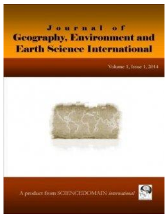

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Flood Vulnerability Assessment in Ilaje, Ondo State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OOA designed the study, managed the literature searches, wrote the protocol, managed the analyses of the study. Author OA performed the geospatial and statistical analysis and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Flood as a natural disaster has been described as a phenomenon which is a part of earth's bio-physical processes, which can be devastating due to anthropogenic activities and climatological factors. The study assessed the land use land cover changes (LULCC), assessed the surface temperature changes and evaluated the flood vulnerability level in the study area between 1986 and 2015 using geospatial techniques.
Supervised classification, using maximum likelihood algorithm, was employed for LULC, mono-window algorithm method was adopted in the study to retrieve the Land Surface Temperature (LST) from the imageries selected for this study and sea level rise and storm surge scenario was modelled at different flood heights.
The result showed changes in LULC characteristics, mean ± standard deviations of 22.0°C ± 0.71; 31.12°C ± 0.81; and 24.6°C ± 0.86 were recorded in 1986, 1999 and 2015 respectively in the study area. Higher LST values were however observed in most built-up and bare surfaces than other land

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use land cover classes while at projected 2, 4 and 6 meters rise, it is expected that 6.56% of the total surface area of the study area will be highly vulnerable to flooding.
It is therefore established that the area is exposed to flooding due to uncontrolled human activities causing climate change which is evident in the land surface temperature values derived and the Land use Land Cover Changes in the study.

Keywords: Land surface parameters; flood; GIS; LULCC; LST.

1. INTRODUCTION

The advancement in the concept of geospatial mapping has greatly increased research on land use land cover change thus providing an accurate evaluation of the spread and health of the world's forest, grassland, water bodies and other resources, and as well helped in understanding the pattern of which has become an important priority. Remote sensing is the science of acquiring information about the Earth using remote instruments such as satellites, is inherently useful for disaster management [1-2]. Satellites offer accurate, frequent and almost instantaneous data over large areas anywhere in the world [3-5]. Flooding, as a natural disaster, has been described as a phenomenon which is a part of earth's bio-physical processes, which can be devastating due to anthropogenic activities and climatological factors [6].

Climatic change, population increase, rapid urbanization among other natural and anthropogenic activities has had a great influence on the environment [7]. Increase in temperature, change in salinity regime, and increased precipitation, sea level rise and storm events are some of the major challenges attributable to environmental change [8]. However, in the past four decades, economic losses due to natural hazards such as flood disasters, global warming, and drought among others; have increased in many folds and have also resulted in major loss of human lives and livelihoods, the destruction of economic and social infrastructure, as well as environmental damages [9]. Forecasting future changes, their impacts and implications for the environment and society require improved scientific understanding of past and present trends and of the inertia and feedbacks in both natural and human systems. There is thus a pressing need to focus the best scientific knowledge and the most advanced modeling and predictive tools on the overall global system hence the study. The aim of this study was to evaluate the consequence of environmental change in a typical coastal environment and the objectives were to assess the pattern of land use land cover change, examine the changes in land surface temperature pattern, and assess potential situation of sea level rise and coastal surges, at projected flood height extent in the study area.

2. METHODOLOGY

2.1 Study Area

The study area is Ilaje Local Government Area, Ondo State, Southwestern Nigeria. Ilaje Local Government Area is a coastal settlement which lies within 4.349948° and 5.149688° East of the Greenwich meridian and 5.842676° and 6.682662° North of the Equator (Fig.1.) and covers an area of three thousand square kilometers. The study area is bounded in the North by Okitipupa local government area, East by Irele and Ese Odo LGAs, South by Warri North in Delta State and west by the Atlantic Ocean.

2.2 Demography and Land Use

The population of the study area, Ilaje local government of Ondo state, is projected to be 350,000 people [10]. Igbokoda, Ode-Ugbo, Ugbonla, Ayetoro, Ode-Mahin and Ode-Etikan are the major settlements in this area with Yoruba being the major tribe. Fishing and plant farming are the main preoccupation of inhabitants of the study area. These activities also serve as the predominant economic activities in the area, with over 60% of the working-age deriving their income from it. However, this reflects on their pattern of land use. The major land use types are broad, and these include non-agricultural land, swamps, forest reserves, exotic plantations, tree crop land and arable land. The non-agricultural land is made up of built-up areas, rocks or lateritic outcrops and bare lands. In the urban centers, construction of roads, buildings, factories, manufacturing plants, bridges and culverts, farmlands and others have reduced drainage channels and erosion passages and or diverted the natural courses of others.

