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Mapping Seasonal Flood Inundation and Developing an Early Warning System for Lagos Metropolis (Nigeria): A study between 1990 and 2011

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ABSTRACT

Flooding has become a major environmental hazard in Lagos metropolis in recent years due to its topography, population growth, rapid urbanization and extreme weather events such as rainfall. Seasonal flood inundation simulation was modeled and an early warning system was developed for Lagos metropolis using DEM (Digital Elevation Model) from SRTM (Shuttle Radar Topography Mission) and monthly flood stage between 1990 and 2011 using GIS (Geographic Information System) technique. Annual rainfall trend was studied between 1971 and 2013 using time series statistic as well as seasonal rainfall distribution between 1971 to 1999 and 1999 to 2013. Seasonal flood stages were studied and used as input in flood simulation. Flood inundation simulation was modeled using HEC-RAS program for 1-in-20 year return period. While the flood hazard map was prepared based on flood inundation level. Risk assessment was performed to produce a flood risk map for Lagos metropolis. Flood velocity, runoff time, depth, duration, location and spatial dimension were captured, studied and used to develop a Flood Early Warning System (FEWS) as well as flood discharge for Lagos metropolis. Affected Local Government Areas and streets were selected to study the impact of flooding on Lagos residents. Finally, research findings and recommendations were highlighted for Lagos metropolis.

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Introduction

Natural disasters happened every year and their impact and frequency seem to have greatly increased in recent decades, mostly because of environmental degradation, such as deforestation, intensified land use, and the increasing population. Floods are among the most frequent and costly natural disasters in terms of human and economic loss (Pradhan, 2009). Flood damage has been extremely severe in recent decades and it is evident that both the frequency and intensity of floods are increasing. In the past ten years, losses amounting to more than 250 billion dollars have had to be borne by societies all over the world to compensate for the consequences of floods. Trend analyses reveal that major flood disasters and the losses generated by them have increased drastically in recent years (Jeb & Aggarwal, 2008). Flooding is caused by several factors and is invariably preceded by heavy rainfall. The other causes of flooding are moderate to severe winds over water, unusual high tides, tsunamis due to undersea earthquakes, breaks or failures of dams, levees, retention ponds or lakes, or other infrastructure that retains surface water. Flooding can be aggravated by impervious surfaces or by other natural and man-made hazards which destroy soil and vegetation that can absorb rainfall (Ajayi et al., 2012).

In a study of the flooding problems in Lagos state, Adeloye and Rustum (2011) indicated that climate change is not the culprit but anthropogenic factors. The investigation revealed that, contrary to popular wisdom, climate change or unusually high rainfall is not the primary cause of the flooding problems in Lagos. Rather, increased urbanization, lax planning laws in relation to the erection of buildings in flood plains and the inadequacy of storm drainage facilities in the city are to blame. Lagos state relies heavily on road transport for the movement of people, freight and services. Roads are susceptible to damage by erosion and flooding caused by excessive rainfall and to the buckling of tarmac due to excessive heat. Floods usually occur during these periods of peak rainfall. These floods are aggravated by the poor surface drainage systems of the coastal lowlands. They are therefore vulnerable to the impact of climate change (BNRCC, 2012). Ibeabuchi et al (2018) went further to state that, service roads is the most affected road type because it connects residential areas, businesses and homes, this further stress the impact of flood on socio-economic activities and comfort of Lagosians. The factors causing flooding in Nigeria (and specifically in Lagos metropolis) can be categorized into: flooding by the water level rising in rivers flowing through urban area, the inundation by local rainfall in urban area and the inundation by local rainfall and high tide in coastal urban area. Water level rising in rivers is caused by uncontrolled discharge from upstream dam and usual flood runoff from upstream catchment (JICA, 1995).

Monitoring flood hazards and processes forms the bases for early warning systems, flood hazards zoning, assessment and risk analyses which often provide the major prerequisite components for flood disaster management before any assessment of the impact of a flood event can begin. Decision makers need to know the magnitude of flooding. Utilization of flood stage or river gauge levels in the land are essential for hazard zoning with remote sensing, modeling and GIS as major tools. The incidences of these flood events and associated hazards of profound magnitudes and disastrous consequences can be monitored effectively using either real time satellites or multi-date satellite imageries. Different flood scenarios can easily be mapped and the risked associated presented in a timely manner (Jeb & Aggarwal, 2008).

The main objective of this study is to integrate flood simulation model from remotely sensed data using GIS (Geographic Information System) for seasonal flood inundation and risk mapping in Lagos metropolis between 1990 and 2011. Flooding is a serious, common, and costly hazard that many countries face regularly. Identification and mapping of flood prone areas are valuable for risk reduction. In the context of flood hazard management, GIS can be used to create interactive map overlays, which clearly and quickly illustrate which areas of the community that is in danger of flooding. Such maps can then be used to coordinate mitigation efforts before an event and recovery after (Awal, 2003); however, these have improved useful in Flood Early Warning System study. An essential part of information required for a Flood Early Warning System (FEWS) action would be flood risk maps that clearly show the areas with the greatest and least vulnerabilities (Oluwasegun et al., 2018). Though Flood Early Warning System (FEWS) is a wholesome concept for effectively reducing the risk of flood in (Lagos metropolis) Nigeria; it has not been fully integrated and is still in its inception stage (FME, 2009). Thus, (Flood) Early Warning Systems is *the set of capacities needed to generate and disseminate timely and meaningful (flood) warning information to enable individuals, communities and organizations threatened by a (flood) hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss* (UNISDR, 2009). Early warning systems, through communication of flood risk assessment and uncertainties, are important to improve the communities' preparedness and to help them make better decisions for their safety (Cools et al., 2016; O'Sullivan et al., 2012).

Study Area

Lagos metropolis consists of the continuously built up area of Lagos metropolis and outlying suburban areas. It stretches from the city core – Lagos Island and the mainland- to outlying suburbs as Ojo, Ikotun, Egbe, Agege, Alimosho, Ketu, etc. Lagos metropolis covers 1171 km^2 area of which $221km^2$ is Lagoons and waterways (Ogunleye & Awomosu, 2010). Lagos metropolis is also known as "Metropolitan Lagos", and officially as "Lagos Metropolitan Area". Lagos metropolis is located within Lagos state which was created in 1967 (Abegunde, 1987). The city of Lagos lies in south-western Nigeria, on the Atlantic coast. It is located between longitudes 507933.87m to 574309.95m Easting and between latitudes 740347.79m to 706462.40m Northing. Currently, Lagos metropolis is divided into sixteen Local Government Areas (LGAs)

(Figure 1) out of the twenty Local Government Areas (LGAs) in Lagos state. Lagos metropolis is the most densely populated city in Nigeria with 7,937,932 residents according to the 2006 census (NBS, 2012). The climate in Lagos is the wet equatorial type (Abegunde, 1987), which is similar to the rest of southern Nigeria. There are two rainy seasons, with the heaviest rains falling from April to July and a lesser rainy season in October and November (Omojola & Elias, 2010). The mean monthly rainfall between May and July averages over 300 mm (12 inches); it comes down to75 mm (3 inches) in August and September, while in January it is as low as 35 mm (1.5 inches) (Okoye & Ojeh, 2015). The main dry season is accompanied by harmattan winds from the Sahara desert, which is between December and early February this can be quite strong. The average temperature in January is about 27°C (79°F) and for July it is about 25°C (77°F). On the average, the hottest month is March; with a mean temperature of about 29°C (84°F); while July is the coolest (Abegunde, 1987).

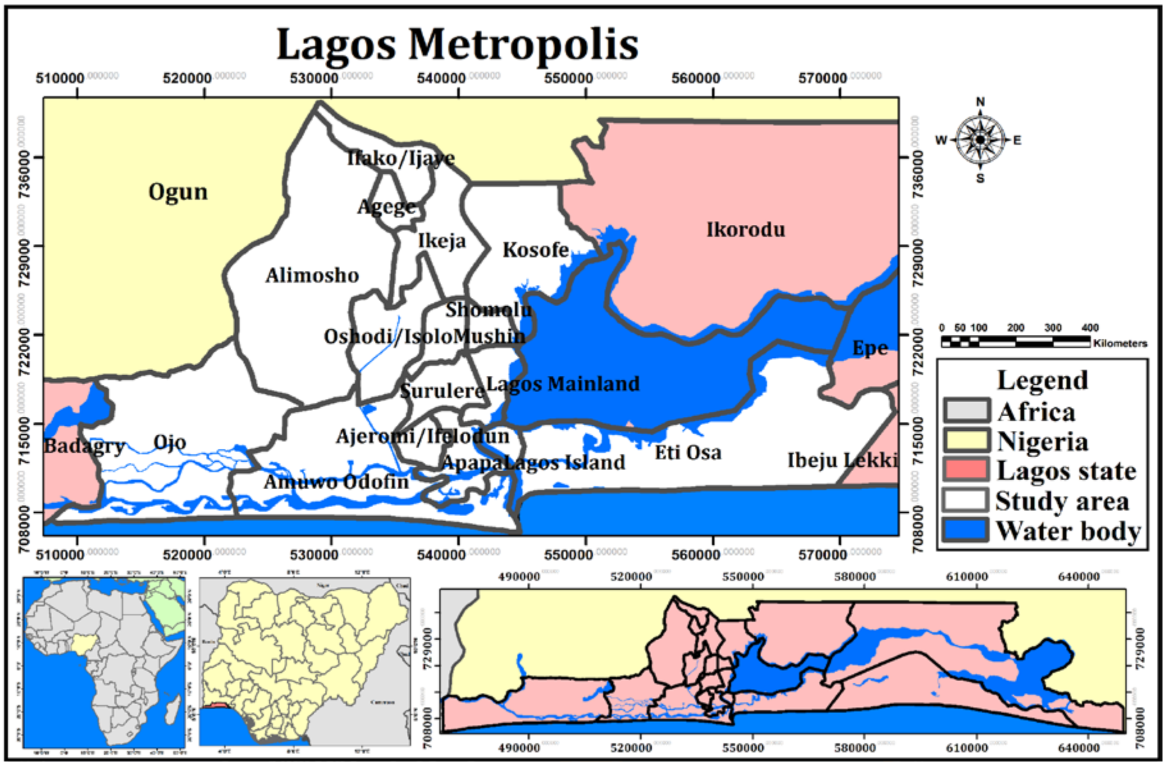

Figure 1. Location of Lagos metropolis.

