Coastal Megacities: The Case of Lagos

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***Abstract*: This paper studies the risk and vulnerable of Lagos as a megacity in Nigeria due to flooding as result of rainfall being one of the major environmental problem of the coastal areas. Statistical, GIS and remote sensing techniques was adopted to map urban growth and seasonal simulation of flood water level changes using HEC-RAS simulation model and their impact on physical environment. The rainfall distribution and seasonal variations were studied. The result reveals that Flood incidents are higher in summer (JJA) and autumn (SON) than in autumn (SON) and lesser in winter (DJF) in Lagos. Vulnerability index was computed by selecting multiple indicators which represents each of the three major components (exposure, sensitivity and adaptive capacity) and the role of rainfall induced climate change was highlighted and stressed using statistical analysis-Ordinary Least Squares (OLS) regression techniques (using ArcGIS software). Flood Risk Index and factors was determined for Lagos which includes uncontrolled expansion of the built-up area, the lack of infrastructure and the failure not only to expand storm water drainage but also to maintain existing drainage systems. In bid to mitigate and adapt to flood control and management in Lagos optimal performance would be insightful to consider policies institutionalization and structural decentralization of operations along the governance framework identified.**

***Keywords*: Megacity, Lagos, Flood, Risk Index, Vulnerability Index, GIS, Remote sensing.**

I. INTRODUCTION

In June 10, 1988, Lagos, Nigeria, was struck by rainfall and the widespread flood that occurred around LUTH, Ishaga was described as being very disastrous, due to the aftermath of the flood over 300,000 people were rendered homeless with properties worth billions of naira wasted (Yang et al., 2010). While rainfall in 1995 was one of importance as it provided an indication of what the future potentially holds for a changing climate in Lagos State? Storm surges accompanied by high tides inundated the beaches and virtually connected the Kuramo Lagoon to the Atlantic Ocean. Many of the streets and drainage channels were flooded, resulting in an abrupt disruption of socio-economic activities in Victoria and Ikoyi Islands during the flooding period. Storms and floods are often associated with loss of life, property and infrastructure damage, loss of GDP and other socio-economic setbacks. These also pose a big challenge to disaster risk management (DRM) (MOE, 2012).

Akani and Bilesanmi (2011) report how Lagos flood forced Lagosians to relocate as a result of the heavy rainfall of 7th and 8th of July 2011 not knowing there was going to be a more devastating torrential rain that will result in “more disastrous floods in Lagos metropolis” in the following week 10th and 11th July 2011 (Mordi, 2011 and Amaize, 2011). Also, the rain of July 2011 was observed; and substantial data and information were obtained from the 10th and 11th July 2011 torrential rains and the consequent floods. The State Ministry of Environment and the Department of Environment in the sixteen Local Government Councils of the Local Government Areas that made up the metropolis provided information on the historical development of the metropolis, drainage systems, floods, challenges and consequences. The 10th July, 2011 corresponds to the date of extreme daily rainfall in the study area and it was recorded that the rain lasted for almost 24 hours which flooded areas like Agege, Egbeda, Jakande Estate, Ojo, Ipaja-Ayobo, Igando, Orile, Ahmadu Bellow way. These events trigger flood events with different magnitudes, as June is mostly recognized as flood-season in most low-lying areas bordering coastal environments (Yang *et al*., 2010).

Despite this, in Nigeria half of the 15 million populations live in Lagos and less than six feet above sea level, including the wealthiest areas of Victoria Island and Lekki Penisula (MOE, 2012), are vulnerable to changes in coastline due to flooding and erosion. This have destroyed the Victoria Island beach and constituted a threat to property and economic activities along the Ahmadu Bello way (Ibe, 1988). Lagos State has a long coastline immediately behind which is a complex belt of barrier islands with active ocean beaches, lagoons and lagoon beaches, lagoonal inlets, creeks, rivers, swamps and sandy uplands and plains. The importance of the coastal zone lies in the fact that it is not only already heavily urbanized but rapid urbanization is continuing, exposing people, infrastructure and the tourism industry to a greater risk of climate change impact, particularly sea level rise. Lagos’s significant is increasing, exposure of people and assets – both within the urban fabric but also outside, connected to the city’s functions through networks of critical infrastructure, financial, and resource flows – will be affected by changes in climate. For Lagos, for example, extreme rain events have an increasing trend between 1901 and 2005; with the trend being stronger since 1950 (IPCC, 2012). This report focuses on the vulnerability and risk of Lagos as a megacity (with population size of 7,937,932 residents according to the 2006 census (NBS, 2006)) to coastal flooding. This study highlights impact of climate-flood and risk on infrastructures in Lagos, Nigeria. Risk from flooding and climate change on infrastructure refers to the probability of harmful consequences or expected loss resulting from interactions between climate hazards, exposure of infrastructures to these hazards and vulnerable conditions; and its capacity (resilience) to adapt to changing conditions without catastrophic loss of form or function.

II. METHODOLOGY

This research integrates remote sensing, GIS and statistical techniques in studying the risk and vulnerable of Lagos as a megacity to coastal flooding. The data acquired includes: (1.) Digital base map of roads, administrative area and slum settlement; (2.) USGS 90m SRTM Digital Elevation Model (DEM) was also be acquired; (3.) Landsat imagery for 1990 (TM) and 2011(ETM$^+$) was acquired, (4.) Meteorological variables - Rainfall data was acquired from ***HadCM3*** - Atmosphere-Ocean General Circulation Models (AOGCMs) for the period between 1971 and 2013; (5.) Monthly flood stage and annual peak flow gauging stations from the federal ministry of transport inland waterways division, Lokoja, Nigeria. Historical flood stage data for a 1-in-20-years return period was picked because of the short reoccurrence and high discharge of flooding seasonally in the study area, and (6.) Collection of socio-economic and population (such as Percentage of GDP and Poverty indexes from Lagos bureau of Statistics, Ministry of economic Planning and budget) data was acquired at the Local Government level, Environmental and hydrological data for vulnerability estimation as well as the review of relevant and current literatures. The study extent covers Lagos metropolis (which now has been granted the status of a megacity) which is located within Lagos state (Figure 1) which was created in 1967 (Mabogunje *et al.*, 1978). The city of Lagos lies in south-western Nigeria, on the Atlantic coast. It is located between longitude 2^0 42' E and 3^0 42' E and between latitudes 6^0 22' N and 6^0 42' N (Abegunde, 1987). In addition, field survey (GPS reading and ground trothing) was conducted to help understand and get first-hand information about land use type and slum settlements throughout the study area which is useful to assess the dynamics of change. From the fieldwork fourteen major slum settlements were identify in Lagos metropolis (table 1). Also, the mean annual rainfalls for Lagos were computed from the monthly rainfall data. Time series analysis was used to depict the temporal trend of mean temperatures and rainfall for the study area. The standardized anomalies of average temperatures and rainfall for the study area were computed using 1971-2013 normal. The standardized mean rainfall anomalies are depicted using graphical method.