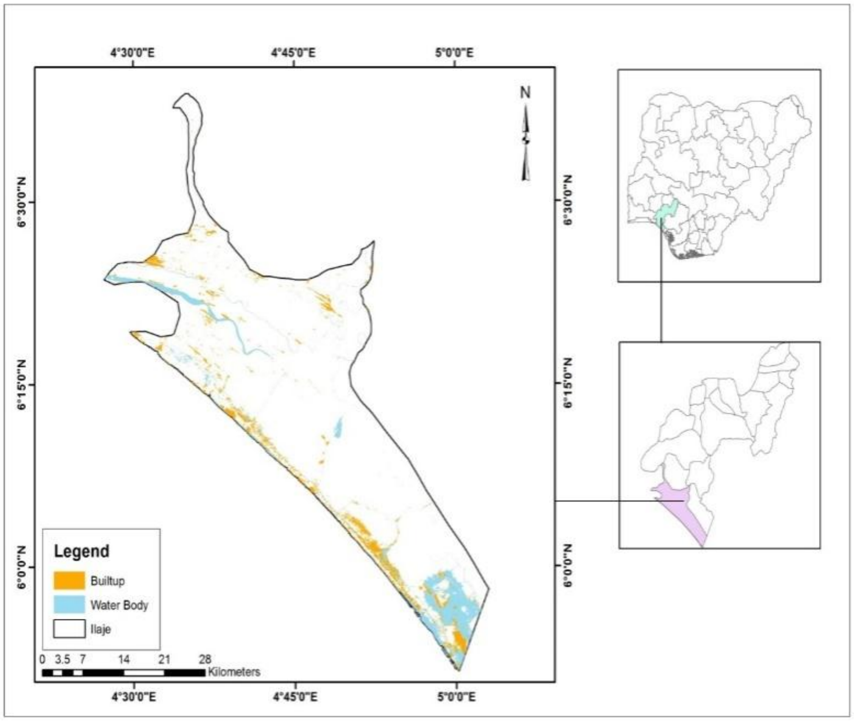


Figure 1. Ilaje, Ondo state, Nigeria

The sources of data for this study are secondary. Satellite imageries covering the spatial extent of the study area were used for this study. Respective imageries (Table 1) from the various Landsat sensors were used for the estimation of land use land cover classes and land surface temperature retrieval. The Digital Elevation Model (DEM) of the study area was retrieved from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) image, from which sea level rise scenarios were modelled. These data were sourced from the archive of the United State Geological Survey (USGS). Due to the position of the study area, within the tropical rainforest, and its proximity to a large river (Lower Niger River), cloud cover is least recorded during the peak of dry seasons, and thus, this informed the choice of period within which data for this study were acquired.

The imageries were firstly preprocessed for geometric rectification. The image bands used for this study were geometrically rectified to Geographic Coordinate System; WGS_84_UTM Zone 32N with an angular unit of 0.0174532925199433°. Atmospheric corrections, contrast stretching, histogram equalization and spatial filtering were as well carried out to improve the spectral information of the bands.

2.3 Image Preprocessing and LULC Classification

The imageries were firstly preprocessed for geometric rectification. The image bands used for this study were geometrically rectified to Geographic Coordinate System; WGS_84_UTM Zone 32N with an angular unit of 0.0174532925199433°. Atmospheric corrections, contrast stretching, histogram equalization and spatial filtering were as well carried out to improve the spectral information of the bands.

Image classification is defined as the extraction of distinct classes or themes; Land use and Land cover categories from Satellite Imagery. It is the process of assigning pixels to classes [11-12]. Image analysis and pattern recognition with image classification is an integral part of Remote Sensing. For this study, supervised classification, using maximum likelihood algorithm, was employed. The choice of this method is based on findings from several studies which have highlighted this technique as a better way of land use land cover classification. Swamps, Built-up areas, Vegetation, Water bodies and bare surfaces were identified across the study area.