Lagos metropolis is highly vulnerable to flooding. According to Ibeabuchi et al (2018), the seasonal extent shows that flood is a continuous problem experienced all-round the year whenever there is rainfall in Lagos, Nigeria more especially in MAM, JJA and SON. Further confirmation shows that within the rainy seasons in Lagos the flood stages reaching its peak in the month of September. In addition in Lagos metropolis, flood hazards are natural phenomena…(but) urbanization aggravates flooding by restricting where flood waters can go, covering large parts of the ground with roofs, roads and pavements, obstructing sections of natural channels and building drains that ensure that water moves to rivers faster than it did under natural conditions. As more people crowd into cities, so the effects intensify. As a result, even quite moderate storms produce high flows in rivers because there are more hard surfaces and drains (Action Aid. Climate change, 2006).

Materials and Methods

The study extent of this research covers Lagos metropolis and selected specifically based on its proximity to the coastline and its annual experience of flooding. The information needed for flood hazard and risk mapping was obtained from two major sources, namely: primary and secondary data source. Primary data was obtained from field survey (GPS reading and ground trotting) conducted to help understand and get first-hand information about the land use and flood site throughout Lagos metropolis which is useful to assess the dynamics of change. Primarily, ground trotting was conducted by gathering information on river undercutting, debris flow, and flooding in the watershed. While secondary data obtained includes: **(1.)** DEM (Digital Elevation Model) from SRTM (Shuttle Radar Topography Mission) 90m resolution. **(2.)** Local Government Area (LGA) and road maps of Lagos metropolis (GIS vector file format) was acquired from Guinea Current Large Marine Ecosystem (GCLME) and Unilag Regional Centre for Environmental Management, University of Lagos, Nigeria. **(3.)** Ikonos satellite imagery with a resolution of 1m covering Lagos metropolis for 2010. **(5.)** Landsat 4 - Thematic Mapper (TM) and 7- Enhanced Thematic Mapper Plus (ETM+) imagery for 1990 and 2011 with a Path/Row of 191/055,056 and a resolution of 30m was acquired from USGS (U.S. Geological Survey) Earth Explorer. **(6.)** Monthly rainfall data was acquired from *HadCM3* (Hadley Centre Coupled Model, Version 3) in Microsoft excel file format from the contribution of the *Coupled Model Inter-Comparison Project* (CMIP), IPCC 4th Assessment Report between 1971 and 2013. **(7.)** Monthly flood stage records for a 1-in-20-years return period between 1971 and 2013 were acquired from Iju station in Lagos from Federal Ministry of Transport Inland Waterways Division, Lokoja, Kogi state, Nigeria. This data was used as input into HEC-RAS simulation to model flood in Lagos metropolis. It is important note that Lagos metropolis has no gaged station and it is not practical to gage all streams, so estimates are often used from gaged streams. Using the guidelines specified, the ungaged location must be on the same stream as the gaged location and the ungaged watershed area must not exceed ±50 percent of the gaged watershed area (Olson, 2009).

For data processing, GPS reading of flood sites from field survey was imported by adding the X and Y coordinates as layers in ArcGIS 10 software for flood sites verification after HEC-RAS simulation. Landsat 4 - TM and 7- ETM+ was used to compile Land Use Land Cover (LULC) maps for the study area using Idrisi Selva software. Two epoch period between 1990 and 2011 was picked to reflex 1-in-20-years return period. Bands 4, 5 and 7 were selected, mosaic and enhanced. While, supervised classification method was adopted to define training sites, extract signatures and classify the remotely sensed imagery using maximum likelihood classification procedure into: (1.) built-up area, (2.) non-built-up area and (3.) water body. Land use created was used as inputs in studying: (1.) The effect of flooding on Lagos metropolis by selecting the built up areas because it what houses the residents, roads, utilities, financial and commercial activities; and (2.) This was used to model flood vulnerability index. LGA map was used to study the effect of flood hazard and risk while it was further used with the road map to extract affect LGAs and streets in Lagos metropolis in Flood Early Warning System study.

Rainfall data collected was analyzed to study the annual rainfall trend using time series analysis, computed in Microsoft Excel 2010 software as well as its seasonal distribution. Time series analysis was used to study the sequence of observation made at equal interval of time between 1971 and 2013. While seasonal rainfall distribution between 1971 to 1999 and 1999 to 2013 was studied to examine seasonal variation and its implication on Lagos metropolis using 2D column graph to depict rainfall depth.

To model flood, the DEM (Digital Elevation Model) was used for TIN (Triangulated Irregular Network) generation in ArcGIS 10 software as required in GeoRAS environment in order to prepare the datasets for 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 the required datasets for creating import file to HEC-RAS. The following were created: stream centerline, main channel banks (left and right), flow paths, cross sections. 3D layer of stream centerline and cross section was also created. Thus, after creating and editing required themes, RAS GIS import file was created (Ibeabuchi et al., 2018). **(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 the different seasons was 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 (Ibeabuchi et al., 2018). **(c.) Post RAS application** includes: (1.) Import RAS GIS export file; (2.) Generate water surface TIN and (3.) Generate floodplain and depth grid. Post-Processing (Post RAS) facilitates the automated floodplain delineation based on the data contained in RAS GIS output file and the original terrain TIN (Ibeabuchi et al., 2018). Using HEC-GeoRAS functionalities, the imported HEC-RAS results are processed with the TIN of the region to generate the flood water surface extents and the flood water depth files for the return period of 1-in-20 years. The water surface profile data is used to develop a water surface TIN, and the intersection of the water surface TIN with the terrain model TIN is provided for flood visualization. The results can be shown in 2-D or 3-D views (Akbari et al., 2014). Water surface TIN and the original terrain TIN was used to automatically generate inundated depth grids and floodplain polygons. Apart from this, HEC GeoRAS was used to generate the velocity TIN and grid. The process of flood simulation stated above was executed in ArcGIS 10 HEC-GeoRAS 4.3.93 extension and Hec Ras 4.0 software. The flood indunation generated was reclassified according to inundation depth stated in table 1, the flood hazard areas were divided into five categories and this was used to generate the flood hazard.

Table 1. Assigned flood hazard index and category for varying Inundation depth

Inundation Depth*	Hazard Index (*H*) *	Flood Hazard Category*	Description**
No inundation	0	Very Low	No Flooding
Less than 1 m	1	Low	Caution 1: *"Flood zone with shallow flowing and standing water"*
1 to less than 2 m	2	Moderate	Caution 2: *"Flood zone with deep standing water"*
2 to less than 3 m	3	High	Warning level and Dangerous for some (i.e. children): *"Danger: flood zone with deep or fast flowing water"*
3 to less than 4 m	4	Very High	Dangerous for most people: *"Danger: flood zone with deep fast flowingwater"*
4 m or more	5	Extreme	Dangerous for all: *"Extreme danger: flood zone with deep fast flowing water"*

Source: Masood and Takeuchi (2011) *; Priest et al (2008) **.

Also, In this study an attempt was made to classify and map the risk index. The risk faced by people must be seen as a cross-cutting combination of vulnerability and hazard (Wisner et al. 2004). Disasters are a result of the interaction of both; there cannot be a disaster if there are hazards but vulnerability is (theoretically) nil, or if there is a vulnerable population but no hazard event. These three elements: Risk (***R***), Vulnerability (***V***), and Hazard (***H***), can be written in a simple form (Wisner et al. 2004) as:

$$Risk = H \times V \qquad \textbf{(1.)}$$

Where, ***R*** **=** Risk, ***H*** **=** Hazard and ***V*****=** Vulnerability. In this study in other to model flood risk, risk index was calculated by multiplying vulnerability and hazard index. Average depth of inundation was assigned as hazard index. Calculating vulnerability index, percentage of area covered with house/living place and agricultural land were considered (using the LULC and Ikonos satellite imagery). The following steps were adopted in preparing a risk map which includes computing: (1) Vulnerability index as:

$$V_{Index} = \frac{10 \times A_H + 2 \times A_{Aryi} + 0 \times A_0}{A_{Cell}} \qquad \textbf{(2.)}$$

Where, V_{Index} = Vulnerability Index (ranging from 0 to 10), A_H = Area covered by House/Living Place, A_{Agri} = Area covered by Agricultural land, A_0 = Area used for none, and A_{Cell} = Area of one cell. While the risk index was computed as:

$$Risk_{Index} = H_{Index} \times V_{Index} \qquad \textbf{(3.)}$$

Where, $\boldsymbol{R_{Index}}$ = Risk Index (ranging from 0 to 50), $\boldsymbol{H_{Index}}$ = Hazard Index (ranging from 0 to 5) and $\boldsymbol{V_{Index}}$ = Vulnerability Index (ranging from 0 to 10). Using the following steps: Step 1: The whole area was divided into 2000m by 200m cells grid. Step 2: Average inundation depth in each cell, was calculated by re-sampling the 20m resolution inundation map obtained from inundation simulation to 300m resolution using bilinear interpolation method. Step 3: For each cell an integer value ranging from 0 to 5 was assigned as a hazard index according to inundation depth (shown in table 1). Step 4: Equation (2) was used for calculating vulnerability index, with a weight factor

10 and 2 used for area covered by house and agricultural land respectively. Step 5: A risk index for each cell was calculated by multiplying hazard and vulnerability index (Equation 3). Step 6: Then these risk values were converted to raster format and imported. Step 7: The risk map prepared was classified into three distinct risk zones, namely: (a) *Low-risk*, (b.) *Medium-risk*, and (c) *High-risk* area according to risk index stated in table 2.