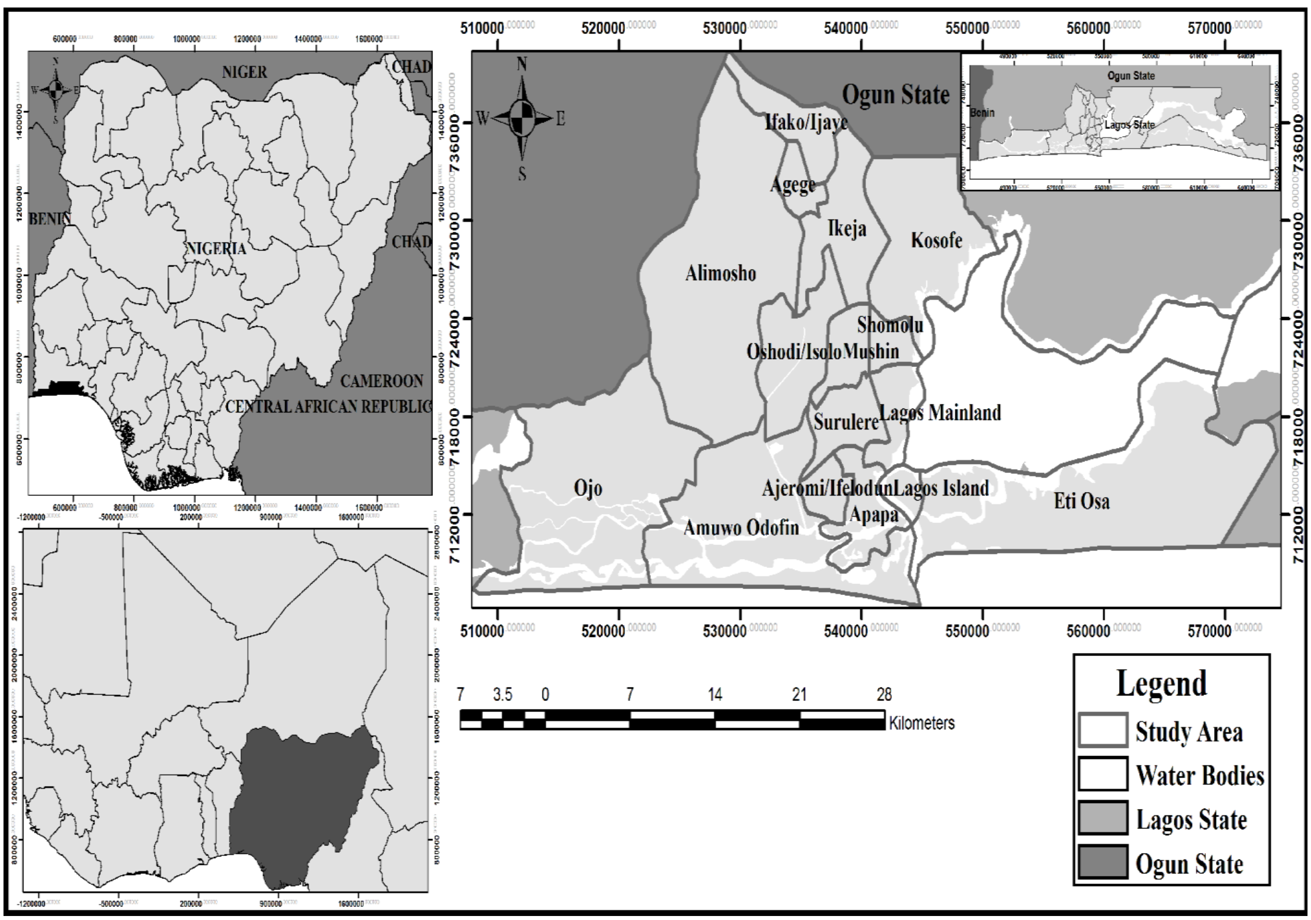

Figure 1.0: The map of the study area (with an inset map of Lagos state) and Nigeria indicating Lagos state.

Table 1: Slum Settlements in Lagos, Nigeria.

Name	X^0	Y^0	Name	X^0	Y^0
Obalende	3.418	6.449	**Otto**	3.379	6.476
Lagos Island	3.391	6.455	**Okobaba**	3.388	6.484
Marine Beach	3.360	6.450	**Makoko**	3.387	6.496
Badia	3.359	6.462	**Iwaya**	3.391	6.512
Ajegunle	3.341	6.457	**IIaje**	3.398	6.533
Ijora Oloye	3.369	6.468	**Oworonsoki**	3.406	6.546
Mile 12 Market Area	3.396	6.614	**Ogudu Village**	3.393	6.574

Source: Author's field work, 2017.

The Digital Elevation Model (DEM) data was used for Triangulated Irregular Network generation in ArcGIS 10 as required in GeoRAS environment in order to prepare data sets required as input to the HEC-RAS simulation. For HEC-RAS Model Application the following steps were adopted**: - (a.) Pre GeoRAS application**: The PreRAS menu option was used for creating required data sets for creating import file to HEC-RAS. Stream centerline, main channel banks (left and right), flow paths, and cross sections were created. 3D layer of stream centerline and cross section was also created. Thus, after creating and editing required themes, RAS GIS import file was created. **(b.) HEC RAS application:** This is the major part of the model where simulation is done. The import file created by HEC-GeoRAS was imported in Geometric Data Editor interface within HEC-RAS. All the required modification, editing was done at this stage. The flood discharge for different return periods were entered in steady flow data. Reach boundary conditions were also entered in this window. Then, water surface profiles were calculated in steady flow analysis window. After finishing simulation, RAS GIS export file was created. Then after, water surface profiles were computed. The resulted was exported creating the RAS GIS export file. **(c.) Post RAS application**: **Post RAS application** (and Mapping) includes: (1.) Import RAS GIS export file; (2.) Generate water surface TIN and (3.) Generate Floodplain and depth grid. (c.) Post-Processing (Post RAS) facilitates the automated floodplain delineation based on the data contained in the RAS GIS output file and the original terrain TIN.

According to inundation depth (table 2) the flood hazard areas was divided into five categories and this was used to classify the Flood hazard map. In research work, model building was used to develop a vulnerability and risk index. Multispectral satellite imagery (Landsat) was used to compile land use/cover maps for these areas and determine the hazard and risk extent of flooding in Lagos metropolis. The developed spectral signatures were used to identify **(1.) built-up areas**, **(2.) non-built-up areas** and **(3.) water bodies**.

Table 2: Assigned Hazard Index and Category for varying Inundation Depth

Inundation Depth	Hazard Index (*H*)	Flood Hazard Category
No inundation	0	Very Low
Less than 1 m	1	Low
1 to less than 2 m	2	Moderate
2 to less than 3 m	3	High
3 to less than 4 m	4	Very High
4 m or more	5	Extreme

Source: Masood and Takeuchi, 2011.

This class was used because the built-up areas are what house the residents and socio-economic activities of Lagos, Nigeria and through this the impact of flooding could be determined. The two epoch period (1990 and 2011) was picked to reflex 1-in-20 years return period. Reference data for ground calibration and validation would be collect by means of GPS-measurements in representative landscape types. Also, Ikonos satellite imagery was used to calibrate and validate the classification procedures in small test areas was found to be 65.2% accurate compared to Landsat ETM^+ (2011). This result analyzes the spatial and temporal patterns of land use/cover and Vulnerability Index change in these regions. NDVI (Normalized Difference Vegetation Index**)** value was computed using remote sensing techniques and used for vulnerability index studies. Vulnerability Index was performed first then validated using Ordinary Least Squares (OLS) regression techniques (using spatial statistics tools, ArcGIS 10 software) to ensure appropriate parameters were picked. Multiple indicators were selected to represent each of the three major components of Vulnerability (Exposure, Sensitivity and Adaptive Capacity). The mathematical formulas applied to the explanatory variables which best predict the dependent variable in the regression model is expressed as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots \dots \dots . \beta_n x_n + \varepsilon \qquad \textbf{(1.)}$$

