicates that 63.34% of the study area is classified as strongly to extremely saline areas, whereas, 36.65% have been classified as slight to moderate saline areas. An overlay operation was carried out using the floodable areas and the salinity map. It was observed that areas that were highly floodable had high salinity and medium and low floodable areas had low salinity level (Figure 5).

Table 3: Outline of the indicators for various ranges of soil salinity

Severity of salinity	Non-saline	Low Moderate	Moderate	High	Severe
Indicators	Most plants unaffected. Uniform "healthy" plant growth. Water logging, if occurs, is not caused by a rising water table.	Sensitive plants affected. Reduced vigour of annual legumes. Some grain legumes affected. Cereals generally not affected. Most horticultural crops affected.	Sensitive plants affected. Reduced vigour of annual legumes. Some grain legumes affected. Cereals generally not affected. Most horticultural crops affected.	Tolerant plants affected. Annual legumes absent. Barley and cereal rye affected. Sea barley grass often dominates. Small bare areas present. Trees may be dying.	Only suitable for highly tolerant plants. Areas of bare ground. Salt crystals occur in summer. Water logging is common. Trees dead or dying.
Approx. soil salinity, ECe (dS/m)	0-2	2-4	4-8	8-16	>16

Source: FactSheet of Primary Industrial and Resources SA

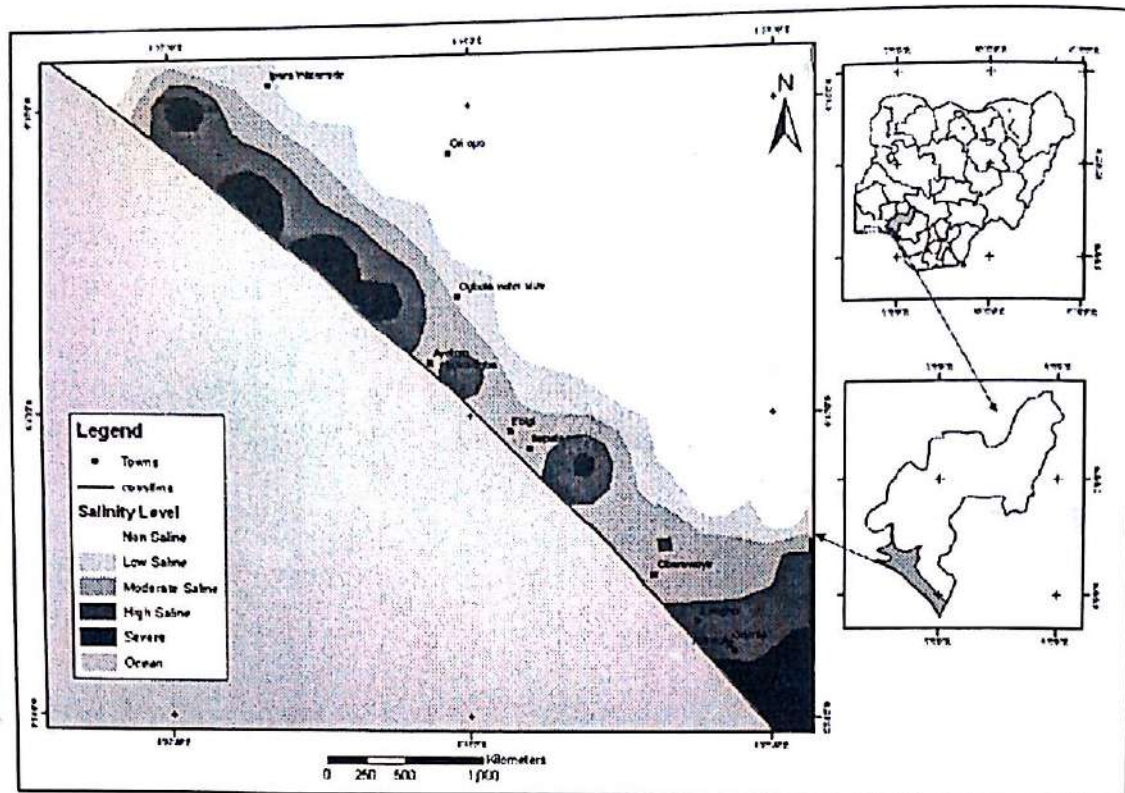


Figure 5: Soil Salinity Classes

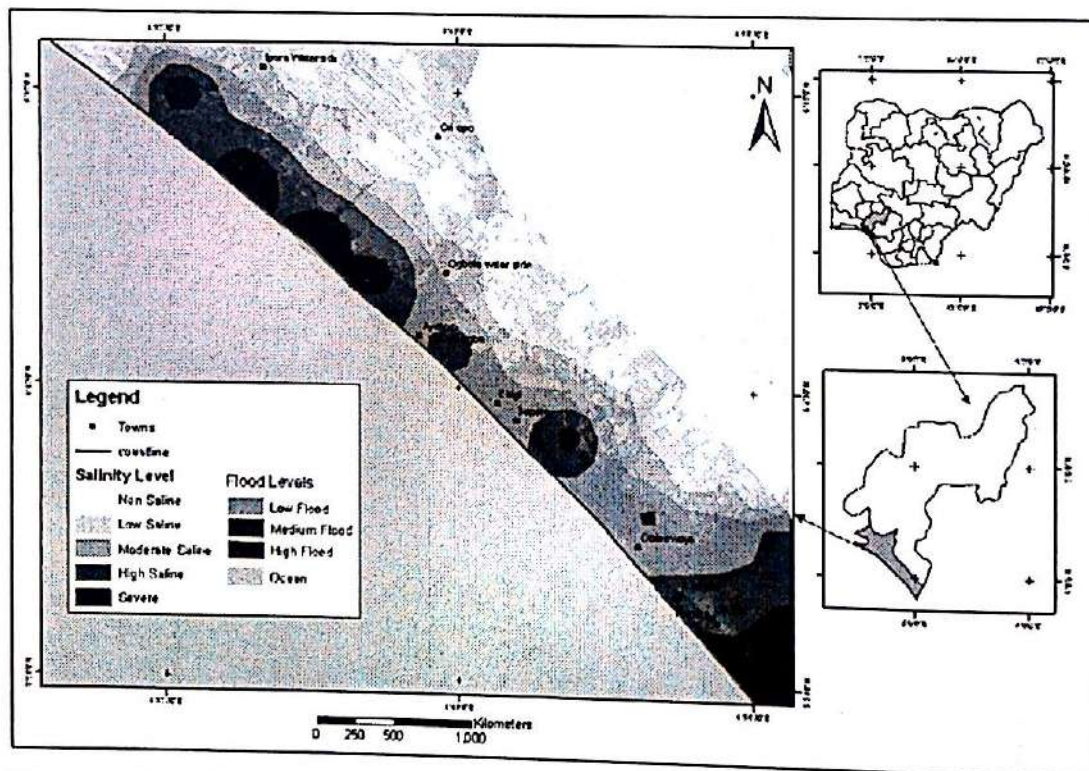
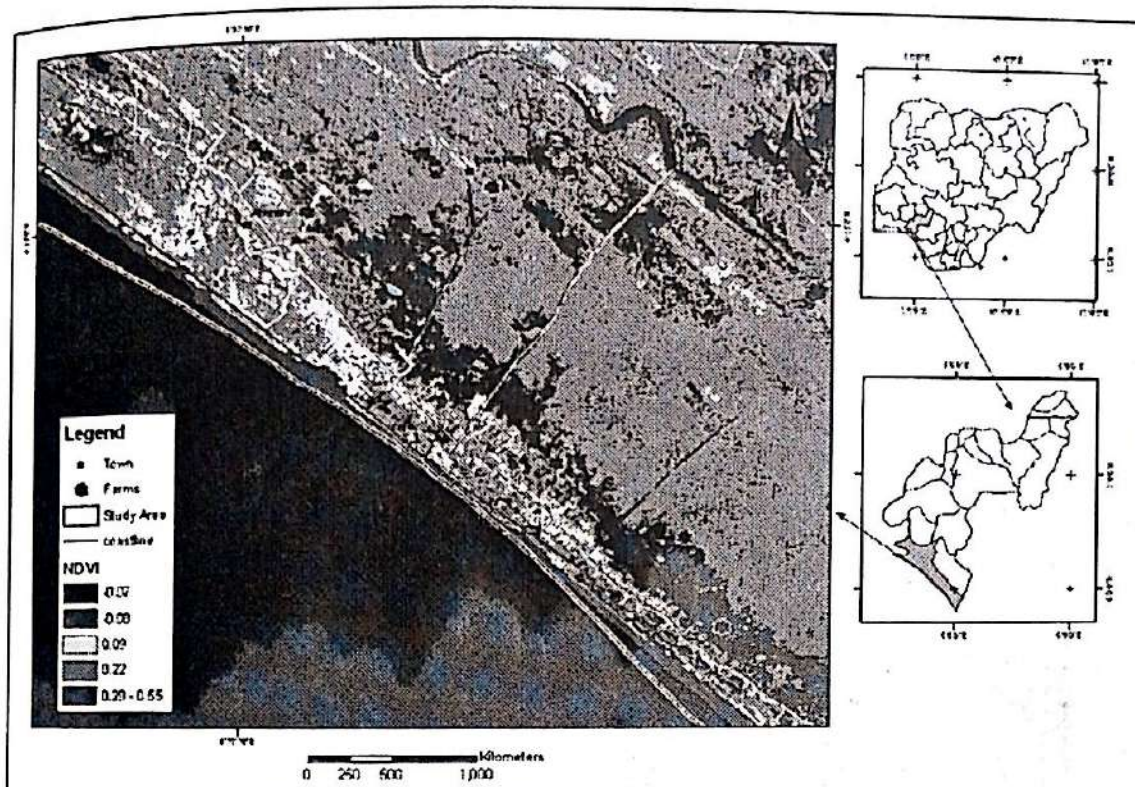