Table 2. Assigned level of flood risk for varying flood risk index value.

Flood Risk Index	Level of Flood Risk
1 to less than 5	Low
5 to less than 10	Medium
More than 10	High

Source: Masood and Takeuchi (2011)

Surface volume was computed using ArcGIS 10 software Polygon volume tool to calculate the volumetric and surface area between polygons of an input feature class and a terrain dataset or TIN surface. The surface discharge was derived by dividing the surface volume by time (in seconds) to obtain the results in cubic meters per seconds. The runoff time or time of concentration was estimating and expressed as:

$$Time(t) = {}^{L}\!/_{60V} \quad \textbf{(4.)}$$

Where, **t** = Time (*minutes*), ***L*** = the overland flow path of distance, and ***V***= the velocity of overland flow in fps or m/s**.** The flow length (Weight raster) is inputted as distances multiplied by ***1/V*** (velocity) to obtain the runoff time. The runoff time was used to estimate flood discharge time to ascertain its risk on the study area.

Location and spatial dimension of flood, depth, duration and velocity of flood was captured using GIS to study and serve as Flood Early Warning System (FEWS) for Lagos metropolis based on historical information gathered. The hazard map depict the hazard potential and probability of occurrence in an area, risk map generally depict the form, the stakes and the vulnerability of human presence in an hazardous area, as potential severity of impact in combination with the probability or tension of the specific type of hazard to occur in the area (Eleni et al.,2011). Spatial queries were performed to determine and select flood high priority areas and streets in Lagos metropolis (by selecting extreme, very high and high flood hazard areas, and high for flood risk areas) (Ibeabuchi & Nwilo, 2020) using LGAs and road map as bases to extract flood affected areas. This was implemented using ArcGIS 10 software. The results will be presented in tables to show affected LGAs and streets where both hazard and risk are high, based on FEWS for Lagos metropolis.

Results and Discussion

Historical Rainfall Trend and Seasonal variations in Lagos metropolis

Annual rainfall of Lagos metropolis was estimated using rainfall records between 1971 and 2013 as shown in figure 2a. Annual rainfall estimated for Lagos metropolis is higher than its surrounding areas and the rainfall difference between the coasts and inlands was due to the fact that the area is a coastal city bordering the Atlantic Ocean and is influenced by its nearness (or location) 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 (Ibeabuchi et al., 2018). Generally, rainfall statistics was computed and the result reveals that in Lagos metropolis a mean of 9.408mm/day, median of 9.36mm/day, mode of 8.19 mm/day, variance of 0.377mm/day and standard deviation of 0.614mm/day with a fairly strong relationship (1.7%) was observed over years between 1971 and 2013 (Figure 2a). Also, a minimum of 8.19 mm/day and maximum of 10.63mm/day were also observed for Lagos metropolis with a total of 404.56 mm/day of rainfall for the study years between 1971 and 2013. Seasonal changes in rainfall between 1971 and 2013 in Lagos metropolis is shown in figure 2b. Season variations were observed with higher rainfall observed in MAM (March, April, May) which is 9.45mm/day higher than in DJF (December, January, February) which is 3.77mm/day, SON (September, October, November) which is 11.51mm/day lesser than JJA (June, July, August) which is 12.26 mm/day higher than MAM which is 9.45 mm/day between 1971 and 1999. Still on figure 2 between 2000 and 2013, seasonal variations were observed with higher rainfall observed in spring (MAM) (10.56 mm/day) than in winter (DJF) (4.403 mm/day), 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 1999 and 2013. Based on the above results between 1971 to 1999 and 2000 to 2013, higher flood incidents' resulting from rainfall was observed in summer (JJA) and autumn (SON) than in autumn (SON) and lesser in winter (DJF). This has created serious problems of flash floods which are aggravated by the poor surface drainage conditions of the coastal lowlands in Lagos metropolis.

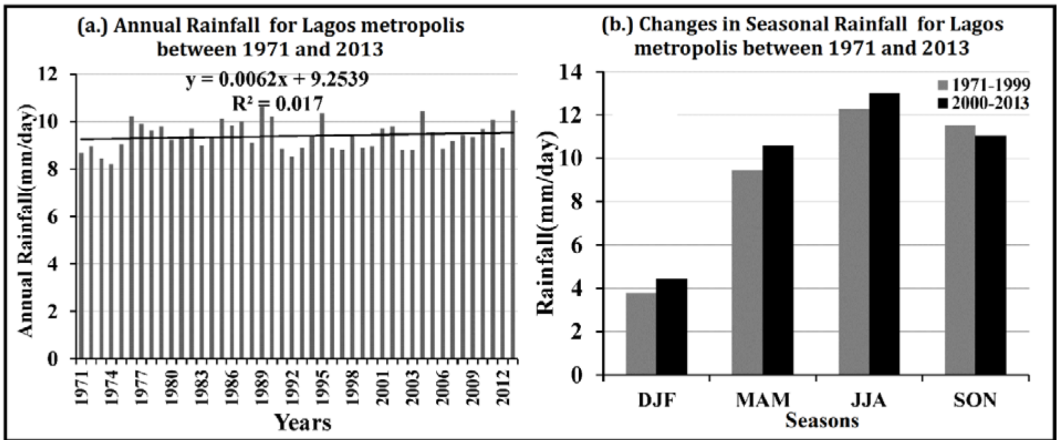

Figure 2. (a.) Monthly maximum Flood stages and (b.) Seasonal maximum Flood stages for Lagos metropolis between 1971 and 2013.

Furthermore, the seasonal and annual rainfall as well as the number of rainy days, show great variability between different locations in Lagos metropolis. Also, the exposure of people and assets in Lagos metropolis to changes in climate and climate extremes has made her vulnerable to flood incident.

Monthly and Seasonal maximum Flood Stages in Lagos metropolis

Monthly maximum flood stages for a 1-in-20 years return period between 1971 and 2013 is presented in figure 3 for monthly and seasonal maximum flood stages in Lagos metropolis. Monthly maximum Flood stages are presented in figure 3a while seasonal flood stages are presented in figure 3b. Seasonal variations in monthly maximum flood stages were observed with higher flood stages (known as *water surfaces*) observed in spring (MAM) (367.33cm) than in winter (DJF) (287cm), autumn (SON) (926cm) is relatively lesser than summer (JJA) (879 cm) but higher than spring (MAM) between 1971 and 2013. This implies higher flood incidents in summer (JJA) and autumn (SON) than in spring (MAM) and lesser in winter (DJF). A mean flood stages of614.83cm annually was recorded and a total of 2459.33cm was observed for Lagos metropolis. This implies that higher surface water and flooding will be experienced in summer and autumn period of the year than in other seasons of the year. From the result presented in figure 3b, flood stages start to rise as rainfall drops start in April, with high sediment discharge in July. The water level rises rapidly attaining its peak between late September and early October then recedes faster than it rise by December, the water that had been retarded inland arrives to sustain a steady flow which continues until April when another drops experience starts.

Mapping the effect of Seasonal Flood Hazard on Lagos metropolis

Seasonal flood inundation map of Lagos metropolis is presented in figure 4 for a 1-in-20 years return period for DJF, JJA, MAM and SON season. According to the flood inundation depth, the whole area has been divided into five categories based on the classification scheme presented in table 1 and result was mapped as shown in figure 5 for Lagos metropolis for a 1-in-20 years return period for DJF, JJA, MAM and SON season for 1990 and 2011. In Lagos metropolis, for DJF season, 64.69km^2 was inundated by low flood hazard, 28.96km^2 by moderate flood hazard, 24.23km^2 by high flood hazard, 18.34km^2 by very high flood hazard and 9.42km^2 by extreme flood hazard in 1990. In 2011, for DJF season 64.44km^2 was inundated by low flood hazard, 28.53km^2 by moderate flood hazard, 20.22 km^2 by high flood hazard, 21.50 km^2 by very high flood hazard and 10.52 km^2 by extreme flood hazard. For a 1 in 20 year return period in MAM, 66.98km^2 was inundated by low flood hazard, 34.81km^2 by moderate flood hazard, 23.96km^2 by high flood hazard, 18.67km^2 by very high flood hazard and 12.73km^2 by extreme flood hazard in 1990. In 2011, for MAM season 77.65 km^2 was inundated by low flood hazard, 27.71km^2 by moderate flood hazard, 19.29km^2 by high flood hazard, 17.29km^2 by very high flood hazard and 9.65km^2 by extreme flood hazard. For a 1 in 20 years return period in JJA, 64.02km^2 was inundated by low flood hazard, 35.73 km^2 by moderate flood hazard, 23.96 km^2 by high flood hazard, 18.68 km^2 by very high flood hazard and 12.73km^2 by extreme flood hazard in 1990.

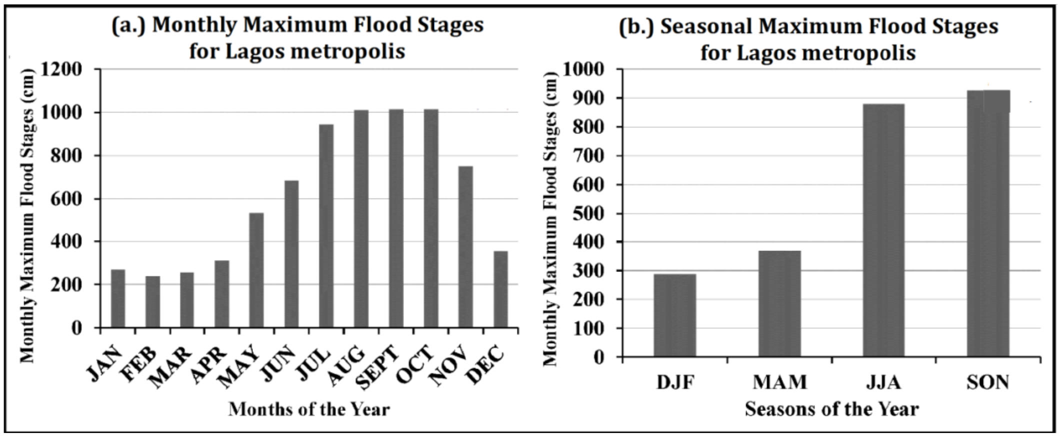

Figure 3. (a.) Monthly maximum Flood stages and (b.) Seasonal maximum Flood stages for Lagos metropolis between 1971 and 2013.