2.4 Land Surface Temperature (LST) Retrieval

The mono-window algorithm method was adopted in this study to retrieve the LST from the imageries selected for this study. The following steps were followed in the retrieval of LST [13-14].

i. Conversion of Digital Number (DN) to AT Spectral Radiance

The digital numbers of the thermal band were converted into radiance values for each of the investigated years using the formula;

$$Radiance = L_{MIN} + \left(\frac{(L_{MAX} - L_{MIN})}{Q_{CALMAX} - Q_{CALMIN}} \right) \times (Q_{CAL} - Q_{CALMIN})$$

Where,

Radiance = (Watts / m2.ster.μm),

L_{MIN} = minimum spectral radiance at Q_{CAL}

L_{MAX} = maximum spectral radiance at Q_{CAL}

Q_{CALMAX} =255

Q_{CALMIN}= 0 (sometimes 1)

Q_{CAL} = Digital Number (DN)

ii. Conversion to AT Reflectance

$$R\lambda = \frac{\pi \times L\lambda \times d2}{ESun\lambda \times Sin(SE)}$$

Where,

$R\lambda$ =At surface reflectance

$L\lambda$ = Spectral radiance

π = 3.142 (constant)

$ESun\lambda$ = Sun elevation angle

$d2$ = earth-sun distance

iii. Conversion from Radiance to Brightness Temperature (in degree Celsius)

Thus, the thermal band radiance values were converted to a brightness temperature value using the Plancks's function Equation as;

$$T = \frac{K2}{In\left(\frac{K1}{L_\lambda} + 1\right)} - 272.3$$

Where;

T = Temperature [Celsius degree]
K1 = Calibration constant 1 [W/ (m^2sr μm)]
K2 = Calibration constant 2 [Kelvin]
In = Natural logarithm
L_λ = Spectral radiance at the sensor's aperture [W/ (m^2sr μm)]

iv. Estimation of Land Surface Emissivity (LSE)

In estimating LSE, Normalized Differential Vegetative Index (NDVI) was utilized for emissivity correction,

$$NDVI = \left(\frac{NIR - RED}{NIR + RED} \right)$$

LSE = $0.004Pv + 0.986$

Pv = $\left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right)^2$:

Where

Pv =Proportion of vegetation, and it can be derived from equation x
NIR = Near InfraRed Band
Red = Red Band
$NDVI_{min}$ = Minimum value of NDVI
$NDVI_{max}$ = Maximum value of NDVI

v. Estimating LST

$$LST = \frac{BT}{1 + w} \times \frac{BT}{p} \times In(e)$$

Where

BT = At-sensor brightness temperature
w = wavelength of emitted radiance

p = $h \times \frac{c}{s}(1.438 \times 10^{-2} mK)$

h = Plank's constant $(6.626 \times 10^{-34} Js)$

s = Boltzmann constant $(1.38 \times 10^{-23} J/K)$

c = velocity of light $(2.998 \times 10^{8} m/s)$

e = LSE

2.5 Digital Elevation Model (DEM)

The topography of the study area (Fig. 2.) was retrieved from Advance Space-borne Thermal Emission and Reflection (ASTER) imagery of a 30m resolution covering the area. The choice of