Where, $\boldsymbol{y}$ = Dependent variable; $\boldsymbol{x}$= Explanatory (Independent) variables; Regression coefficients = $\boldsymbol{\beta}$: and Residuals = $\boldsymbol{\varepsilon}$. The result reveals that the *R-squared* model explains 78% of the variation in the dependent variable with an *Adjusted R-Squared* value of 0.1925. The model has a smaller *AIC* a better fit with the observed data value and is a better model (taking into account model complexity). The *Jarque-Bera statistic* is significant (0.686 (Prob< 0.05), (2) *df:* 0.709), the key variable are incorporated into the model) and the relationships are linear. The *t*-test is used to assess that variable is statistically significant using *Joint Wald statistics* (27.272 Prob (>chi-square), *df:* 0.00417). *Joint F-Statistic* value was used to assess overall performance of the model and was found to be significant. A statistically significant relationship was ascertained between all indicators, and the residual of the indicators was tested for autocorrelation, given the z-score of -0.49, the pattern does not appear to be significantly different than random, this means the variables in the model is not over or under predicting event and likely concludes that there is no missing variable. Finally, the selected indicators were used to map Vulnerability Index (using Raster calculator in ArcGIS). Socio-Climatic Exposure Index combines data on the severity of regional climate change, economic capacity, and assets at risk to map exposure (Preston, 2008; Diffenbaugh et al. 2007). The aggregated index is calculated as follows:

$$\boldsymbol{Socio-Climatic\ Exposure} = CCI \times (PI + WI + POV) \quad \textbf{(2.)}$$

Boori et al (2014) method was used and remodel to study Sensitivity and Adaptive Capacity Index using indicators stated below. For Sensitivity Index (or Indicator) is calculated as follows:

$$\boldsymbol{Sensitivity\ Index} = CCI \times (CWI + FORNDVI + AGR + CEI + CSG \quad \textbf{(3.)}$$

And Adaptive Capacity Index is calculated as follows:

$$\boldsymbol{Adaptive\ Capacity\ Index} = CCI \times (PI + VHI + URI + POV + CSG) \quad \textbf{(4.)}$$

Where: ***CCI***=Climate Change Index [The rainfall was classified into three: 1. Low (<25mm), 2.Moderate (25–60mm) and 3.High (>60mm)]; ***PI***= Population Index; ***WI***=Wealth Index; ***CWI***=Coastal Wetlands Index; ***FOR (NDVI)*** = Forest (NDVI) Index; ***AGR***= Rain-fed-Agriculture Index; ***CEI***=Coastal Elevation Index; ***CSG***= City Size/Growth Index; ***VHI***= Vulnerable House type Index*;* ***LUS***= Land Use Index, ***POV***= Poverty Index and ***URI***= Untarred Road Index. Each indicator measures on a different scale (or different units), so it`s necessary to standardize them. The ArcGIS Fuzzy Membership tool reclassifies or transforms the output raster into a 0 to 1 scale indicating the strength of a membership in a set, based on a specified fuzzification algorithm with 0.0 representing low exposure and low sensitivity index, and 1.0 representing high exposure and high sensitivity index. And for Adaptive Capacity Index, 0.0 representing high adaptive capacity and 1.0 representing low adaptive capacity (Preston et al, 2008). The output was then reclassified into five groups: Very high (1-0.8), High (0.8-0.6), Moderate (0.6-0.4), Low (0.4-0.2) and Very Low (0.2-0.0). In the Vulnerability Index the values of Exposure, Sensitivity and Adaptive Capacity were combined to create vulnerability (Islam et al, 2016):

$$\boldsymbol{V = [(E + S) - AC]} \quad \textbf{(5.)}$$

Where, **V** = Vulnerability; **E** = Exposure; **S** = Sensitivity and **AC** = Adaptive Capacity. The final Vulnerability value depends equally on all three components (i.e. exposure, sensitivity and adaptive capacity). The Flood Vulnerability Risk Index was computed based on IPCC (2012) outlined drivers of flood risk have been largely driven by socioeconomic processes and factors, such as poverty, ecosystem degradation, and poorly governed rapid urbanization (Ranger et al., 2011).

$$\boldsymbol{Flood\ Vulnerability\ Risk\ index} = CCI \times (POV + URI + CEI + LUS) \quad \textbf{(6.)}$$

Zonal statistics in spatial statistics toolbox in ArcGIS was used to assign Hazard index values (table 2) to each LGA and used for risk assessment analysis. The Flood Risk Assessment was computed by multiplying Flood Hazard by Vulnerability Index and the results was assigned a ranking value of 0.0 to 1 (using the ArcGIS Fuzzy Membership) and then reclassified into five groups as stated above. Same Index value was applied to Vulnerability Index and Flood Vulnerability Risk Index. The Risk, Vulnerability, Exposure, Sensitivity and Adaptive Capacity Index were computed for the slum settlements and Local Government Area to study impact flooding on the study area.

III. RESULTS AND DISCUSSION

3.1 Urban Development and Environmental Change

The changes in land use/land cover for the period between 1984 and 2011 respectively for Lagos, Nigeria is shown in figure 2a. The built-up area increased from 390.385 km^2 to 616.765 km^2 in 2011. Bare ground was observed to be 13.123 km^2, 173.367 km^2 for agricultural area, 140.066 km^2 for forest area and 157.711 km^2 for wetland in 1990. While for 2011, bare ground was observed to be 26.564 km^2, 82.489 km^2 for agricultural area, 26.771 km^2 for forest area and 137.934 km^2 for wetland in 2011.The results imply that built-up areas witnessed an increase at the expense of agricultural land, water bodies, wetland, and vegetation. Land reclamation achieved through filling up of swamps and floodplains, and destruction of mangroves and wetlands have generally reduced the flood storage capacity of the urban land as case of Tin can Island, Eko Atiantic city and Lagos Island areas (between 2010 and 2011) (figure 2b). Furthermore, between 1990 and 2011, wetlands cover, which is an important buffer against coastal floods, had significantly been reduced. Rapid and largely unplanned urban growth has resulted in land use changes (figure 2c) and subsequent changes in the hydrological fluxes in the urban watershed thereby increasing flood hazard and risk in many parts of the metropolis. While along the Lekki Peninsula development has been undertaken with little or no consideration for sea-level rise and the possible risks of flooding, making this rapidly urbanizing area and its growing population vulnerable to sea-level rise and climate change.

3.2 Historical Rainfall observations, trends and distribution in Lagos, Nigeria.

The annual rainfall of the Lagos, Nigeria was estimated using rainfall records for the time period between 1971 and 2013. The annual rainfall was estimated (Figure 3a) for Lagos, Nigeria was relatively higher than the annual rainfall in other surrounding area out sketch of Lagos and the rainfall difference between the coast and inland was due to the fact that area is coastal cities bordering the Atlantic Ocean and the influenced by its nearness to the equator and the Gulf of Guinea. It is affected by atmospheric interactions in which the Inter- Tropical Convergence Zone (ITCZ) is a controlling factor. Generally, rainfall statistics was computed and result reveals that in Lagos metropolis a mean of 9.408 mm/day and median of 9.36 mm/day was observed and mode of 8.19 mm/day between the study years, with a fairly strong relationship (1.7%) observed over years between 1971 and 2013 in Lagos, Nigeria (Figure 3a and b).