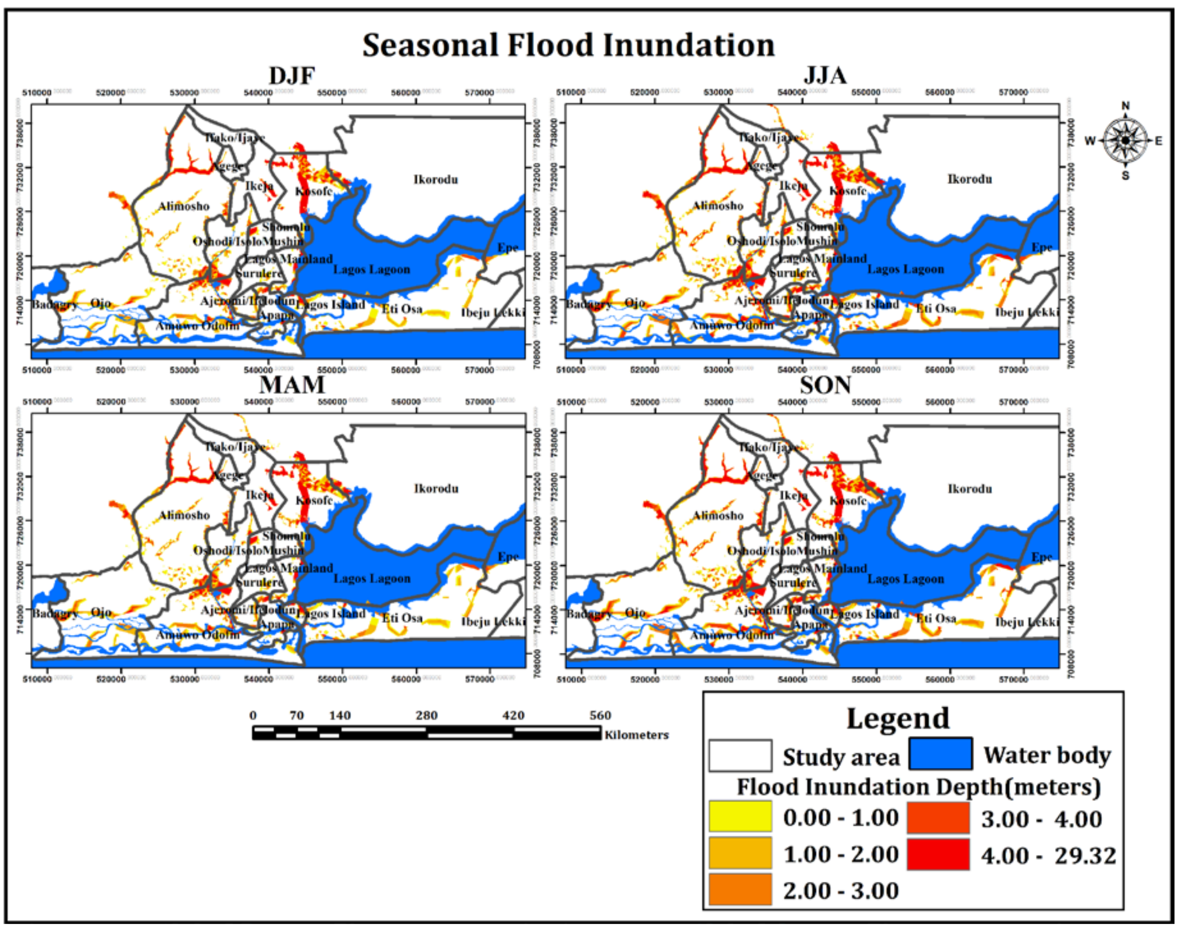

Figure 4. Flood inundation depth for Lagos metropolis for DJF, MAM, JJA and SON season for a 1 in 20 years return period.

For 2011, 38.3 km^2 was inundated by low flood hazard, 26.86km^2 by moderate flood hazard, 12.15km^2 by high flood hazard, 14.92km^2 by very high flood hazard and 6.02km^2 by extreme flood hazard. For a 1 in 20 year return period in SON, 40.17km^2 was inundated by low flood hazard, 33.65km^2 by moderate flood hazard, 29.11km^2 by high flood hazard, 27.76km^2 by very high flood hazard and 14.95km^2 by extreme flood hazard in 1990.

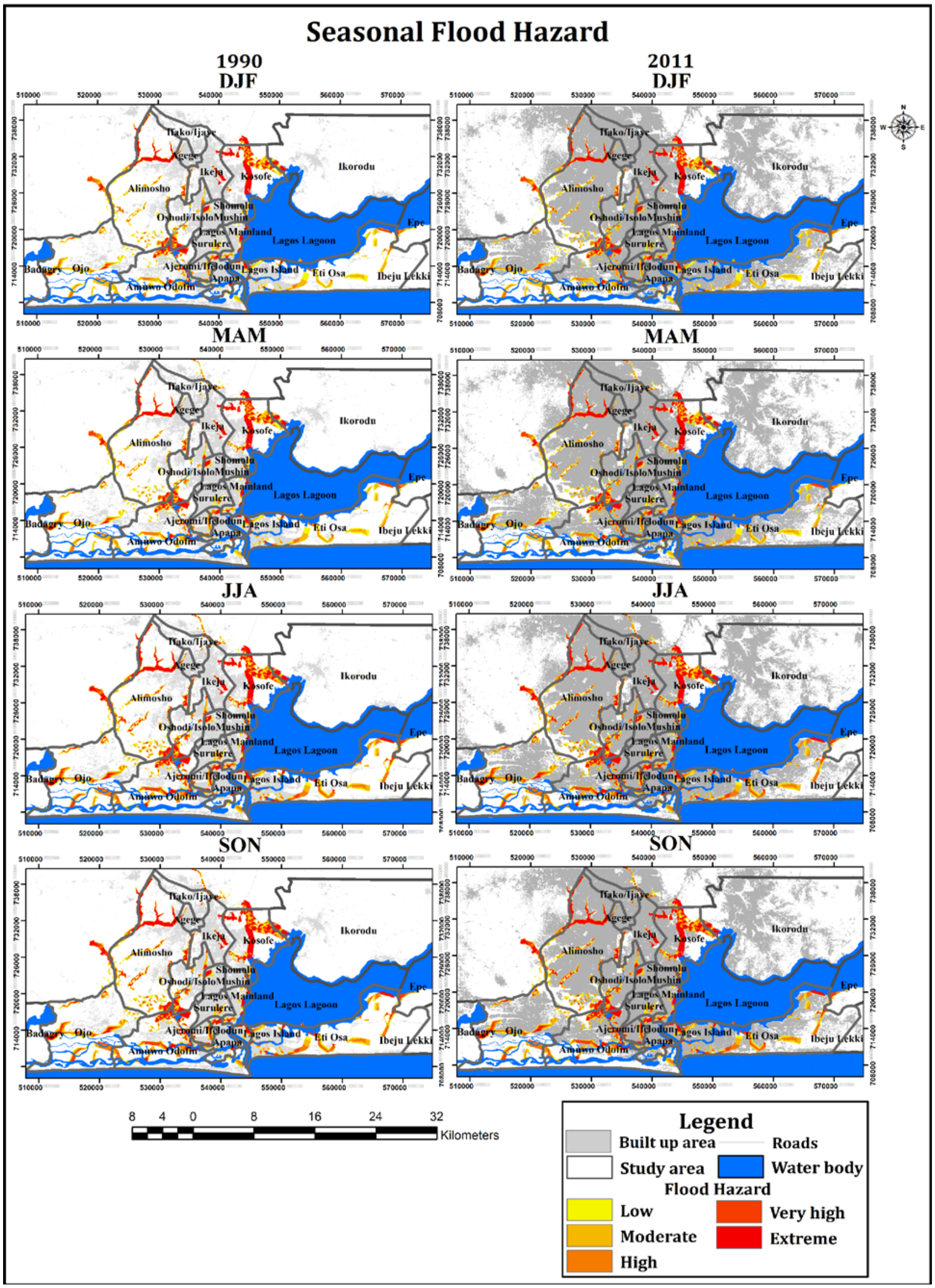

Figure 5. Flood hazard for DJF, JJA, MAM and SON season in Lagos metropolis for 1990 and 2011 for a 1 in 20 years return period.

For 2011, 38.10km^2 was inundated by low flood hazard, 19.15km^2 by moderate flood hazard, 11.19km^2 by high flood hazard, 11.73km^2 by very high flood hazard and 5.93km^2 by extreme flood hazard. Higher and extreme seasonal flood were ranked as highest for 1990 and 2011 for SON season with low flood dominating DJF season. Vulnerability to flood hazard experienced increases from extreme to low flood hazard for DJF season while sharp undulating changes were observed for SON, MAM, and JJA season with JJA season ranked as the highest for 1990 and 2011.

