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URBAN FLOOD VULNERABILITY MAPPING OF LAGOS, NIGERIA

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Abstract

The paper aimed to demonstrate how the application of HEC-RAS and GIS techniques can be utilized for better results when carrying out a flood vulnerability mapping and assessment. Digital interpretation that uses HEC-RAS and GIS to conduct hydraulic modelling, flood inundation mapping and visualization were adapted. Similarly, Digital Terrain Model (DTM) and aerial imagery of lansat8 OLI of the study area were used. The data were analysed with the aid of ArcGIS 10.1 application with HEC-GeoRAS tool extension and HEC-RAS 4.1 software application. The results showed: 1) the flood vulnerability map of Lagos (Figure 4) generated using the combination GIS techniques and RAS packages. The flood risk depicted shown areas that have 1 % probability of flood occurrence in 100 years; 2) The topography of Lagos (Figure 5) indicated the pattern of the city terrain to be relatively flat in the centre and it also has few meters high above sea level especially in the south-eastern areas; 3) of the 20 local government areas Lagos state (Figure 6) only two (Agege and Ifako) were found not to be at risk of flooding. We concluded that flood vulnerability of this kind is important for Nigeria and other countries to aid decision on flood disaster planning.

Key words

Flood, Mapping, GIS, Flood Vulnerability

1. Introduction

Flood is an overflow of water that covered the land surfaces that are normally dry. This includes overflow from water bodies like river, lake, sea and also overflow as a result of heavy rainfall, snow melt and/or dam break resulting in some of that water to escape out of its natural boundaries (Leinster, 2009). It is a natural event that occurs on the land surface which can affect people and the environment negatively or even positively. "Among all kinds of natural hazards of the world: flood is probably the most devastating, widespread and most frequent" (Sanyal, 2004 P.383). Flood vulnerability is defined as "probability of flood occurrences and its potential consequences" (Alexander 2011, p.6). So, flood vulnerability mapping is the presentation or representation of areas that are at risk of flood events on maps. Flood vulnerability mapping is very important for an appropriate urban planning to reduce the likelihood of flood occurrence and also reduce the consequences of flood disaster when it happen (Kaoje 2016).

Flood is the most common occurring natural disaster that affects humans and their surrounding environment (Leinster, 2009). This natural disaster is common in Nigeria, it has been occurring in almost every raining season. According to Nigerian National Emergency Management Agency (NEMA), in 2012 alone about 1.3 million Nigerians have been displaced and 431 have died from various floods occurrences. In that same year 30 of 36 Nigeria's states were affected by the floods (IRIN 2012). A lot of physical damages were recorded, including destruction of houses and farmlands. Economic life was halted, people displaced and some lost their lives. It is understood that flood is a hazard that can be avoided or minimize not only by building more dams or constructing more flood defence systems but also by the use of modern technologies and appropriate urban planning that provide information on flood risk areas (Cinque, et al 2003). The GIS application have gained a wide acceptability as (Atkinson 2008) noted that based on the legal system in the USA, GIS is currently been seen in favourable light when the topic appears in litigation. Alexander et al (2011) supported the argument that "mapping has become the keystone for flood risk management and communication in representing spatial relationships between hazard and vulnerability and resulting risk".

In the light of the above, areas that are at risk of flood need more sophisticated approach. An accurate management and information can easily avoid the damage caused by floods. Therefore, this paper is designed to demonstrate how the application of HEC-RAS and

GIS techniques can be utilized for better results when carrying out a flood vulnerability mapping and assessment. The study will also identify areas that are vulnerable to flood in Lagos state.

2. Study Area

2.1 Location

Lagos is an urban settlement located in the south-western part of Nigeria, between latitude $6^0 20' 00''$N to $6^0 40' 0''$N and longitude $2^0 50' 0''$E to $4^0 20' 0''$E. It is one of the 36 states of Nigeria. The state covers an area of approximately 3,496km^2 with a population of 9,113,605 (NPC 2010). Lagos urban area is the largest city in Nigeria, as well as in West Africa. The city is one of the fastest growing and one of the most populous cities in the world (Datu, 2014). It is also the largest commercial city and former capital city of Nigeria. The state has 20 Local Government Areas and it bordered with Ogun State to north and east, Republics of Benin to west and Atlantic Ocean in the south.