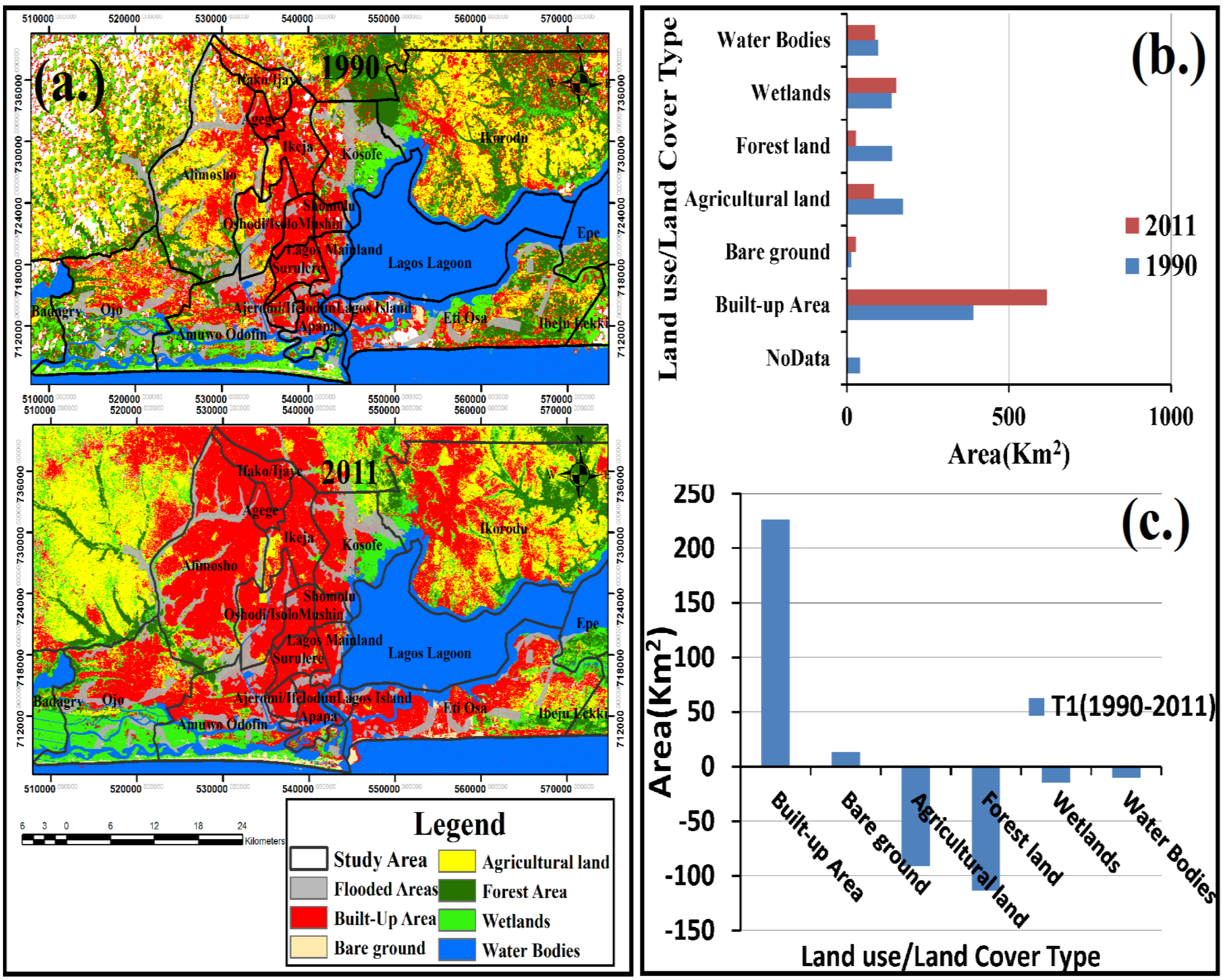

Figure 2.0: (a.) The land use/ land cover map of Lagos, Nigeria between 1990 and 2011 indicating flooded areas. **(b.)** The land use/ land cover chart of Lagos, Nigeria between 1990 and 2011. **(c.)** Land use rate of change for Lagos, Nigeria between 1990 and 2011.

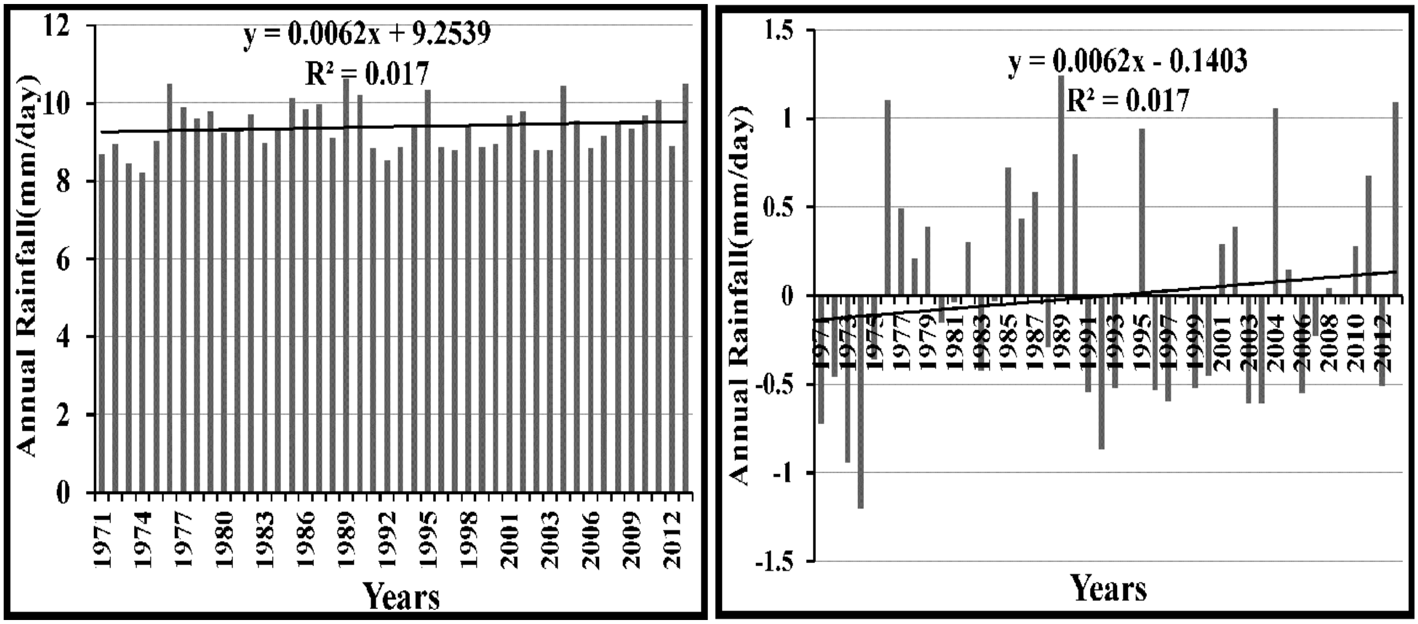

Figure 3.0: (a.) Annual rainfall trends in Lagos, Nigeria between 1971 and 2013. (b.) Annual rainfall variation in Lagos, Nigeria between 1971 and 2013.

And minimum of 8.19 mm/day and maximum of 10.63 mm/day was also observed in the study area with a total of 404.56 mm/day of rainfall or the study years. Season variations were observed with higher rainfall observed in spring (MAM) (9.45mm/day) than in winter (DJF) (3.77 mm/day), autumn (SON) (11.51 mm/day) is lesser than summer (JJA) (12.26 mm/day) but higher than spring (MAM) (9.45 mm/day) between 1971 and 1999. And between 2000 and 2013, Season variations were observed with higher rainfall observed in spring (MAM) (10.56 mm/day) than in winter (DJF) (4.403), autumn (SON) (11.03 mm/day) is lesser than summer (JJA) (12.99 mm/day) but higher than spring (MAM) (10.56 mm/day) between 1971 and 1999. This implies higher surface runoff and flood incidents in summer (JJA) and autumn (SON) than in autumn (SON) and lesser in winter (DJF).