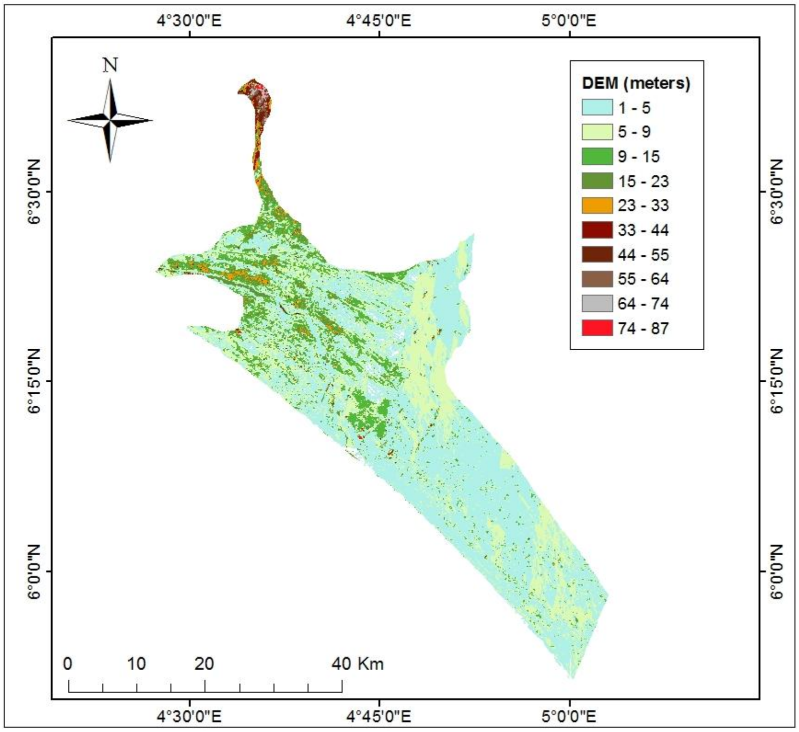


Figure 2. Topography of Ilaje

ASTER for this study is because a free data, covers a very large area and it's a relatively suitable substitute in cases where the required topographic information is not available. Also, ASTER DEM has been proven to be reliable for the delineation of flood-prone areas [15,8,16]. Recent studies have indicated that DEMs are dispensable in the visual and mathematical analysis of landscapes for hydrological models [17,8,18]. The purpose of DEM in this study is to have a basis for the estimation of areas vulnerable to flooding and coastal inundation because of their low surface elevation.

2.6 Scenario of Sea Level Rise, Coastal Surge, and Flood Inundation

Five scenarios were selected to represent the pattern of potential sea level rise, storm surge prediction and flood inundation in the study area. Normal wave height around the Gulf of Guinea range between 0.9 and 2 meters, while during storm surge event, wave height could exceed 4 m [19]. However, global sea level could rise to about 6 m by 2100 [20]. Based on these, this study modelled sea level rise and storm surge scenario of 0.5 m, 0.9 m, 2.0 m, 4.0 m and 6.0 m height. The scenarios represent reasonable estimates of low, medium, and high predictions of sea level rise for this region.

3. RESULTS

3.1 Land Use Land Cover Distribution

The study area covers an area of 146,681.73 hectares (Table 1). The land cover was classified into 5 categories; namely, water bodies, built-up areas, vegetation/agricultural lands, swamps and bare soil. The result of the spatial distribution of land use land cover categories in the study area between 1986 and 2015 are presented in Figures 3 (a, b, c). The land use land cover showed variations in characteristics between 1986 and 2015 (Table 3). An overview of land cover change between 1986 and 2015 (Table 3) showed that between 1986 and 1999, 62.59% of the land use land cover class were unchanged, while between 1999 and 2015, 65.59 were unchanged (Figures. 4a, b, c). The highest change in land use pattern occurred between 1986 and 1999 where 7.28% of Vegetation was converted to the swamp.

Table 1. Land use land cover characteristics of Ilaje between 1986 and 2015

LULC Class	1986		1999		2015	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Water	12132.81	8.33	14426.82	9.87	16191.18	11.04
Bare surface	14044.41	9.64	16199.46	11.08	11613.24	7.92
Swamp	11076.66	7.61	15684.21	10.73	9178.65	6.26
Vegetation	103248.81	70.89	93047.76	63.63	101446.47	69.16
Built-up	5144.22	3.53	6875.19	4.70	8252.19	5.63