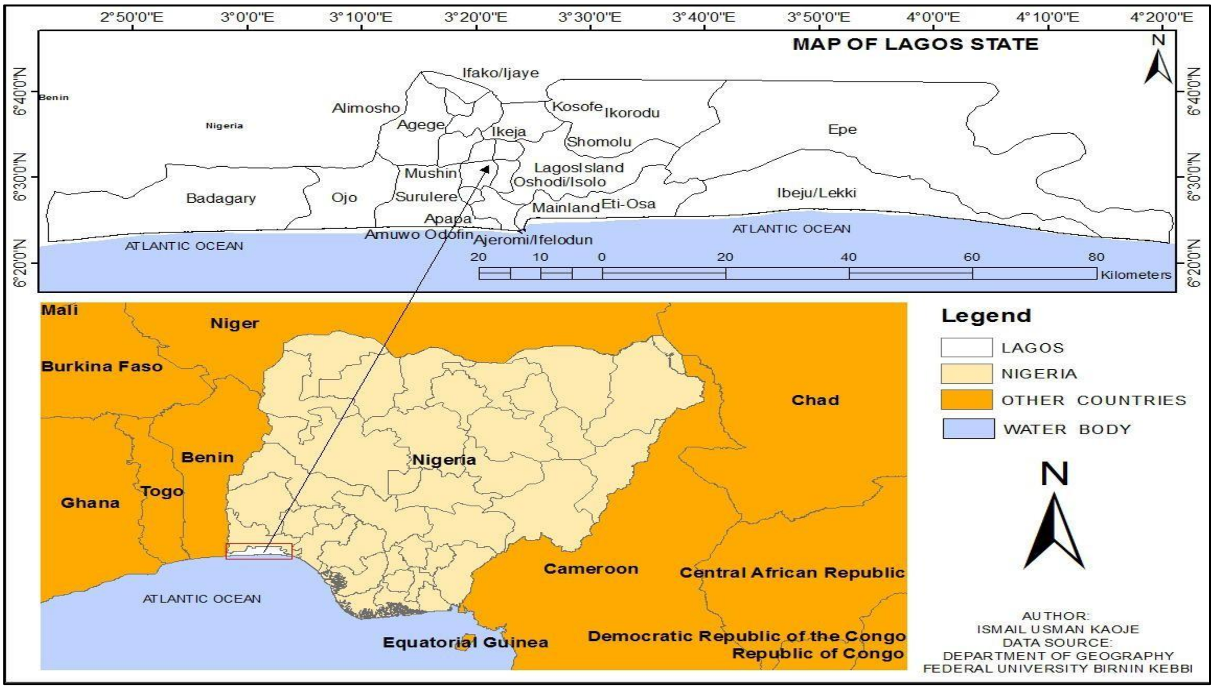


Figure 1: *Location Map of Lagos*

2.2 Climate

The state experiences Tropical wet and dry climate coded A_W according to Koppen's classification (Aderogba, 2012). Two air masses, namely Tropical Maritime and Tropical Continental, blowing from the Atlantic Ocean and the Sahara Desert respectively determine the two dominant seasons wet and dry. The wet season lasts from April to October, while the dry season lasts for the remaining period of the year (Aderogba, 2012) from November to March.

Rainfall is highly seasonal and controlled by movement of Inter-Tropical Front. June is the wettest month with an average precipitation of 315.5mm, while January is the driest month with an average precipitation of 13.2mm. Lagos is located near the equator with no significant difference between the coolest month and the hottest month. Average temperature range is between 28.5^0C to 25.0^0C while the hottest and coolest months are March and August respectively (Aderogba, 2012).

2.3 Relief and Hydrology

The topography of Lagos can be divided into two main geographical areas: the Island and the Mainland. The Island areas of Lagos are land surfaces that are surrounded by water from creeks and Atlantic Ocean. These areas are collection of Islands that are separated from each other by lagoons and creeks and they are also separated from the rest of the state mainland. The Islands and the Mainland are connected by bridges. The two major urbanized areas of Lagos in Lagos islands are Victoria Island and Lagos Island (Soladeye, and Ajibade, 2014). On the other hand, the areas of mainland Lagos are non-island areas of the state, these areas are connected to each other and the rest of the country by land. It is where a huge population of Lagosians live, and most industries are located there. The topography of both the islands and the mainland areas are dominated by lagoons and sandbars, and the terrain is relatively flat on most of the land areas. The terrain is low-lying and the highest point on Lagos Islands 8 metres above sea level while on the mainland areas and other part of the state the highest point is 79 meters above sea level.

The drainage system of Lagos State is characterized by a network of lagoons and waterways. The state also bordered with Atlantic Ocean in it southern part, so most of the waterways are flowing to the south toward the coastline. The major water bodies are the Yewa and Ogun Rivers, Lagos and Lekki Lagoons. Others are Ologe Lagoon, River Imede and River Omu (Soladeye, and Ajibade, 2014). These water bodies contributed in shaping the major topography of Lagos. The drainage system of the state and the terrain pattern which is relatively flat increases the risk of pluvial flooding: “that is flooding as a result of high intensity of rainfall” (Kaoje, 2016 PP: 137). Likewise, the state bordering the ocean in the South also increases the risk of tidal flood. Lagos is one of the states in Nigeria that experiences flooding almost every year during raining seasons.