3.3 Flood events and Hazards in Lagos, Nigeria.

Flood Hazard map for Lagos, Nigeria for 1990 and 2011 is shown in figure 4. In Lagos, Nigeria, the projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions. There is high confidence that locations currently experiencing adverse impacts such as coastal flooding and inundation will continue to do so due to increasing sea levels, all other contributing factors being equal. The results concludes that the frequency of heavy precipitation and flood events has increased over Lagos, Nigeria during the late 20th century, and that it is more likely than not that there has been a human contribution to this trend which are indirect impacts of climate change on flood are related to low laying topography (between a slope of 1 and 1.63^0) and urbanization (figure 4) caused by associated adaptation actions, which can be dangerous for Lagos transportation and residents. The flood inundation depth of the study area has been divided into five categories based on the classification scheme in table 1 above. For a 20 year return period in DJF, 64.691 km^2 was inundated by low flood hazard, 28.961 km^{2}by moderate flood hazard, 24.235 km^2 by high flood hazard, 18.336 km^2 by very high flood hazard and 9.421 km^2 by extreme flood hazard in 1990. For 2011, 64.442 km^2 was inundated by low flood hazard, 28.533 km^{2}by moderate flood hazard, 20.219 km^2 by high flood hazard, 21.500 km^2 by very high flood hazard and 10.519 km^2 by extreme flood hazard. For MAM, 66.984 km^2 was inundated by low flood hazard, 34.808 km^{2}by moderate flood hazard, 23.963 km^2 by high flood hazard, 18.676 km^2 by very high flood hazard and 12.729 km^2 by extreme flood hazard in 1990. For 2011, 77.648 km^2 was inundated by low flood hazard, 27.706 km^{2}by moderate flood hazard, 19.296 km^2 by high flood hazard, 17.296 km^2 by very high flood hazard and 9.647 km^2 by extreme flood hazard. For JJA, 64.022 km^2 was inundated by low flood hazard, 35.733 km^{2}by moderate flood hazard, 23.963 km^2 by high flood hazard, 18.676 km^2 by very high flood hazard and 12.729 km^2 by extreme flood hazard in 1990. For 2011, 38.303 km^2 was inundated by low flood hazard, 26.862 km^{2}by moderate flood hazard, 12.146 km^2 by high flood hazard, 14.918 km^2 by very high flood hazard and 6.0183 km^2 by extreme flood hazard. For JJA, 64.022 km^2 was inundated by low flood hazard, 35.733 km^{2}by moderate flood hazard, 23.963 km^2 by high flood hazard, 18.676 km^2 by very high flood hazard and 12.729 km^2 by extreme flood hazard in 1990. For a 2011, 38.303 km^2 was inundated by low flood hazard, 26.862 km^{2}by moderate flood hazard, 12.146 km^2 by high flood hazard, 14.918 km^2 by very high flood hazard and 6.0183 km^2 by extreme flood hazard.

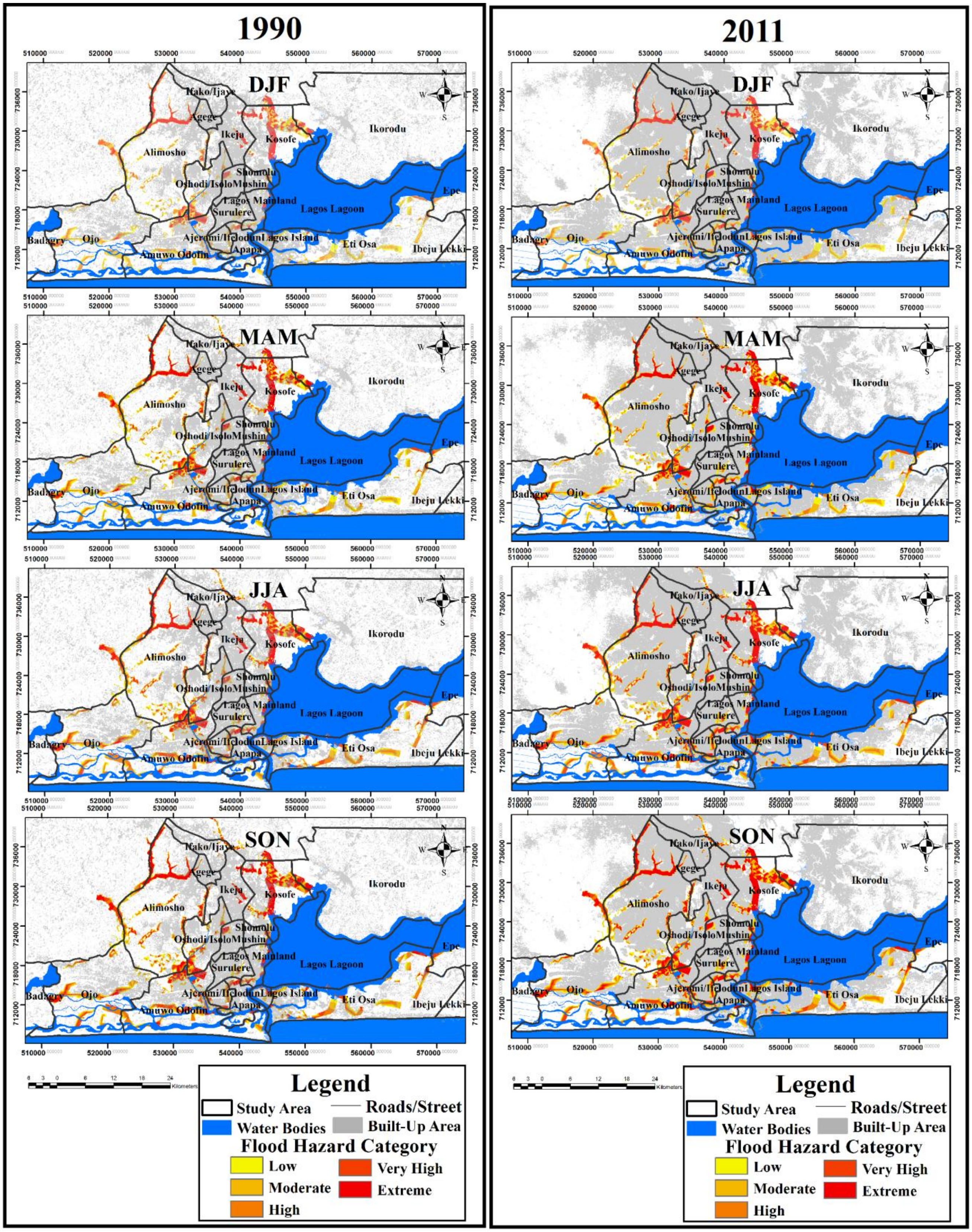

Figure 4.0: Flood Hazard map for Lagos, Nigeria for 1990 and 2011.