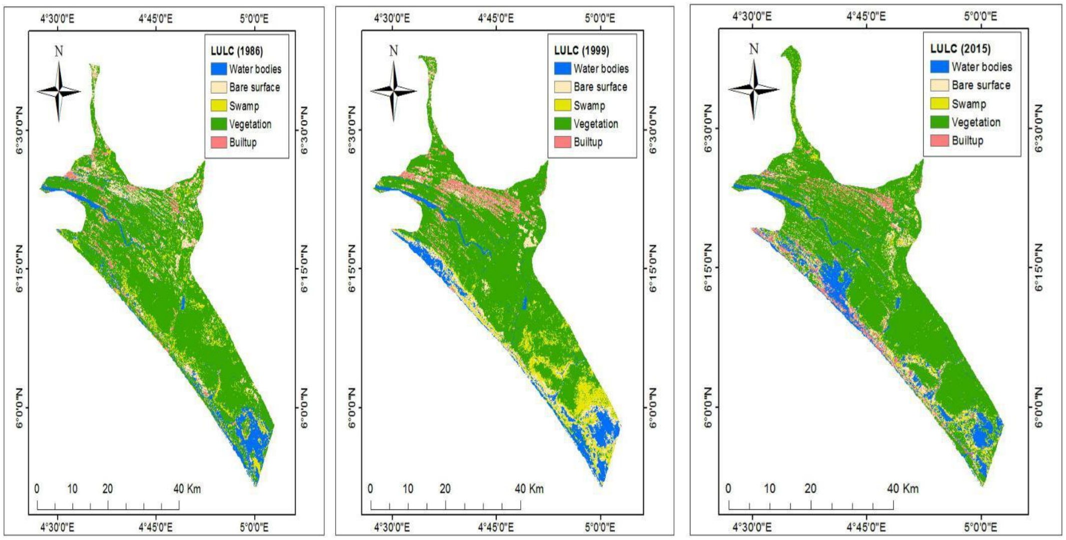
Table 2. Land use land cover change between 1986 and 2015

LULCClass	1999-1986		2015-1986		2015-1999		Trend analysis
	Area (ha)	Percent	Area(ha)	Percent	Area(ha)	Percent	$y = a \pm bX(R^2)$
Water	2294.01	1.54	4058.37	2.71	1764.36	1.17	*y = 10191.9 ± 2029.185X (0.994)
Bare surface	2155.05	1.44	-2431.17	-1.73	-4586.22	-3.16	y = 16383.54 ± -1215.585X (0.281)
Swamp	4607.55	3.12	-1898.01	-1.35	-6505.56	-4.47	y = 13877.85 ± -949.005X (0.080)
Vegetation	-10201.05	-7.26	-1802.34	-1.73	8398.71	5.53	y = 101050.02 ± -901.170X (0.027)
Built-up	1730.97	1.17	3107.97	2.09	1377	0.92	*y = 3649.23 ± 1553.985X (0.996)

** = Significant at P ≤ 0.05*

Table 3. Changes in land use land cover class between 1986 and 2015

Reference class	New class	1999-1986		2015-1986		2015-1999	
		Area (ha)	%	Area (ha)	%	Area (ha)	%
Unchanged		91152.9	62.59	93204	63.99	95908.59	65.59
Water Bodies	Bare surface	2344.95	1.61	1051.74	0.72	1015.56	0.69
Water Bodies	Swamp	2109.15	1.45	1839.6	1.26	1190.34	0.81
Water Bodies	Vegetation	988.29	0.68	2852.64	1.96	3624.3	2.48
Water Bodies	Built-up	238.59	0.16	638.82	0.44	724.95	0.5
Bare surface	Water Bodies	114.57	0.08	784.44	0.54	2655.09	1.82
Bare surface	Swamp	1034.91	0.71	749.16	0.51	2077.65	1.42
Bare surface	Vegetation	7066.26	4.85	8256.15	5.67	6380.1	4.36
Bare surface	built-up	2435.85	1.67	1833.84	1.26	2120.94	1.45
Swamp	Water Bodies	2461.41	1.69	2484.54	1.71	1912.86	1.31
Swamp	Bare surface	1210.14	0.83	874.17	0.6	1660.14	1.14
Swamp	Vegetation	5694.03	3.91	5753.07	3.95	8985.87	6.14
Swamp	Built-up	111.78	0.08	684.81	0.47	1073.52	0.73
Vegetation	Water Bodies	5276.7	3.62	6810.66	4.68	3572.1	2.44
Vegetation	Bare surface	7889.67	5.42	6166.08	4.23	4691.52	3.21
Vegetation	Swamp	10603.71	7.28	4955.85	3.4	3624.84	2.48
Vegetation	Built-up	1911.33	1.31	3325.95	2.28	1234.98	0.84
Built-up	Water Bodies	122.31	0.08	361.53	0.25	179.46	0.12
Built-up	Bare surface	1231.11	0.85	1063.62	0.73	1267.47	0.87
Built-up	Swamp	337.14	0.23	282.33	0.19	208.62	0.14
Built-up	Vegetation	1312.11	0.9	1673.91	1.15	2124.54	1.45