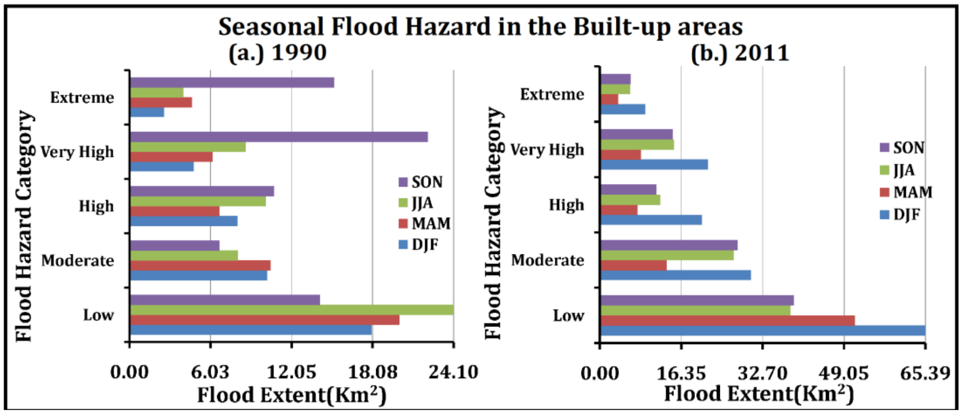

Figure 6. Extent of hazard in the built up areas of Lagos metropolis for DJF, JJA, MAM and SON season covered by flood in 1990 and 2011 for a 1 in 20 years return period.

The most vulnerable to flood hazard are built-up areas as shown in figure 5 and graphically presented in figure 6 showing the level of damage incurred in Lagos metropolis for 1990 and 2011. This also reveals that the extent of flood is wider in the lower parts of the study reach as compared to the upper reach due to variation in channel geometry and reduction in slope of the area. Figure 7 shows the seasonal flood extent for the Local Government Areas (LGAs) in Lagos metropolis for 1990 and 2011. The flood incident and damage incurred is higher in JJA and MAM than in SON and lesser in DJF in Lagos metropolis for 1990 and 2011 using the Local Government Areas (LGAs) in Lagos metropolis. The most affected LGAs include: Lagos Island, Eti Osa, Amuwo Odofin, Kosofe, Ajeromi/Ifelodun Local Government Areas (LGAs) followed by Apapa, Ojo, Lagos mainland and Surulere. The effects of flooding in Lagos metropolis include: (1.) inundation of some low-lying riverside areas; (2.) higher flooding in areas currently at risk of flooding; and (3.) expansion of areas being exposed to flooding (Ibeabuchi et al., 2020).

Mapping the effect of Seasonal Flood Risk on Lagos metropolis

Seasonal flood risk of Lagos metropolis is shown in figure 8, based on the classification scheme in stated in table 2 for a 1 in 20 years return period for DJF, JJA, MAM and SON season for 1990 and 2011. For DJF season, 43.67km^2 was inundated by low flood risk, 83.01km^2 by moderate flood risk, and 16.94km^2 by high flood risk in 1990. In 2011, for DJF season 55.64km^2 was inundated by low flood hazard, 73.24km^2 by moderate flood hazard, and 17.54km^2 by high flood risk. For a 1 in 20 year return period in MAM, 57.54km^2 was inundated by low flood risk, 81.87km^2 by moderate flood risk, and 14.76km^2 by high flood risk in 1990. In 2011 for MAM season, 45.24km^2 was inundated by low flood risk, 92.94km^2 by moderate flood risk, and 13.37km^2 by high flood risk. For a 1 in 20 year return period in JJA, 56.13km^2 was inundated by low flood risk, 91.52km^2 by moderate flood risk, and 26.13km^2 by high flood risk in 1990. In 2011 for JJA season, 53.12km^2 was inundated by low flood risk, 101.56 km^2 by moderate flood risk, and 19.246km^2 by high flood risk. For a 1 in 20 year return period in SON, 41.36km^2 was inundated by low flood risk, 76.84km^2 by moderate flood risk, and 27.44km^2 by high flood risk in 1990. In 2011 for SON season, 56.57km^2 was inundated by low flood risk, 98.15km^2 by moderate flood risk, and 20.17km^2 by high flood risk. Moderate seasonal flood risk were ranked as highest between 1990 and 2011 with high flood dominating JJA season followed by SON season and the lowest risk was observed in DJF season in terms of flood risk category. However, the most vulnerable to flood risk is the built-up areas as shown in figure 8 and graphically presented in figure 9 showing level of damage incurred in Lagos metropolis.

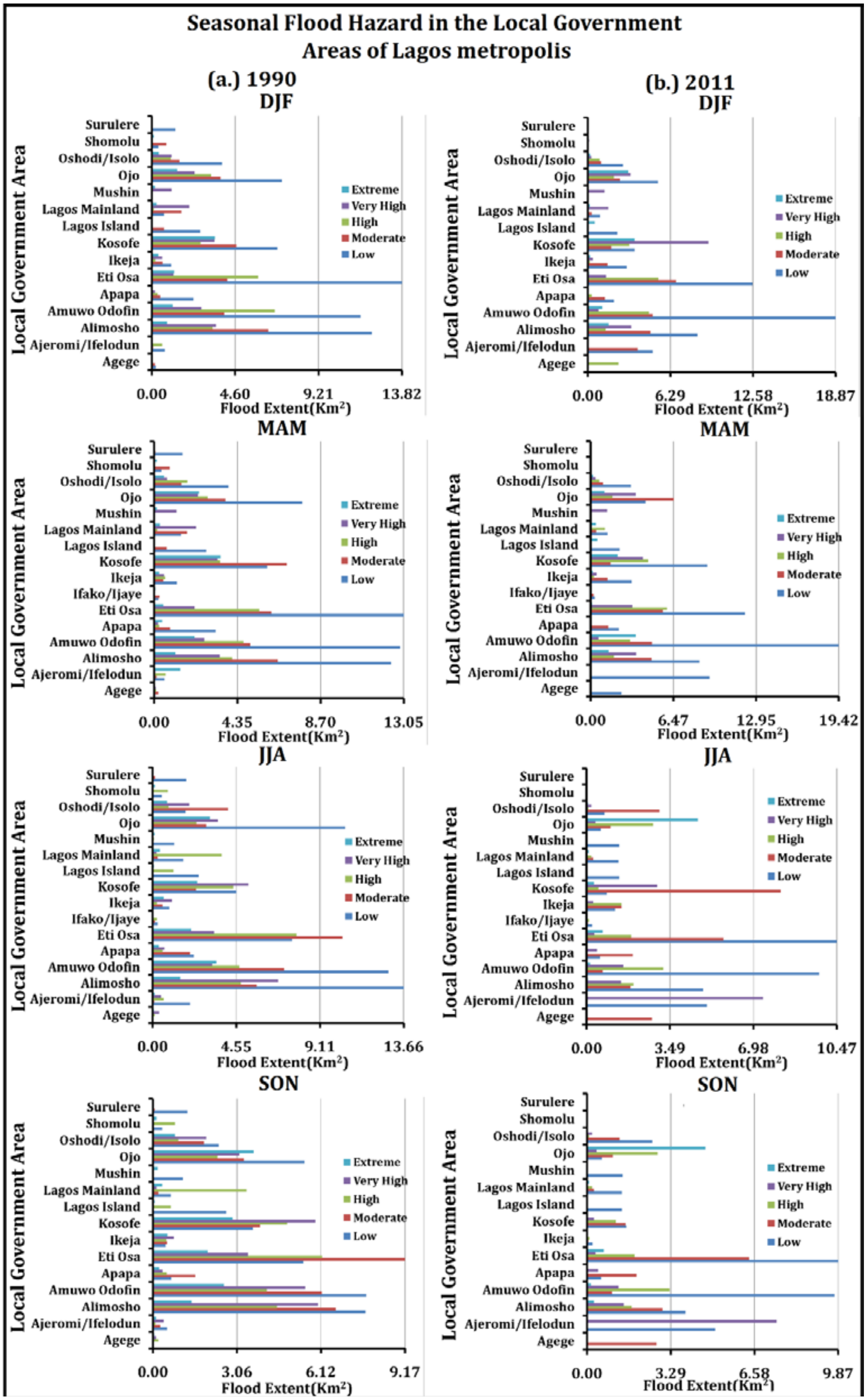

Figure 7. Flood hazard for DJF, JJA, MAM and SON season in the Local Government Area of Lagos metropolis for 1990 and 2011 for a 1 in 20 years return period.