Figure 6: Salinity surface and Floodable Areas

Effects of Salt Water Intrusion on Vegetal Land Cover

The second objective is to determine the effects of salt water intrusion on vegetal land cover over the last 26 years. NDVI was used to check the presence and condition of vegetation in the area for four time periods (1986, 2000, 2005, and 2012) based on the formula given in the

methodology. The essence of this was to know if the extent of salt water inundation affected the growth, density and health of vegetation within the study area. The results from this analysis are illustrated below.



From the above NDVI histogram (Figure 8) for the year 1986, the vegetation along the coast yields values ranging 0.09 to 0.22, while the vegetation 2km and above from the coastline yielded values ranging from 0.22 to 1.0. Water bodies have the lowest values ranging from -0.7 to 0.9. These values indicate that vegetation that is about 2km to the coastline is healthy and has not been affected by salt water.

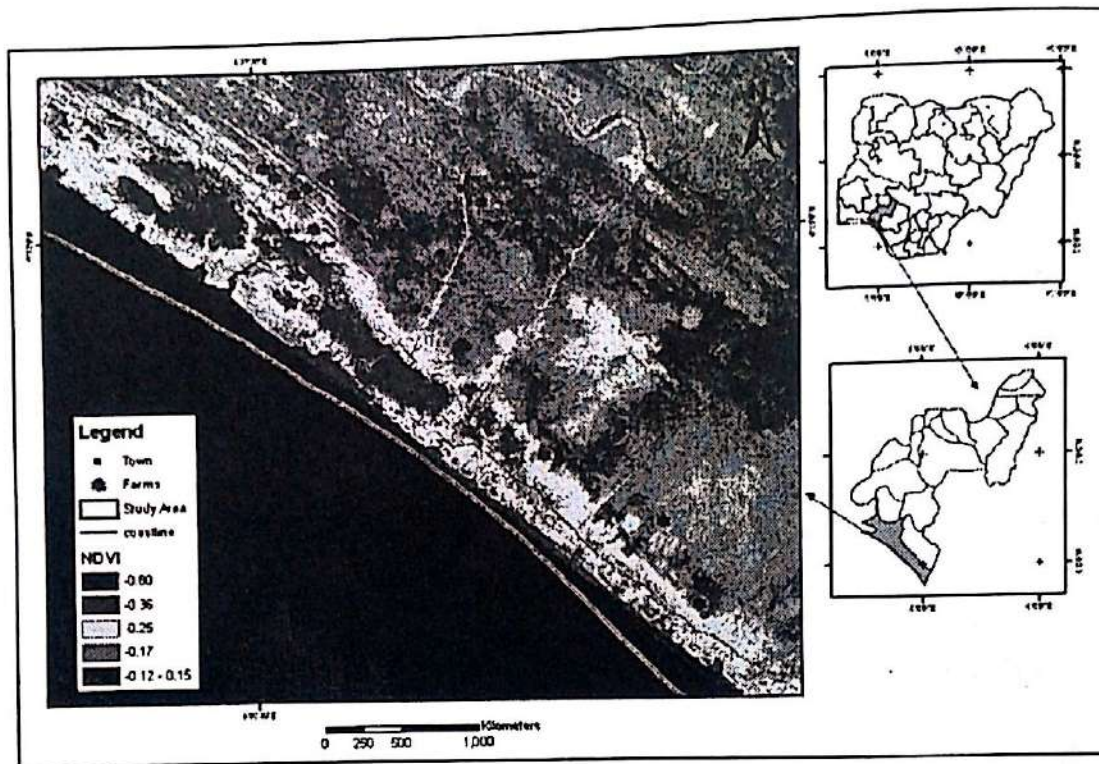


Figure 9: NDVI 2000

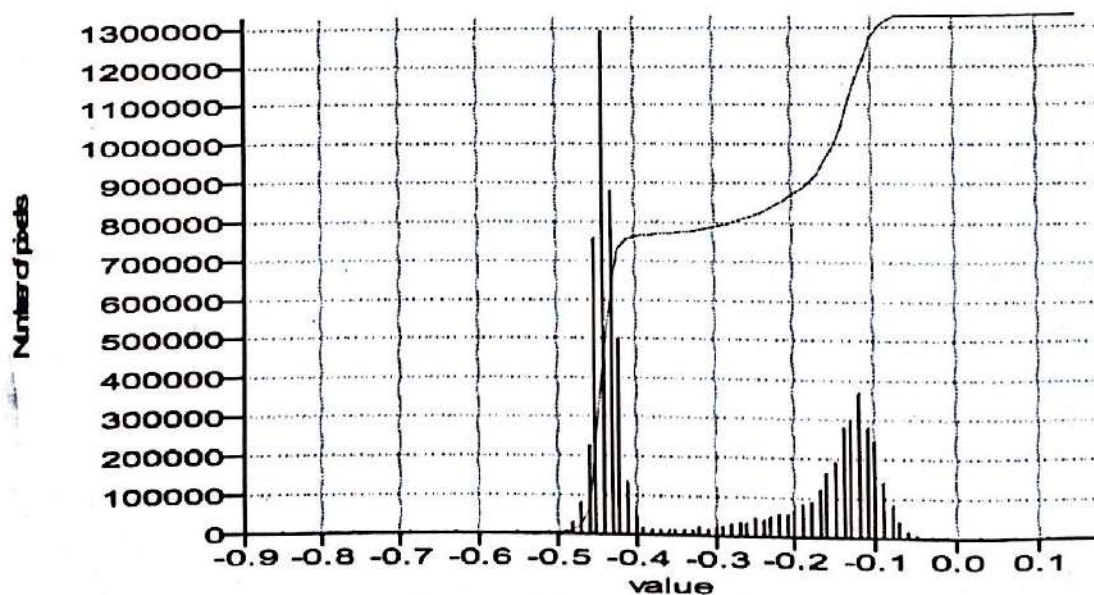


Figure 10: Histogram NDVI 2000

From the above NDVI histogram for the year 2000, vegetation along the coast yields value ranging -0.2 to -0.17, while the vegetation 2km away from the coastline yielded values ranging from -0.17 to -0.1. Water bodies has the lowest values ranging from -0.9 to 0.0-0.2. These values

indicate that there is a drop in the health of vegetation from 0.22 to -0.2 along the coastline and 0.1 to -0.1 2km away from the coastline. The results further indicate that the vegetation is gradually being affected by salt water inundation.