(a) (b) (c)

Figure 3. (a-c): Distribution of land use land cover features in Ilaje LGA, Ondo State in (a) 1986, (b) 1999 and (c) 2015

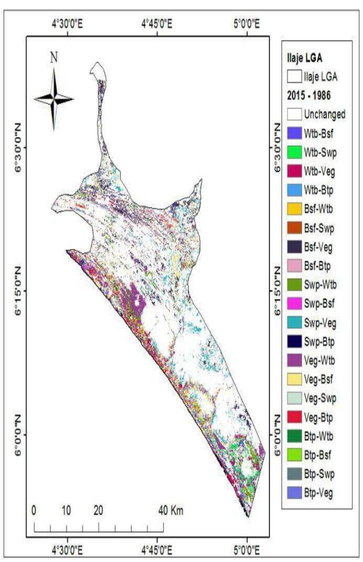


Figure 4a. 2015 - 1986 change detection

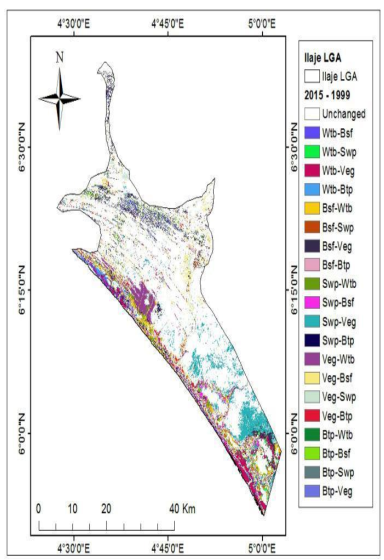


Figure 4b. 2015 - 1999 change detection

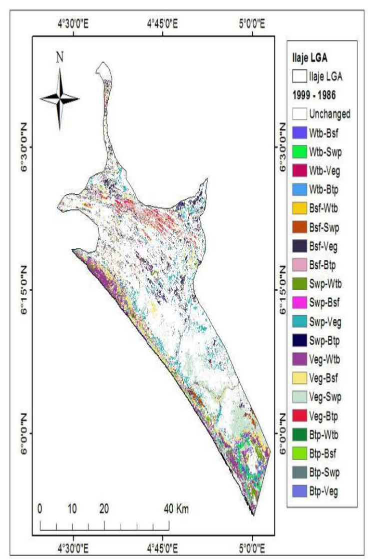


Figure 4c. 1999 - 1986 change detection

3.2 Variations in Land Surface Temperature

The temporal pattern of land surface temperature across the identified land use land cover in the study area is shown in Table 5. The table showed that LST across the LULC varied between 19.8°C and 28.3°c in 1986, 27.1°C and 45.4°C in 1999 and 21.3°C and 35.6°C in 2015. A mean ± standard deviations of 22.0°C ± 0.71; 31.12°f ± 0.81; and 24.6°f ± 0.86 were recorded in 1986, 1999 and 2015 respectively in the study area. The result further showed that temperatures were generally high in Built-up areas and low in vegetated areas (Figure 5a-c).