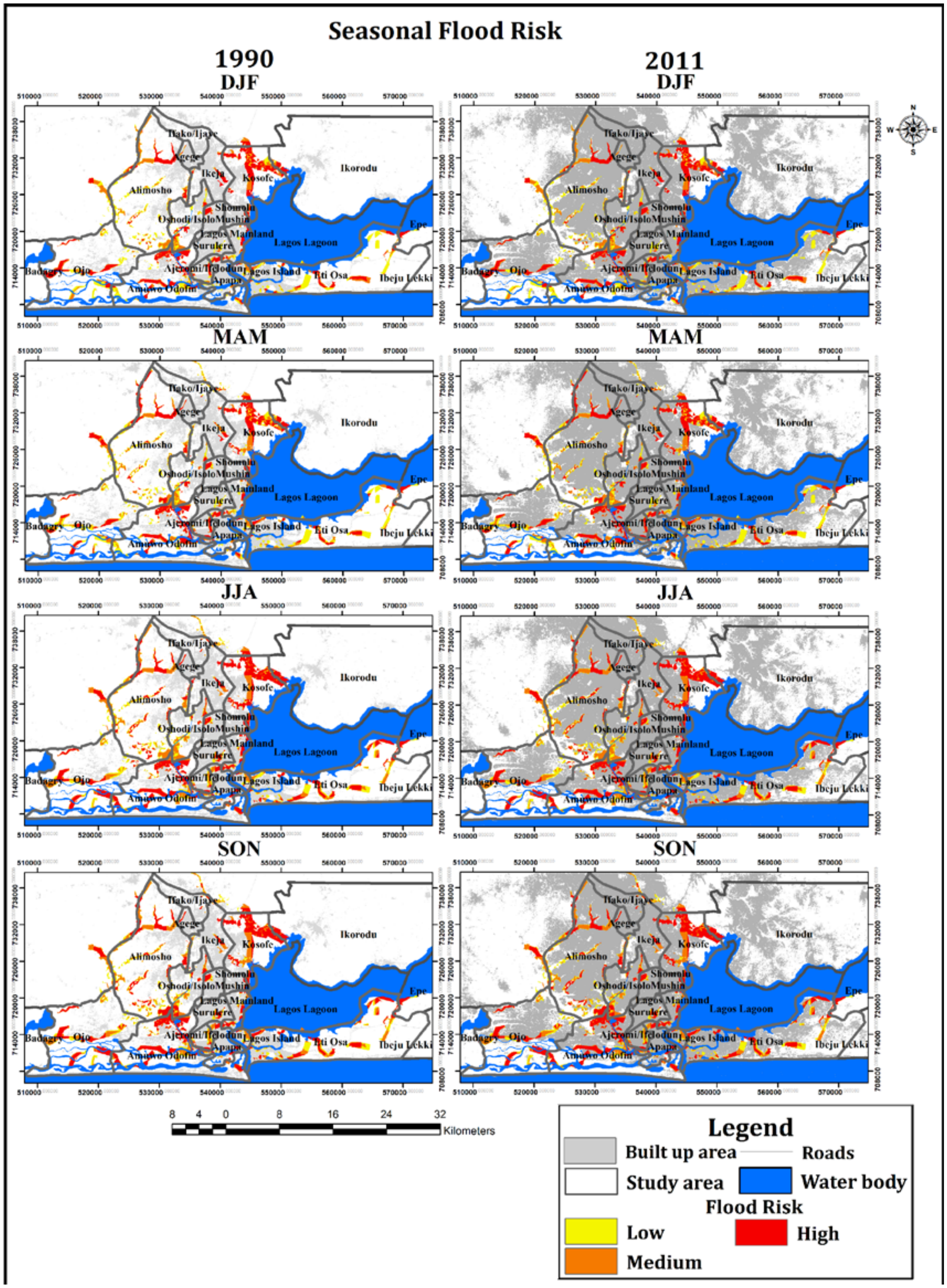

Figure 8. Flood risk for DJF, JJA, MAM and SON season in Lagos metropolis for 1990 and 2011 for a 1 in 20 years return period.

The risk extent and damage of flooding shows that flooding is a continuous problem experienced all-round the year whenever there is rainfall in Lagos metropolis more especially in MAM, JJA and SON, with higher impact in JJA and SON season. Furthermore, this reveals that Lagos is a coastal city which is constantly inundated by flooding.

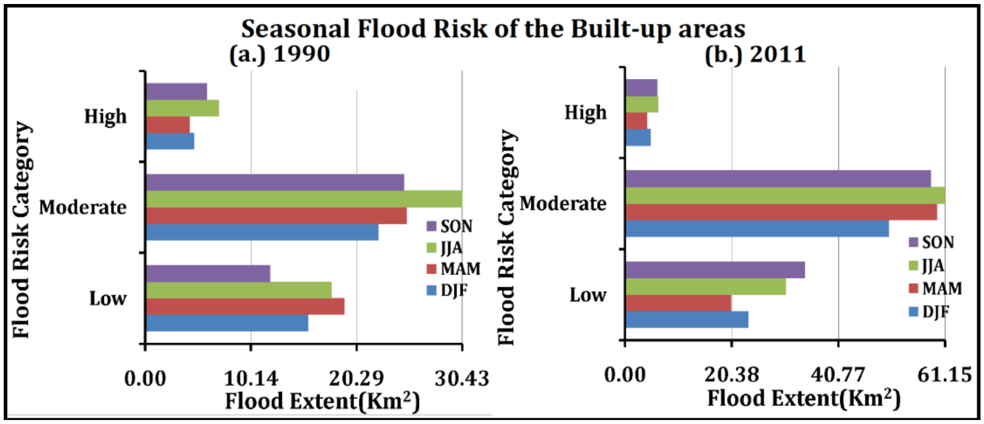

Figure 9. Extent of risk in the built up areas of Lagos metropolis for DJF, JJA, MAM and SON season covered by flood in 1990 and 2011 for a 1 in 20 years return period.

The results concludes that the frequency of heavy rainfall (as presented Figure 2) and flood risk (as presented Figure 8)events has increased over Lagos metropolis between the late 20th and early 21st century, and that it is more likely than not that there has been a human contribution to this trend due to its low laying topography (between a slope of 1 and 1.63^{0}), urbanization which has caused serious disruption of movement and transportation, socio-economic activities and the population of Lagos metropolis. Flood risk areas for the LGAs are shown in figure 10 for Lagos metropolis. The risk of flood incident is higher in JJA and MAM than in SON and lesser in DJF in Lagos metropolis. The most affected LGA includes Lagos Island, Eti Osa, Amuwo Odofin, Kosofe, Ajeromi/Ifelodun LGA followed by Apapa, Ojo, Lagos mainland and Surulere.

Flood Seasonal Discharge, Runoff-Time and Velocity for Lagos metropolis

Seasonal flood velocity was mapped and presented in figure 11. Seasonal variations in flood discharge were observed in spring (MAM) which is 387254699.21m^3/s higher than winter (DJF) which is 5461694.99 m^3/s and autumn (SON) which is 490974298.98 m^3/s relatively lesser than summer (JJA) which is 483628497.28 m^3/s but higher than spring (MAM) between 1990 and 2011. This implies that higher flood incidents is observed in summer (JJA) and autumn (SON) than in autumn (SON) and lesser in winter (DJF) due to high discharge as a result of rainfall runoff. Also, flood runoff velocity was mapped for Lagos metropolis and presented in figure 11. A high flood velocity was recorded for Lagos metropolis with fast flood rates in the inland areas between 0.34 – 3.00m/s of Ikeja, Ifako/Ijaye, Alimosho, Oshodi/Isolo and Ojo areas than areas boarding the coastline and water body between 0.02 – 0.34 m/s as shown and presented in figure 11. This implies a higher damage inland than the coastline regions and water body because most built up areas are found inland in Lagos metropolis. Flood runoff time was mapped for Lagos metropolis and presented in figure 12. For flood runoff (discharge) time, a maximum discharge time of 56.96hrs (2.29days) and a minimum of 1.33hrs were recorded for Lagos metropolis. This is high due to human inferences and the low-lying nature of Lagos metropolis' terrain. The flood discharge time in figure 12 marches the record of the flood velocity in figure 11.

Developing Flood Early Warning Systems for Lagos metropolis using GIS

Flood Early Warning Systems (FEWS) map for Lagos metropolis is shown in figure 13. To develop a FEWS, flood warning and danger level within Lagos metropolis was calculated using figure 4. It was observed that a recorded gauge height (or flood depth) of 1m as a threshold value is marked as the starting point were flooding begins and the water level at 3m is marked as the warning level as shown in table 1, these are important bench mark for flood warning systems. Gauge height exceeding 3m causes flooding in the settlements. Therefore, gauge height greater than 4 m is demarcated as danger level. At the start of the rainy season, the hazard done by flooding is high, so in MAM season warming notes should be give out to residents of Lagos metropolis more especially those that is situated around floodplains.

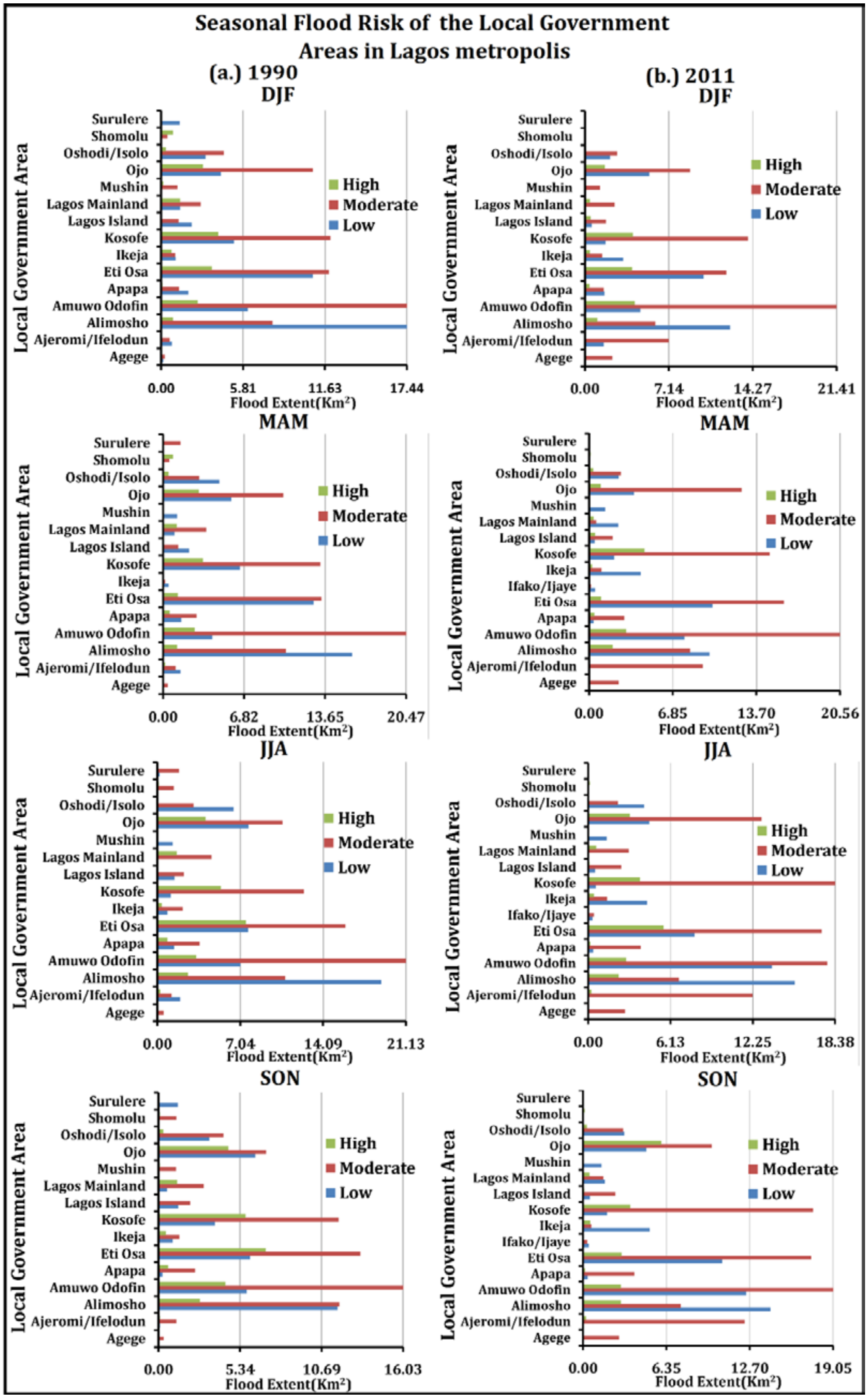

Figure 10. Flood risk for DJF, JJA, MAM and SON season in the Local Government Area of Lagos metropolis for 1990 and 2011 for a 1 in 20 years return period.