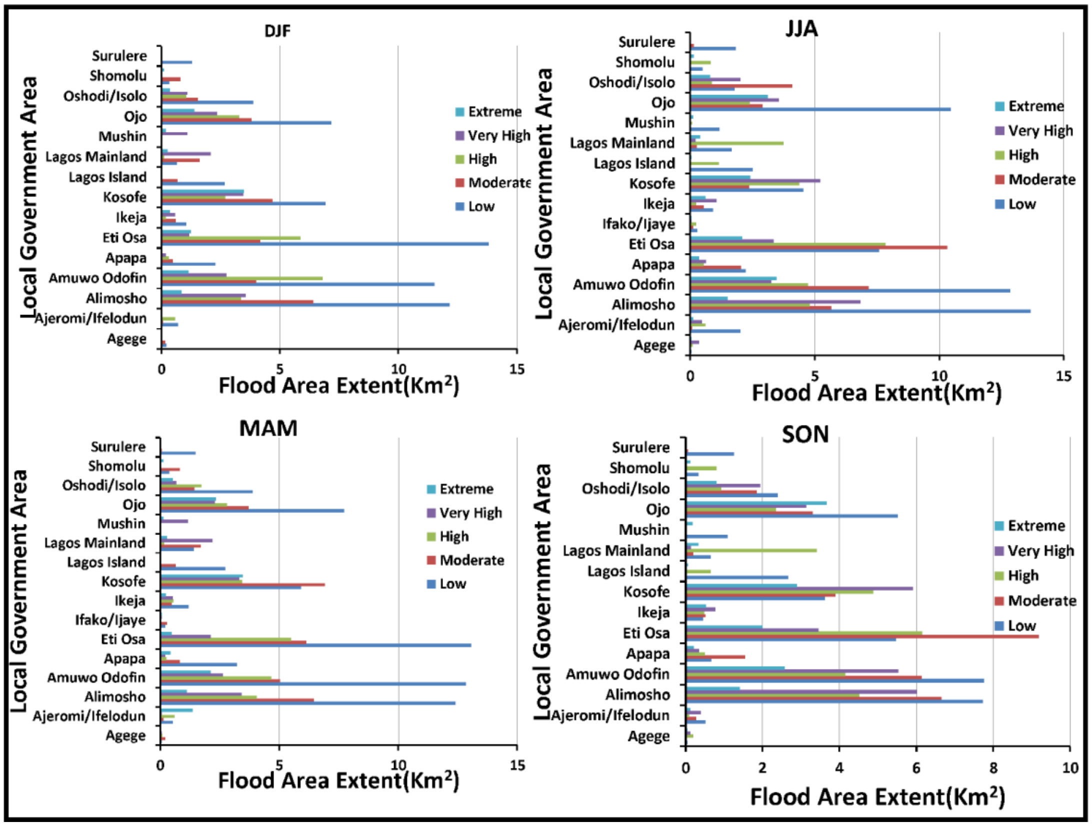

Figure 5.0: Flood Hazard for the different Local Government Areas in Lagos, Nigeria for 1990.

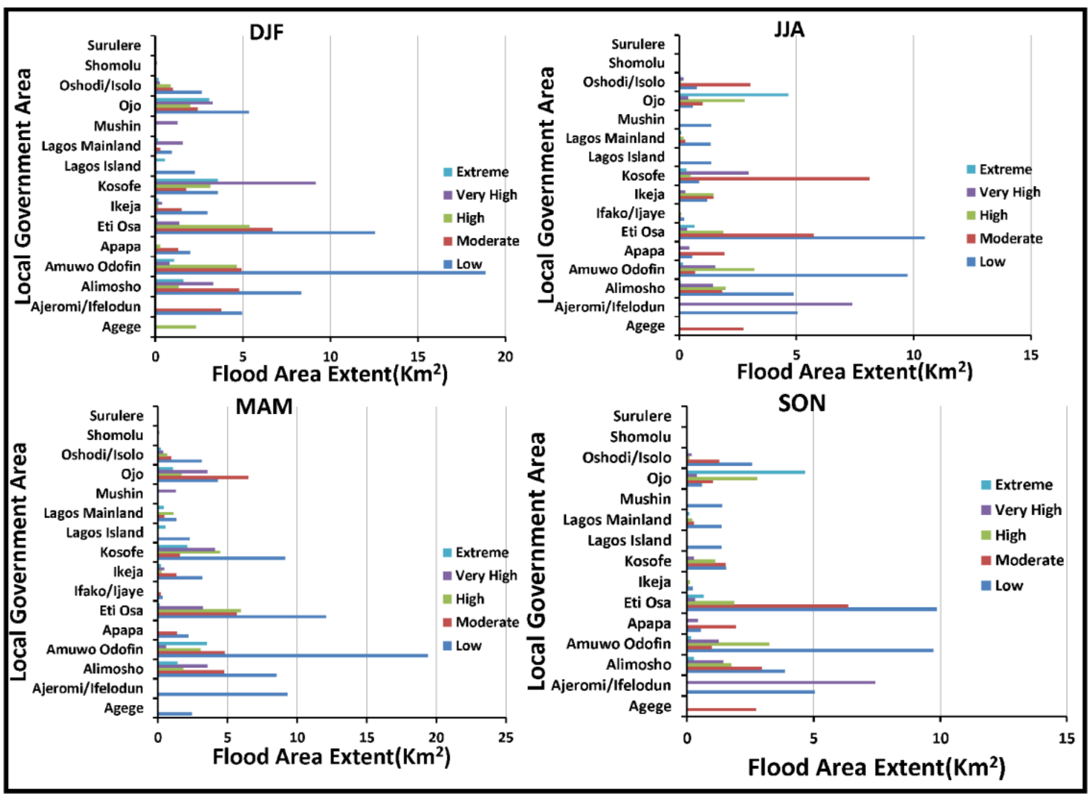

Figure 6.0: Flood Hazard for the different Local Government Areas in Lagos, Nigeria for 2011.

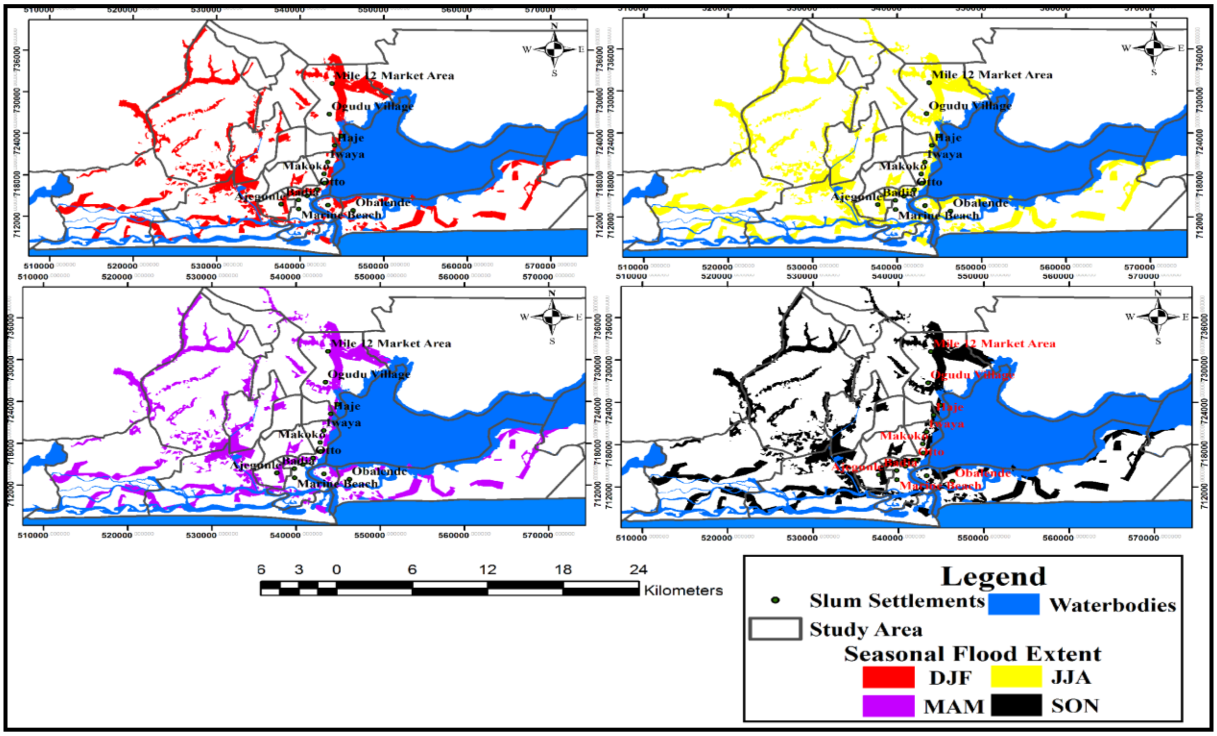

Figure 7.0: Seasonal flood extent and slum settlements in Lagos, Nigeria.