3.3 Modelling Flood Inundation at Projected Sea Level Height

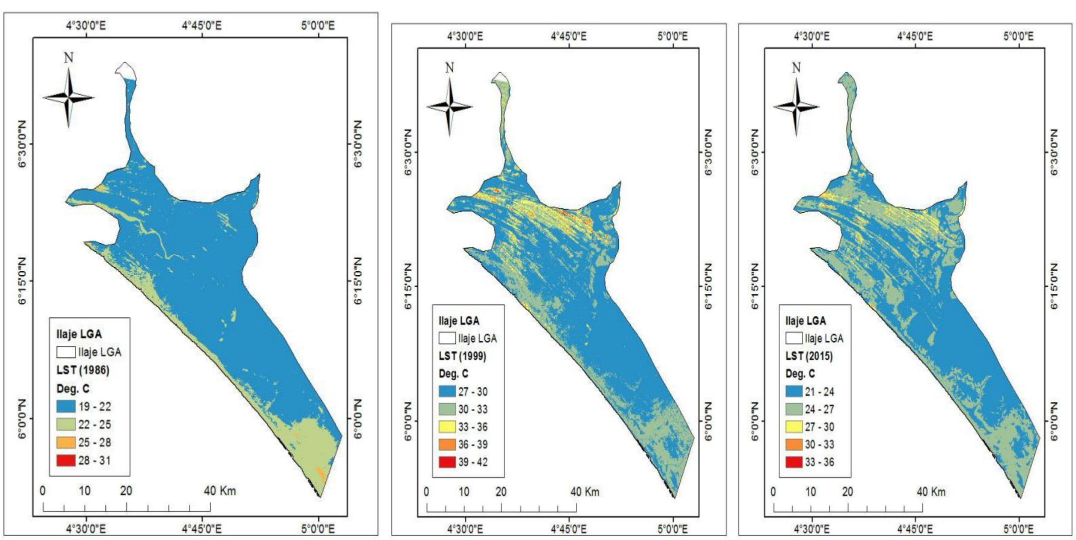
Table 5 shows the total surface area of Ilaje local government area of Ondo State, vulnerable to flooding at varying projected sea level height and storm surge from the Gulf of Guinea (Figs. 6a-c). The result showed that at 0.5 and 0.9-meter rise in sea level, no flooding will be observed in the study area. However, at projected 2 meters rise in sea level height, 9,629.97 hectares (i.e. 6.56% of the total surface area) of the study area will be highly vulnerable to flooding. At projected 4 and 6 meters rise in sea level, 48,973.82 hectares and 94,594.99 hectares respectively of the total surface area of the study area will be flooded. However, the variations in flood vulnerability across the identified land use land cover types showed that 5912.20 hectares, 3423.68 hectares, and 653.51ha of Built-up areas (comprising mostly of Buildings, Roads, and other man-made features) will be vulnerable to flood inundation at 6 meters, 4 meters and 2 meters respectively. The variations in other land use land cover types are presented in Table 5.

4. DISCUSSION

The result showed that there has been major urbanization occurring in this area, because of increased human activities leading to changes in land use and cover characteristics. Between 1999 and 2015, the study area gained a proportion of built-up, vegetation and water bodies, but swamps and bare surface reduced. Unlike other studies [21] which had shown that due to the high rate of urbanization, vegetation depletions are usually at its peak. The increase in vegetated area in this study may be as a result recent tree planting and horticultural beautification of places in Ondo State. Also, human encroachment into the swampy areas for purposes such as building and constructions as well as policy intervention could have led to the reduction in Swamps and Bare surface [16;22]. The increase in built-up however can be attributed to population growth and recent urbanization and urban expansion which have led to the development of more infrastructural facilities and settlements while the gradual increase in water body may be due to rainfall intensification and sea level rise. As have been indicated in recent studies in Nigeria, several factors, such as spread of rural settlements [23]; evolution of rural networks [24] and government policy [25-26,2] have been modifying the original form of land cover. The effect of these changes has however been known to influence the land surface temperature pattern of such area [27-30]

This study indicated that there had been variations in the Land Surface temperature pattern over the years (between 1986 and 2015) in the study area. Higher LST values were however observed in most built-up and bare surfaces than other land use land cover classes. Studies have shown that in most settlements, increased population leading to higher vehicular movements and relatively higher number of buildings often has a relative effect on the temperature [31-32]. Also, the effect of a recent increase in global atmospheric temperature and climate change might as well influence the LST pattern in the study area.

However, the general effect of the increased temperature pattern and changes in land use land cover, especially along the coast could influence surge on the coast thereby leading sea - land invasion [33,16,34].



(a) (b) c)

Figures 5 (a-c): Spatial variation in LST across the study area in (a) 1986, (b) 1999 and (c.) 2015

Table 4. Temporal variation in land surface temperature across the land use land cover types in Ilaje LGA