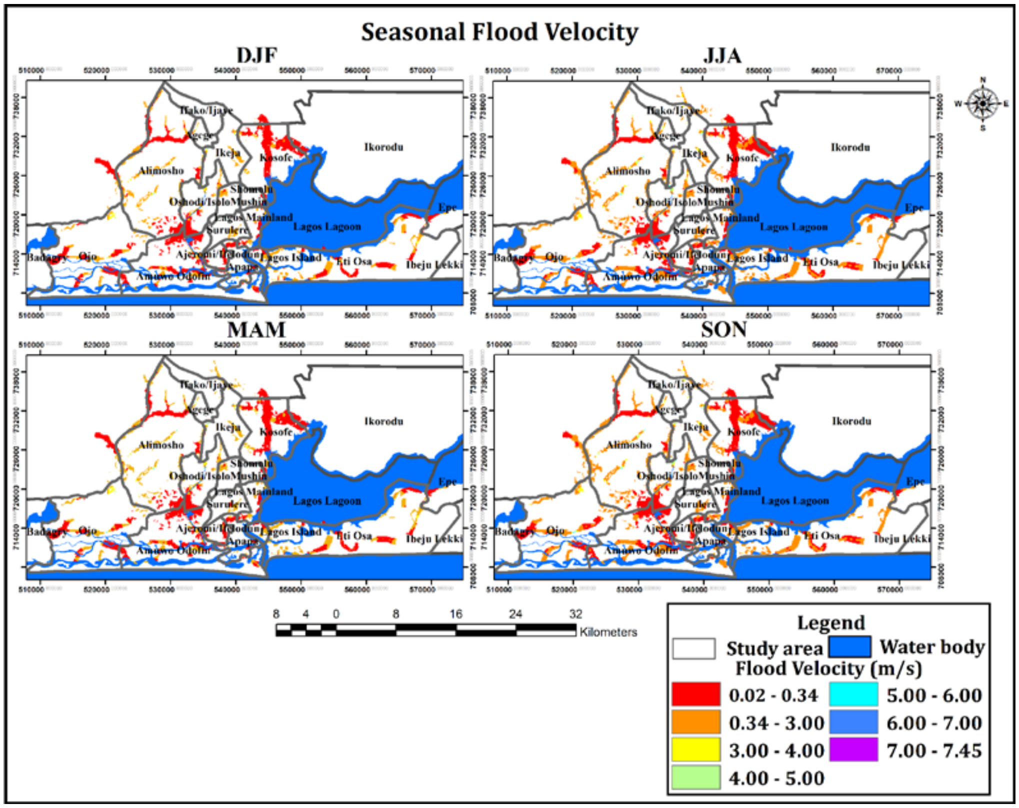

Figure 11. Flood velocity for DJF, MAM, JJA, and SON season in Lagos metropolis for a 1 in 20 years return period.

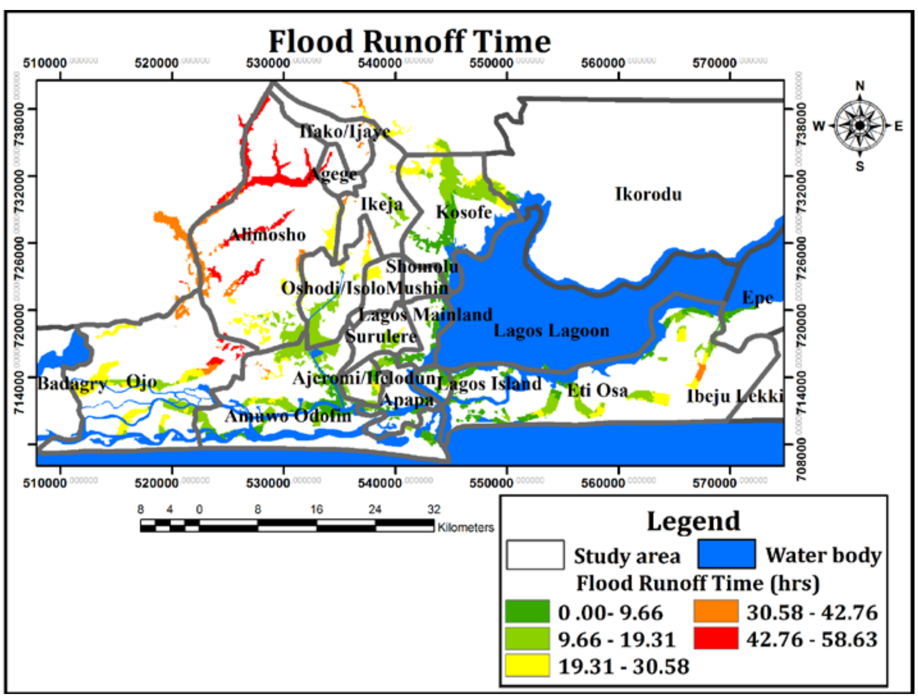

Figure 12. Flood runoff time for Lagos metropolis.

This is because the warning level is frequently exceeded and the danger level also exceeded at different times by annual floods and the trend of discharge has consistently increased, attributed to changes in rainfall pattern and climate regime of Lagos metropolis. Also other measure adopted includes, the flood velocity and runoff time, this could service as warming to those living on floodplain and encroaching development. Lagos metropolis has a long flood duration time lasting 2.29days; this however characterizes its high number of casualties and extends of the damage done. Historical information on the intensity and magnitude of floods, and information on the extent and depth of previous flood events or flood predictions, and flood marks mention was captured using GIS and model to serve as an early warning system for Lagos metropolis. Using the Flood Early Warning Systems (FEWS) map in JJA season for Lagos metropolis as a case study, affected Local Government Areas (LGAs) and streets were highlighted to show areas affected by flood and tabulated below in table 3 and 4 (Appendix 1). In conclusion, the following facts were observed about flooding in Lagos metropolis, water depth, inundation extent and duration as well as depth averaged velocity are factors that influence the level of flood impacts on the study area.

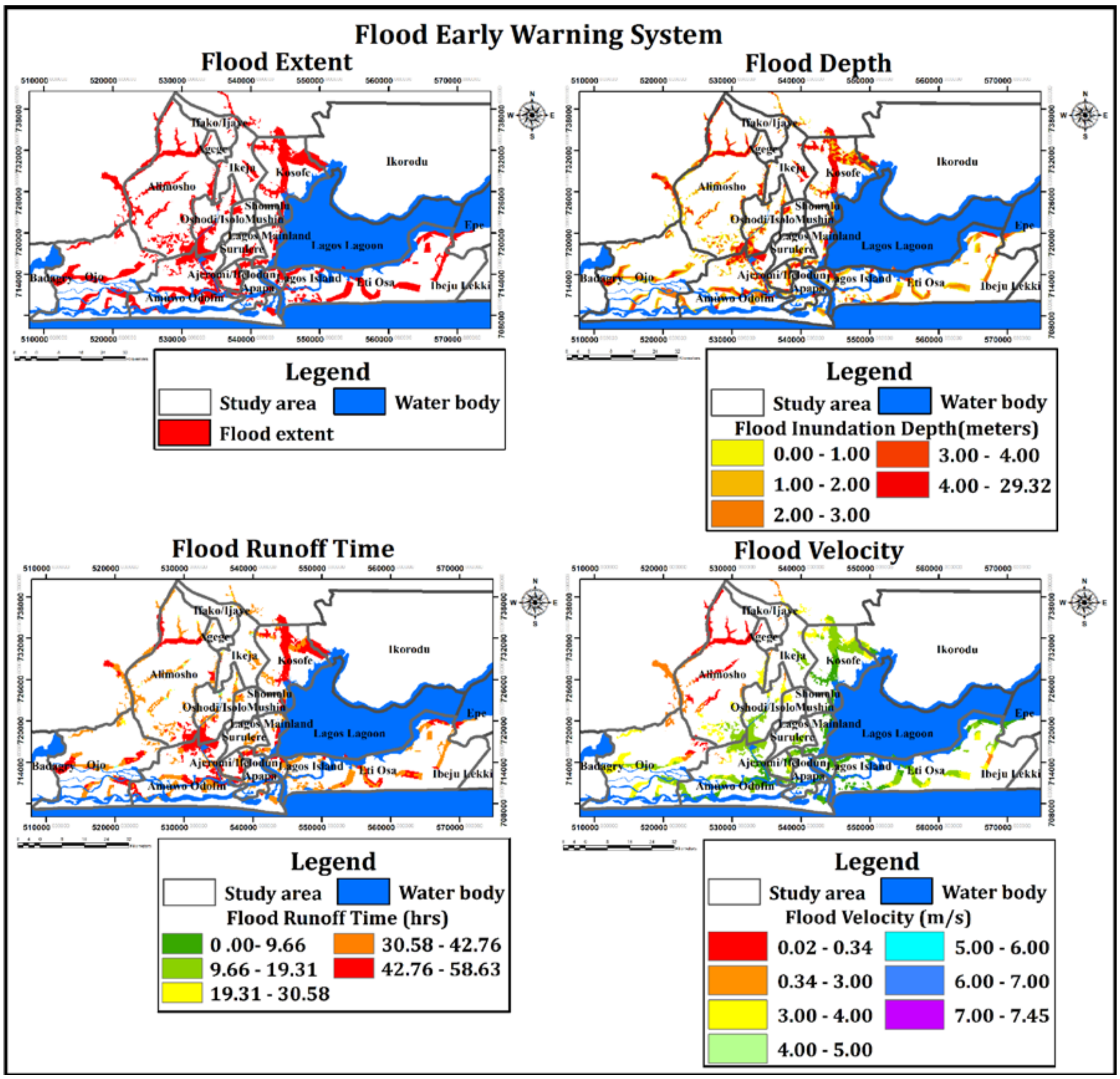

Figure 13. Flood Early Warning System (FEWS) in JJA season for Lagos metropolis showing flood extent, depth, runoff time and velocity.