For a 20 year return period in SON, 40.174 km^2 was inundated by low flood hazard, 33.653 km^{2}by moderate flood hazard, 29.11 km^2 by high flood hazard, 27.759 km^2 by very high flood hazard and 14.946 km^2 by extreme flood hazard in 1990. For a 2011, 38.101km^2 was inundated by low flood hazard, 19.147 km^2 by moderate flood hazard, 11.198 km^2 by high flood hazard, 11.727 km^2 by very high flood hazard and 5.926 km^2 by extreme flood hazard. The most vulnerable to flood hazard is the built-up area and is shown in figure4 above. The flood areas inundated areas for different Local Government Area is shown in figure 5 and 6 in Lagos, Nigeria. The flood incident is higher in summer (JJA) and spring (MAM) than in autumn (SON) and lesser in winter (DJF) in Lagos, Nigeria. Some affected communities includes Apese in Eti Osa LGA, Olaosebikan, Aina road and Ijero street in Kosofe, Ketu mile 12 market (figure 2), reclaimed land Tin island and Lagos Island, Abibu and Ikorodu street in Ojo, Apapa Oworonoshoki expressway –Apapa and Dockyard road. The most vulnerable flood hazard communities are the slum settlement which includes Ogudu Village (high flood hazard), llaje (very high flood hazard), Iwaya (high flood hazard), Makoko (high flood hazard), Otto (very high flood hazard), Oworonsoki (high flood hazard) and Ajegunle(low flood hazard) as shown in figure 7. The seasonal extent shows that flood is continuous problem experienced all-round the years whenever there is rainfall in Lagos, Nigeria more especially in MAM, JJA and SON, peak flooding period was observed to in JJA when rainfall reaches its peak (section 3.2). Furthermore, the reveals that Lagos is coastal city which is constantly inundated by flooding.

3.4 Coastal Vulnerability Assessment in Lagos, Nigeria.

The character and severity of impacts from flooding depends on the extremes themselves, exposure and vulnerability. In this report, adverse impacts are considered disasters when they produce widespread damage and cause severe alterations in the normal functioning of communities or societies. Exposure to coastal climate change and flooding was computed and result reveals that Shomolu and Mushin have low exposure index of 0.211 and 0.249, followed by Lagos Island (0.379), Ajeromi/Ifelodun (0.165) while Lagos mainland (0.493) is affected by moderate exposure, Ifako/Ijaye (0.71) and Oshodi/Isolo (0.64) is affected by High exposure rate and Amuwo Odofin, Apapa, Eti Osa, Ikeja, Kosofe, Ojo, and Alimosho is affected by very high exposure rate (1). This implies that the exposure rate to climate change and flood prone hazard are high and harmful to infrastructures and resources present (figure 8a and 9a). Sensivity to coastal flooding was computed and result reveals that Agege and Mushin has low Sensivity index rate of 0.287 and 0.29, Shomolu (0.24), Ikeja (0.39), Lagos Island (0.379) followed by Lagos mainland (0.469), Oshodi/Isolo (0.483), Surulere (0.364) and is affected by moderate exposure, Apapa(0.59) is affected by High exposure rate and Amuwo Odofin (0.998), Eti Osa (1), Kosofe (0.99), Ojo, and Alimosho(0.899) is affected by very high exposure rate. This implies that degree of infrastructures and resources present and the exposure rate to flood prone hazard fares badly in Lagos, Nigeria (figure 8b and 9a). Adaptive capacity to coastal flooding was computed and result reveals that Ajeromi/Ifelodun has a very high

Adaptive capacity index rate of 0.18, Lagos Island (0.209), Mushin (0.269), Shomolu (0.232), Surulere (0.358) and Agege (0.225) has high Adaptive capacity index rate. Lagos mainland (0.574) is affected by moderate Adaptive capacity, Ifako/Ijaye (0.648) and Oshodi/Isolo (0.702) is affected by low Adaptive capacity (low resilience) rate and Amuwo Odofin (1), Eti Osa (1), Apapa (0.94), Kosofe (1), Ojo, Ikeja and Alimosho(1) is affected by very low adaptive capacity (very low resilience) rate. This implies that capacity of the sector to adapt (adaptive capacity) by minimizing negative impacts to flood prone hazard fares badly in Lagos, Nigeria and its ability to cope is low for the study area(figure 8c and 9a). And vulnerability index was computed and result reveals that Agege (0.27), Surulere (0.309), Ajeromi/Ifelodun (0.304), Ikeja (0.39), Lagos mainland (0.388), Shomolu (0.34) and Mushin (0.266) has a low vulnerability index rate. Ifako/Ijiaye (0.447) and Oshodi/Isolo (0.424) has moderate vulnerability index rate. And Apapa has a high vulnerability index rate of 0.615. Lagos Island (0.836), Amuwo Odofin (1), Eti Osa (1), Kosofe (1) and Alimosho (0.904) has a very high vulnerability index rate. This implies that the susceptibility of infrastructures to harm from flood hazards was found to be high and dangerous for the study area (figure 8d and 9a). In the study area, 14 slums were identified. Many of these cities are already characterized by significant population and asset exposure to coastal flooding, and elevation information reveals that all settlement are located between 0 to 23m which are located on floodplain with a steep slope which means their residents suffer from a considerable degree of physical exposure and social vulnerability to losses from flood events. The flood vulnerability risk index is shown in figure 8e for the different local government areas in Lagos, Nigeria. Oworonsoki, Ijora and Oloye (0.34 and 0.322) have low sensivity, Badia (0.59), Ajegunle (0.58), Otto (0.58), Okobaba (0.49), Makoko (0.45), Iwaya (0.48) and llaje (0.48) have moderate sensivity index. Marine Beach has a high sensivity index. And Obalende, Lagos Island, Ogudu Village and Mile 12 Mark area have a very high sensivity index (of 1). And Ajegunle has a very low exposure rate of 0.18, followed by Lagos Island (0.209) and IIaje (0.232) with a low exposure rate. Otto, Okoba, Makoko and Iwaya (0.57) has a moderate exposure rate. And rest settlement have very high exposure rate. Ajegunle has a very high adaptive capacity rate of 0.18, followed by Lagos Island (0.209) and IIaje (0.232) with a high adaptive capacity rate. Otto, Okoba, Makoko and Iwaya(0.57) have a moderate adaptive capacity rate. And rest slum settlement have very low adaptive capacity rate (that is Obalende, Marine Beach, Badia, Ijora Oloye, Oworonsoki, Ogudu Village and Mile 12 Mark area). Ajegunle has a moderate vulnerability rate of 0.47, followed by Marine Beach (0.54). Obalende has high vulnerability index rate. Lagos Island, Badia, Ijora Oloye, Okobaba, Oworonsoki, Ogudu Village, Mile 12 Market area, Otto, Okoba, Makoko, Iwaya and llaje have very high vulnerability index (between 0.99 and 1).