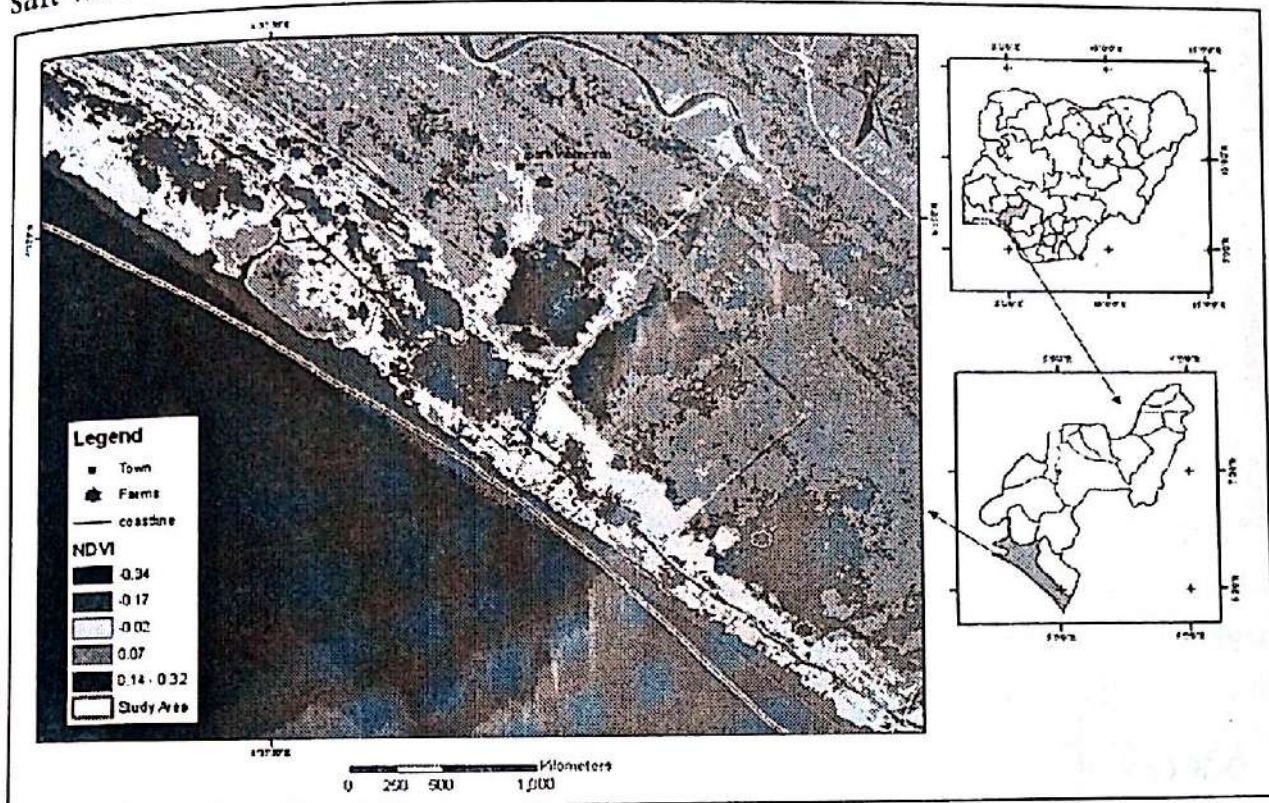


Figure 11: NDVI 2005

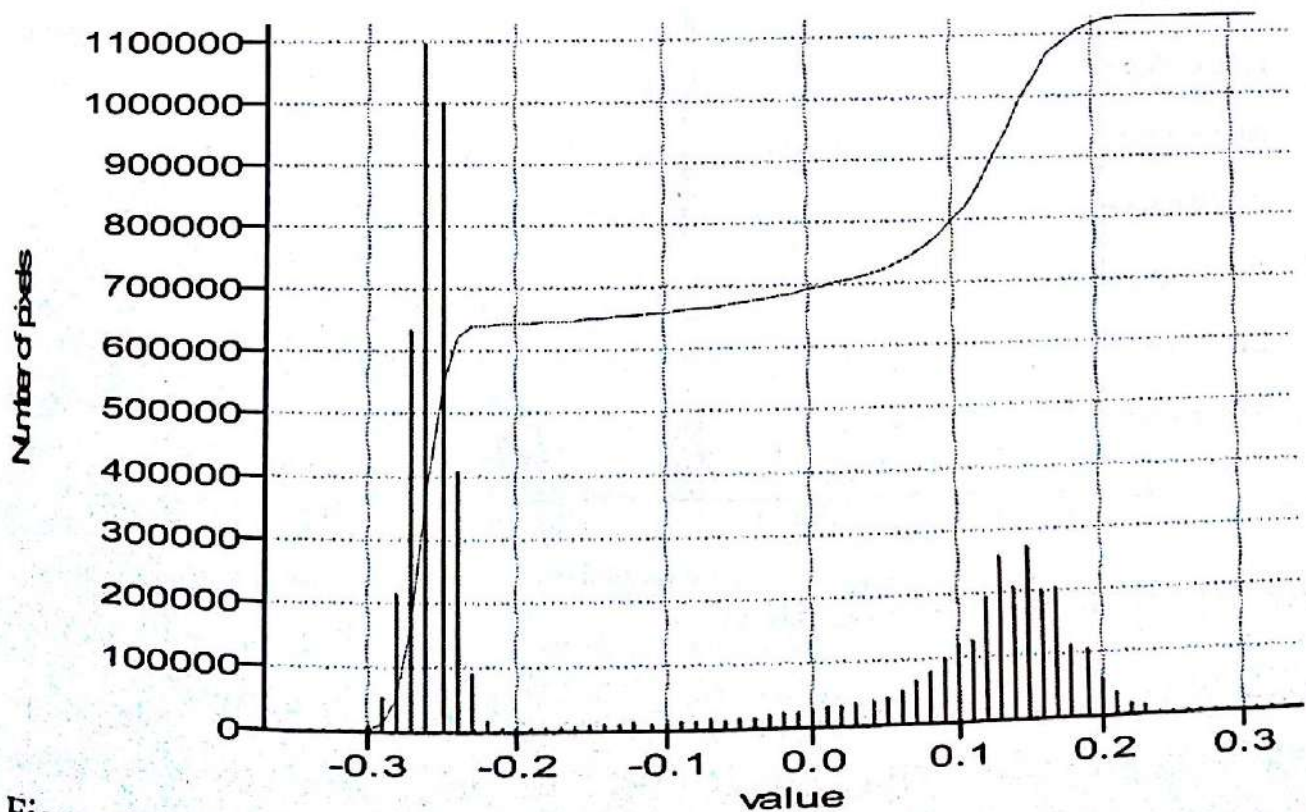


Figure 12: Histogram NDVI 2005

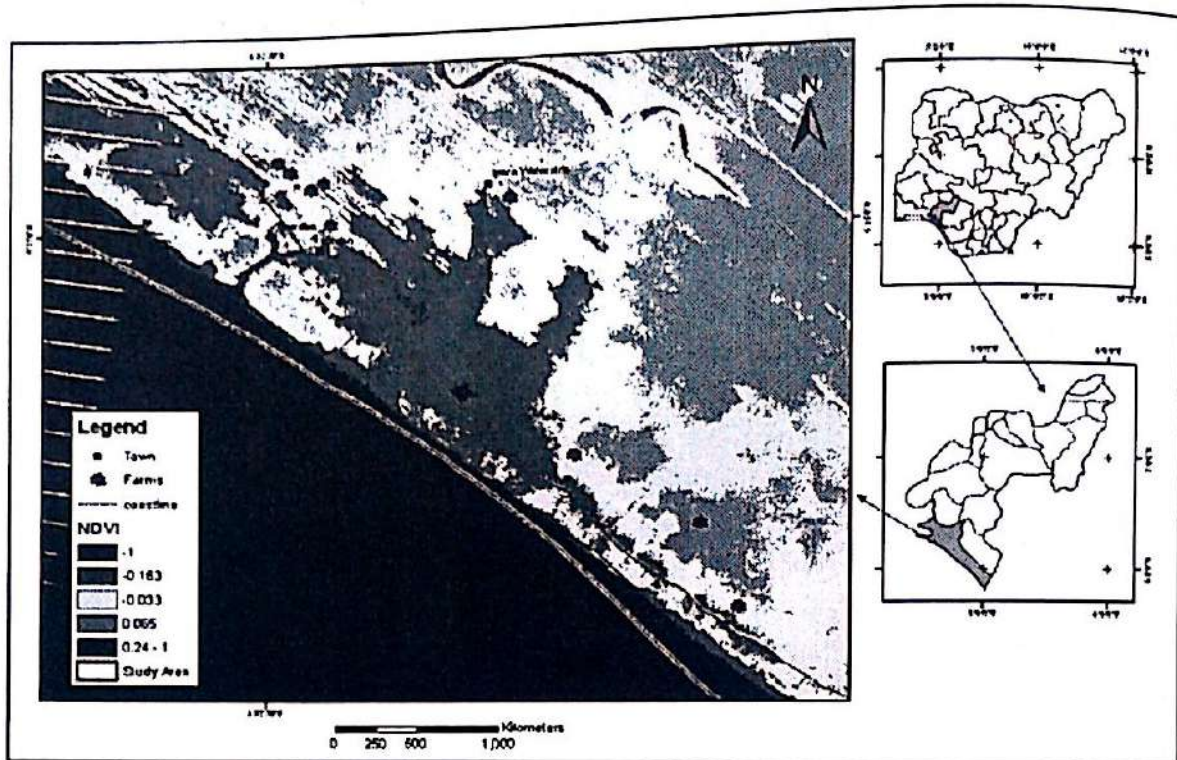


Figure 13: NDVI 2012

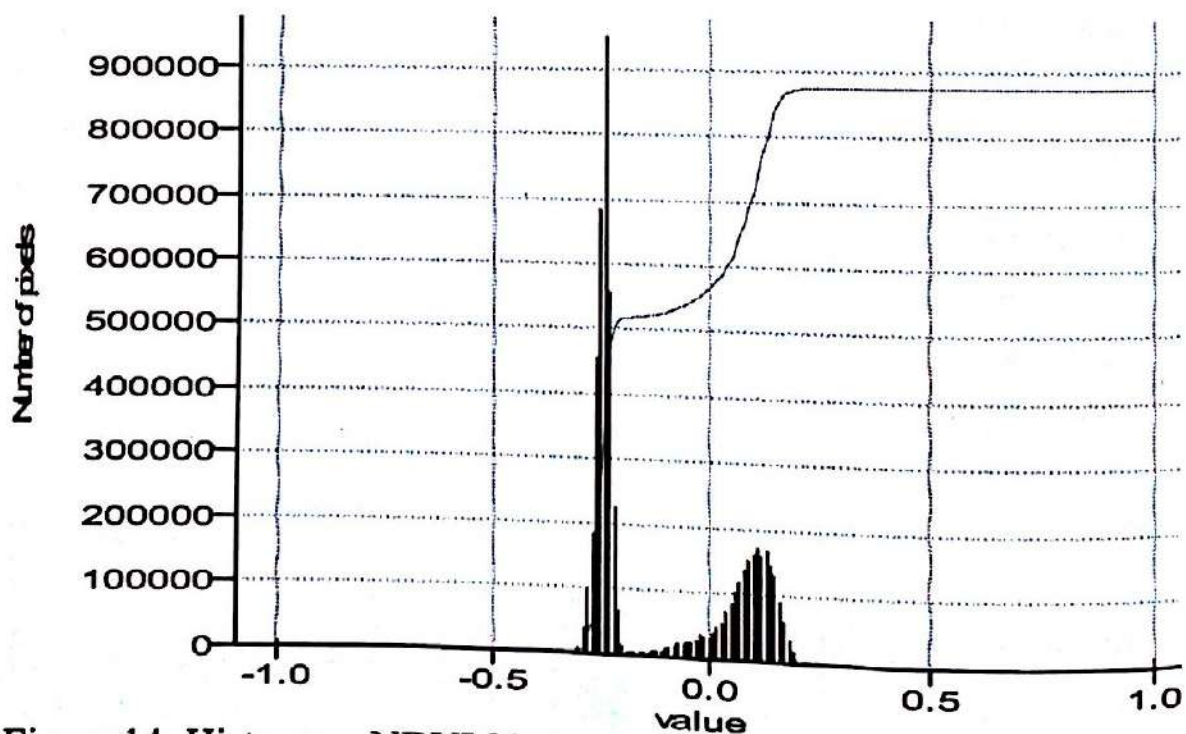


Figure 14: Histogram NDVI 2012

From the above NDVI histogram for year 2005 and 2012, vegetation along the coast yields values ranging (-0.2 to -0.17), while the vegetation 2km away from the coastline yielded values ranging from (-0.17 to -0.1). Water bodies has the lowest values ranging from -0.9 to -0.2. These values indicate that there is a drop in the health of vegetation from (0.22 to -0.2) along the coastline and (0.1 to -0.1) 2km away from the coastline. The results further indicate that the vegetation is gradually being affected

by salt water inundation. From 1986 to 2012 the vegetation index dropped from +1 to less than -1 which indicates that the health of the vegetation is seriously stressed and depreciating.

Conclusion

The result of the soil analysis carried out in this research for the coastal areas of Ondo State (Ilaje LGA), showed elevated concentrations of the salt which exceeded the normal plant tolerant levels. Salt is of essential importance for plant growth, but can cause harm to plant when in excess. Crops grown on saline soil may suffer from leaf loss, retarded growth and translocation of iron in plant. Remote Sensing and GIS has proven a remarkable method in identifying, analyzing floodable areas and accessing salinity of soil, vegetation changes over time. There is need for mitigation and sustainable control of floodable areas to combat the negative impact on the soil and vegetation on the coastal communities located there. Adequate measures and timely predictions need to be carried out to know the extent of impact and suggest best practices to protect the soil and vegetation around the coastal areas. The populace around such a coastal flooding area should be advised to relocate far from the reoccurring coastal flood disaster.

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