LULC	1986		1999		2015	
	Min - Max (°C)	Mean ± SD (°C)	Min – Max (°C)	Mean ± SD (°C)	Min - Max (°C)	Mean ± SD (°C)
Water bodies	20.2 - 26.3	22.9 ± 0.71	27.1 - 34.0	29.7 ± 0.78	21.3 - 35.6	23.7 ± 1.05
Bare surface	20.2 - 24.1	21.5 ± 0.53	27.9 - 41.0	31.5 ± 1.34	22.4 - 33.5	25.0 ± 1.20
Swamp	19.8 - 28.3	21.9 ± 1.43	27.5 - 34.0	30.3 ± 0.91	21.6 - 33.9	24.5 ± 1.09
Vegetation	19.8 - 26.3	21.0 ± 0.68	27.1 - 34.4	29.5 ± 0.87	21.9 - 32.1	23.7 ± 0.85
Built-up	19.8 - 27.9	22.7 ± 1.11	29.6 - 45.4	34.5 ± 1.68	21.8 - 35.1	26.0 ± 1.88
Average	19.8 - 28.3	22.0 ± 0.71	27.1 - 45.4	31.12 ± 0.81	21.3 - 35.6	24.6 ± 0.86

Table 5. Variations in flood prone areas at varying projected flood heights

LULC	Area $_{6m}$(%)	Area $_{4m}$(%)	Area $_{2m}$(%)	Area$_{0.9m}$(%)	Area$_{0.5m}$(%)
Water	11403.92 (12.07)	5637.76 (11.52)	1239.80 (12.88)	-	-
Bare surface	7868.56 (8.33)	3691.28 (7.54)	559.79 (5.82)	-	-
Swamp	6655.54 (7.04)	2738.36 (5.60)	401.02 (4.17)	-	-
Vegetation	62673.48 (66.3)	33445.80(68.34)	6772.25(70.35)	-	-
Built-up	5912.20 (6.26)	3423.68 (7.00)	653.51 (6.79)	-	-
Sum	94,594.99 (100)	48,973.82 (100)	9,629.97 (100)	-	-

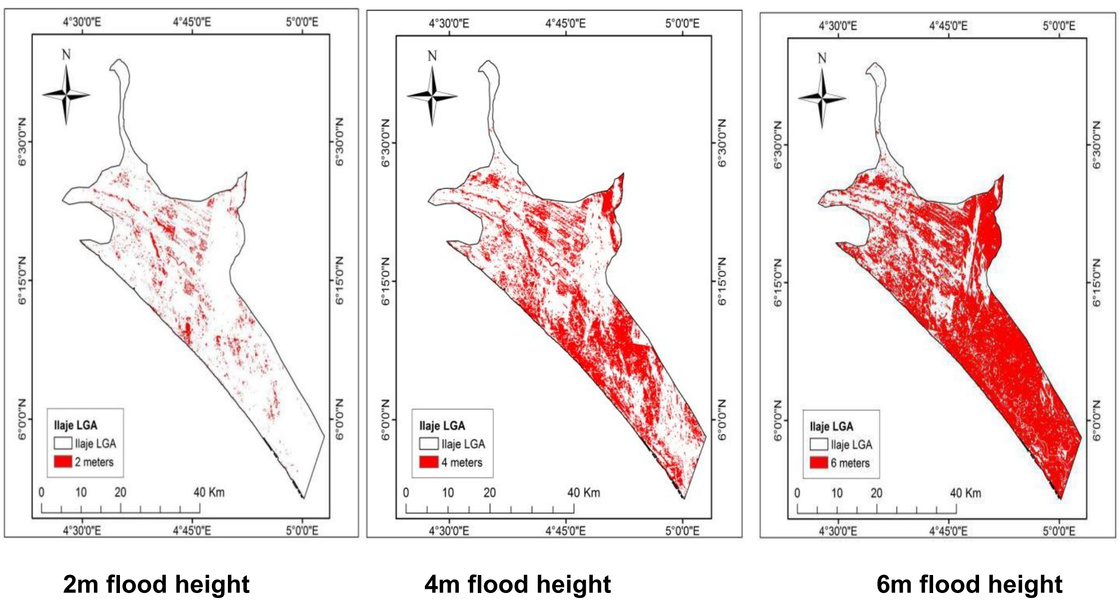


Figure 6. Spatial distribution of flood prone areas in Ilaje LGA at projected flood heights

5. CONCLUSION AND RECOMMENDATION

This study has shown that at flood height below One-meter, significant flooding might not be observed in the study area. However, at projected 2, 4 and 6 meters rise, it is expected that at least 6.56% of the total surface area of the study area will be highly vulnerable to flooding. There is need for adequate measures and timely predictions need to be carried out to know the extent of likely flood impact and suggest best practices to protect the coastal areas and notably to relocate away from the flood plains.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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