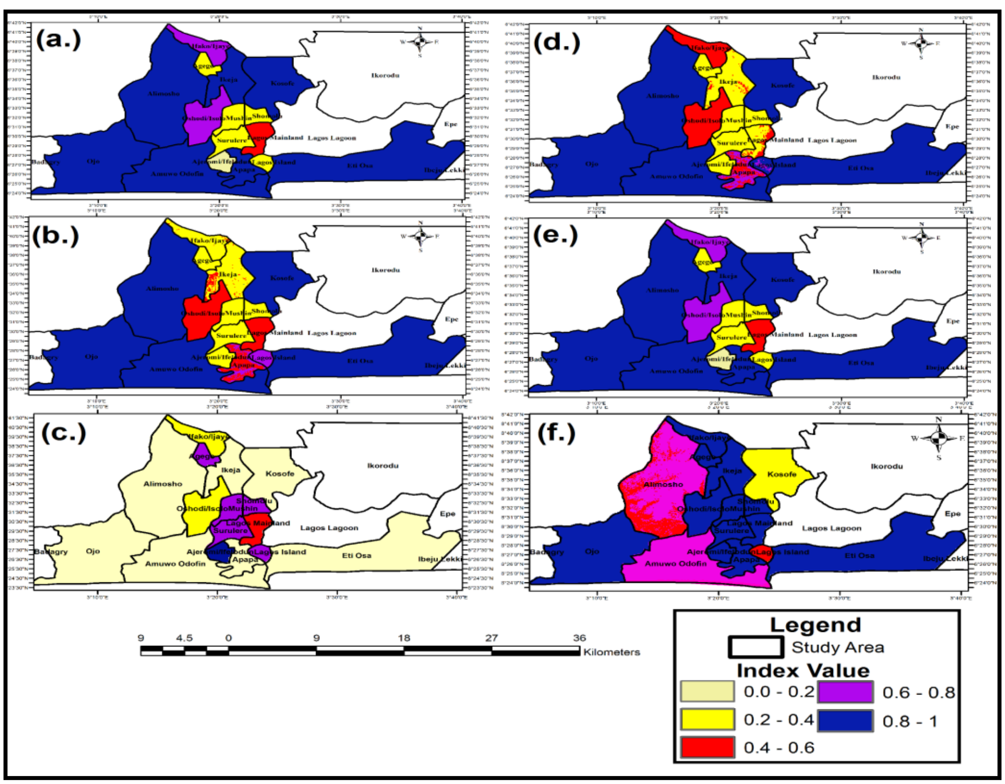

Figure 8.0: (a.) Exposure Index, (b.) Sensitivity Index, (c.) Adaptive Capacity Index, (d.)Vulnerability Index, (e.) Flood Vulnerability Risk Index and (f.) Flood Risk Assessment index in for Lagos, Nigeria.

3.5 Risk Assessment Mapping for Flood Prone Areas

Flood risk index was computed and result reveals that Ajeromi/Ifelodun, Apapa, Eti Osa, Ifako/Ijaye, Ikeja, Lagos mainland, Mushin, Ojo, Oshodi/Isolo, Shomolu, Surulere and Agege has a high risk index rate (between 0.976 and 1). Alimosho, Amuwo Odofin and Lagos Island was classified as having a high risk index rate (between 0.6 and 0.8) while Kosofe was classified as having a low risk index rate (between 0.2 and 0.4) (figure 8f and 9b). This implies that the risk from flooding on the infrastructure due to exposure of infrastructures to these hazards and vulnerable conditions for the study area are high between 1990 and 2011. However, Individuals and communities are differentially exposed based on inequalities expressed through levels of wealth and poverty, disability, and population characteristics. Indicator (flood risk drivers) such as untarred roads, vulnerable house type, poverty index were combined with the risk and vulnerability value to show how most affected local government and infrastructures fare due to flooding (figure 9b) this implies that the risk to climate related flooding are high in the study area. For Mile 12 market area and Ogudu village the risk to flooding are low, moderate for Lagos Island and very high for the rest of the slum settlement for the study area.

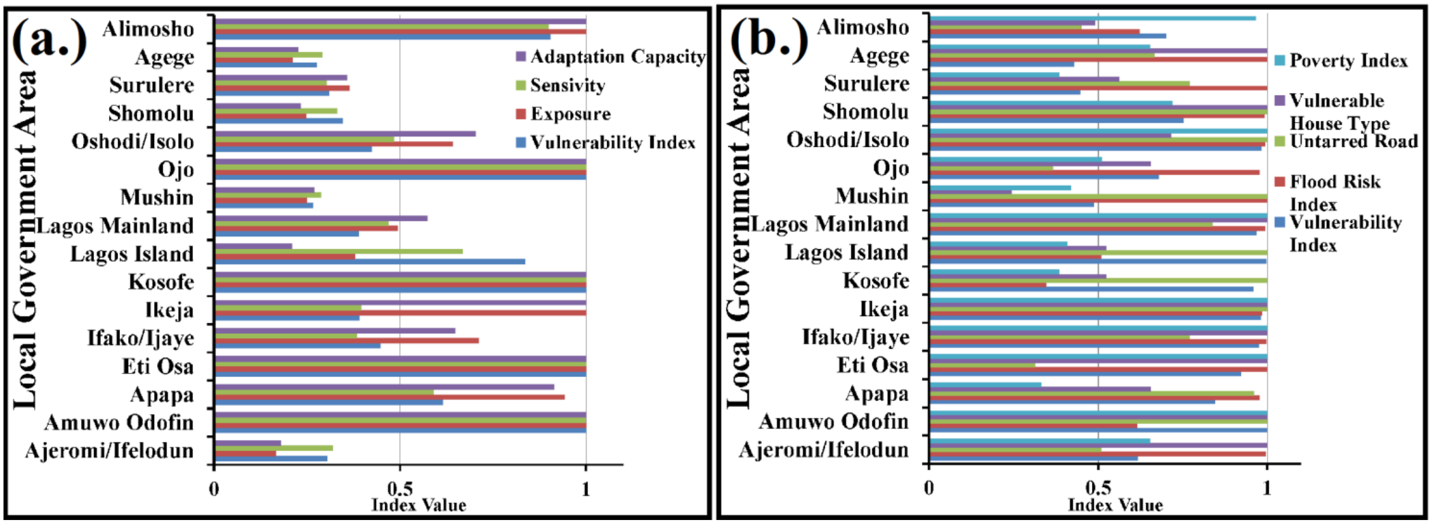

Figure 9: (a.) Flood Vulnerability Index between 1990 and 2011 for Lagos, Nigeria. **(b.)**Flood Risk Index for Lagos, Nigeria between 1990 and 2011.

IV. CONCLUSIONS

Lagos is expanding rapidly both in area and population, with a concomitant increase in the urban poor population in coastal areas being at risk of flooding. Despite the challenges posed by flooding, which are exacerbated by urban development, the vulnerability of the urban poor to floods has not been taken into consideration in urban planning and development. Since flooding in communities is very much linked to the provision of adequate infrastructure and management of the environment (including land use management), the vulnerability of the poor urban population is highly linked to poor urban management and government's inability to deal adequately with the issues. An added vulnerability faced by large sections of the urban poor in metropolitan Lagos is the fear that the state government may evict them from land sites deemed to be vulnerable to floods, with very inadequate or no provision for finding alternative accommodation that meets their needs. A range of measures to increase the adaptive capacity of the urban poor that governments at different levels should pursue include: (1.) Enforcement of urban planning laws; (2.) Restrictions on land reclamation activities in newly developing areas; (3.) Construction of more primary, secondary and tertiary drainage systems, taking into account storm run-off responses under high intensity rainfall; (4.) Proper solid waste collection; and (5.) Management and environmental education for citizens.

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