Conclusion

Flood has remained a major problem of Lagos metropolis for years. These floods have been reported to be more destructive along the coastline and rivers bordering Lagos metropolis. The main problem associated with flooding in Lagos metropolis is its eroding nature and constant flooding of the inlands areas. Valuable socio-economic activities and residential area is being lost with each flood season due to bank cutting and water impoundment. The identification of risk and hazard areas was done to determine the vulnerability of flood areas. Change in seasonal rainfall pattern and human intervention were identified as the main causes of flood hazards and risk. Changes in climate pattern made these areas more vulnerable. HEC-RAS flood simulation and GIS was used to produce a flood hazard and risk map. The objective of flood hazard and risk map is to provide residents with the information on the range of possible damage and the disaster prevention activities. The effective use of hazard and risk map can decrease the magnitude of disasters. Special attention of the concerned body on this disaster should be drawn for the mitigation and to minimize loss from damage. As land development and urbanization is going on that area both maps should be updated regularly. The following recommendations are made for upgrading these maps: **(1.)** Rainfall, evaporation, percolation which is ignored in current study can be included for further studies. **(2.)** Town watching, conversation with local people and survey are very important work for making an effective flood hazard map, but this could not be performed for this study and for future studies this should be conducted. **(3.)** For risk mapping, hazard index has been assigned according to inundation depth. But other factors such as frequency of flood, duration of flood should be considered. For assigning vulnerability index, factors such as percentage of area covered by built-up area were considered. But there are lots of factors other than that responsible for degree of vulnerability which should be considered for future studies.

Conflict of interest

The author declare that there was no conflict of interest.

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APPENDIX 1

Table 3. Affected streets and residents in JJA season for Flood Early Warning Systems (FEWS) in Lagos metropolis.

Street Name	Road Class	Local Government Area	Street Name	Road Class	Local Government Area
Abukuru Street	Service Roads	Ajeromi/Ifelodun	Wasiu Ogunlana Road	Service Roads	Amuwo Odofin
Apapa Oworonshoki Expressway	Expressway	Ajeromi/Ifelodun	Adeponle Street	Service Roads	Apapa
Aroworade Street	Service Roads	Ajeromi/Ifelodun	Akorede Street	Service Roads	Apapa
Ladega Street	Service Roads	Ajeromi/Ifelodun	Amusa Street	Service Roads	Apapa
Odofin Street	Service Roads	Ajeromi/Ifelodun	Church Street	Service Roads	Apapa
Ogungbe Street	Service Roads	Ajeromi/Ifelodun	Giwa Street	Service Roads	Apapa
Oguntokun Street	Service Roads	Ajeromi/Ifelodun	Ireti Owoseni Street	Service Roads	Apapa
Oja Street	Service Roads	Ajeromi/Ifelodun	Sule Street	Service Roads	Apapa
Oyegbemi Street	Service Roads	Ajeromi/Ifelodun	Alimosho Road	Service Roads	Eti Osa
Sanni Aro Street	Service Roads	Ajeromi/Ifelodun	Ijeh Village Road	Collector Roads	Eti Osa
Allhaji Alhaja Street	Service Roads	Alimosho	Adegbeyeni Street	Service Roads	Ikeja
Bosoro Street	Service Roads	Alimosho	Alfred Olaiya Street	Service Roads	Ikeja
Jimoh Street	Service Roads	Alimosho	Bolanle Close	Service Roads	Ikeja
Kajola Street	Service Roads	Alimosho	Methodist Church Street	Service Roads	Ikeja
Kokumo Street	Service Roads	Alimosho	Omodara Street	Service Roads	Ikeja
Lateef Adeleye Street	Service Roads	Alimosho	Shodipo Close	Service Roads	Ikeja
Mosalasi Street	Service Roads	Alimosho	Abbi Crescent	Service Roads	Kosofe
Ogunrinde Street	Service Roads	Alimosho	Adebisi Okunwa Oladapo Avenue	Service Roads	Kosofe
Ola Momi Street	Service Roads	Alimosho	Adeite Osogun Street	Service Roads	Kosofe
Olorun Timilehin Street	Service Roads	Alimosho	Aimasiko Street	Service Roads	Kosofe
Prophet M.A Olorunsegun Avenue	Service Roads	Alimosho	Aina Road	Collector Roads	Kosofe
Road. 07	Service Roads	Alimosho	Akanimodo Street	Service Roads	Kosofe
Road. 09	Service Roads	Alimosho	Akin Tijani Street	Service Roads	Kosofe
Salawu Street	Service Roads	Alimosho	Apostle Afinjuoba Street	Service Roads	Kosofe
Samuel Onajole Street	Service Roads	Alimosho	Asije Avenue	Service Roads	Kosofe
SF Adewale Close	Service Roads	Alimosho	Baptist Church Street	Service Roads	Kosofe
Taju Salami Street	Service Roads	Alimosho	Bosere Street	Service Roads	Kosofe
Tejuola Akintade Street	Service Roads	Alimosho	Celestial Street	Service Roads	Kosofe
Maria Road	Service Roads	Amuwo Odofin	Falege Aina Street	Service Roads	Kosofe

Table 4. Affected streets and residents in JJA season for Flood Early Warning Systems (**FEWS**) in Lagos metropolis.

Street Name	Road Class	Local Government Area	Street Name	Road Class	Local Government Area
Ibikunle Street	Service Roads	Kosofe	Rotimi Lane	Service Roads	Mushin
Igboye Street	Service Roads	Kosofe	Rowland Street	Service Roads	Mushin
Isaac Omojole Street	Service Roads	Kosofe	Unity Close	Service Roads	Mushin
Issac Adenuga Street	Service Roads	Kosofe	Adebisi Bamigbelu Street	Service Roads	Ojo
Kayode Taiwo Street	Service Roads	Kosofe	Aiyelero Street	Service Roads	Ojo
Kolawole Street	Service Roads	Kosofe	Alh. Risikatu Seriki Street	Service Roads	Ojo
Ladipo Close	Service Roads	Kosofe	Amodu Toogun Lane	Service Roads	Ojo
Lanre Shittu Close	Service Roads	Kosofe	Ayilara Street	Service Roads	Ojo
New World/Oldimeji Street	Service Roads	Kosofe	Church Close	Service Roads	Ojo
Odulake Street	Service Roads	Kosofe	Jimoh Street	Service Roads	Ojo
Ogidi Street	Service Roads	Kosofe	Kunle Bolarinwa Street	Service Roads	Ojo
Ogundipe Street	Service Roads	Kosofe	Saka Street	Service Roads	Ojo
Ogunmade Street	Service Roads	Kosofe	Adedeji Street	Service Roads	Oshodi/Isolo
Ojurayo Street	Service Roads	Kosofe	Aduke Thomas Street	Service Roads	Oshodi/Isolo
Olawole Close	Service Roads	Kosofe	Alh. Rafiu Street	Service Roads	Oshodi/Isolo
Omo Banta Close	Service Roads	Kosofe	Church Street	Service Roads	Oshodi/Isolo
Omo Banta Street	Service Roads	Kosofe	Eyin Ogun Street	Service Roads	Oshodi/Isolo
Omosebi Street	Service Roads	Kosofe	Jubrila Street	Service Roads	Oshodi/Isolo
Oremeji Street	Service Roads	Kosofe	Odunmbaku Street	Service Roads	Oshodi/Isolo
Western Avenue	Expressway	Kosofe	Okeleye Street	Service Roads	Oshodi/Isolo
Alakoro Street	Service Roads	Lagos Island	Olusoji Street	Service Roads	Oshodi/Isolo
Church Street	Service Roads	Lagos Island	Oluwole Street	Service Roads	Oshodi/Isolo
Idi-Omo Street	Service Roads	Lagos Island	Salami Street	Service Roads	Oshodi/Isolo
Obun Eko Street	Service Roads	Lagos Island	Alh. Yinusa Street	Service Roads	Shomolu
Ajayi Olaiya Street	Service Roads	Lagos Mainland	Ifesowapo Street	Service Roads	Shomolu
Victoria Street	Service Roads	Lagos Mainland	Keke Street	Service Roads	Shomolu
Alh. Akinwumi Street	Service Roads	Mushin	Opeloyeru Street	Service Roads	Shomolu
Daramola Street	Service Roads	Mushin	Rebecca Ayetiwa Street	Service Roads	Shomolu
Oshinkalu Street	Service Roads	Mushin	Seriki Street	Service Roads	Shomolu