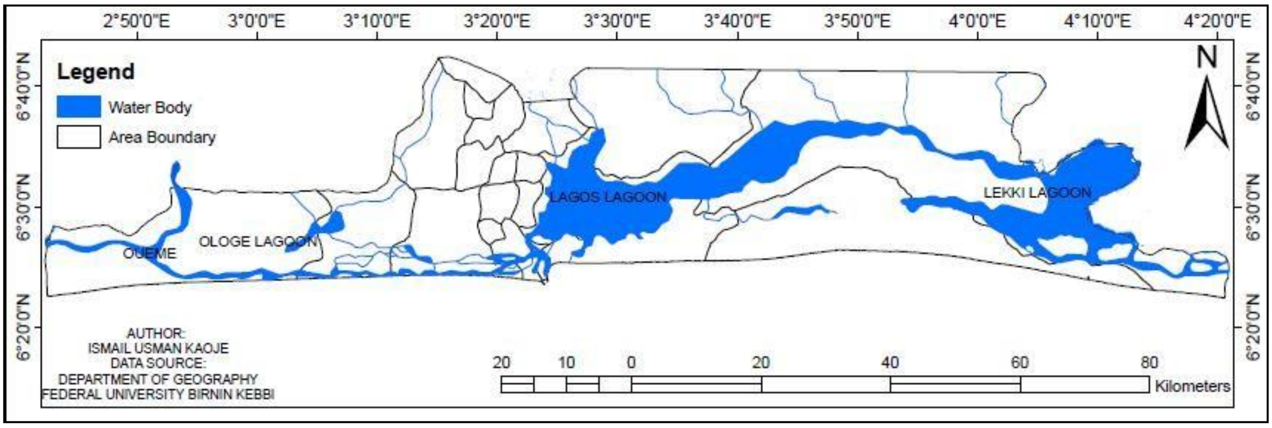


Figure 2: *Hydrological map of the study area*

3. Materials and Methods

The city of Lagos as mentioned in the previous sections of this paper is located in South-Western Nigeria with a relatively flat terrain (areas with low elevations) and it has the networks of lagoons and waterways flowing through it, all the water bodies in Lagos empties their waters in the coastal area (Atlantic ocean). The spatial pattern of the city makes it more vulnerable to flood hazard, the phenomenon draws the interest of this research to study the flood vulnerability pattern of Logos.

3.1 Methods

Considering the nature of this research that involve the study of real world phenomena which uses spatial data to scientifically model a flood risk pattern is theoretically classified as a "quantitative research". Therefore, the techniques adopted in this research for flood vulnerability mapping of Lagos is digital interpretation that uses HEC-RAS and GIS to conduct hydraulic modelling, flood inundation mapping and visualization. Note in GIS there are several techniques and approach that can be used in conducting flood risk assessment. The reason for adopting the above methods for this research is that it provides accurate when conducting flood analysis (National Academy of Sciences 2007).

3.1.1 Hydraulic modelling

Hydraulic modelling in the field engineering and geography is concerned with the flow and conveyance of fluids, mainly water and sewage. However, GIS Hydraulic models are utilized to simulate the behaviour of the flow in the main channel and floodplain. Hydraulic models usually used runoff hydrographs that are generated from hydrological modelling as input. The input that can be useful for hydraulic modelling is geometry data of the river which can be prepared in GIS. Alaghmand, (2010) recognized HEC-GeoRAS extension of ArcGIS as one of the software application that can prepare geometric data for input into hydraulic modelling. The model provides information on where water from overflow will run to and be accumulated. It can be used to find out the actual amount of water that can cause flooding in an area. In fact it is the basic tool and techniques of understanding the hydrological behaviour of an area. So, in this research HEC-GeoRAS and HEC-RAS software packages are used in simulating hydraulic model of the study area.

3.1.2 Flood Inundation Mapping and Visualization

Flood modelling in GIS is used to produce flood vulnerability maps for flood planning and analysis. Flood mapping was first initiated by the U.S. Army in 1988 in the United States, for the purpose of producing flood maps for the National Insurance Program (NFIP) due to the reluctance of the private insurance industry in providing insurance policies (Alaghmand, 2010). HEC-RAS packages are among the most popular Digital flood model applications available. Although in recent years several flood modelling packages have been developed. Initially the aim of flood modelling has primarily been on mapping flood events, but the 2007 flood events in the UK have shifted the emphasis to the impact of surface water flooding (National Archive 2013).

Alaghmand, (2010) categorize flood modelling and mapping into three methods namely the historical method, the analytical method, and the physiographic methods. “All these three methods share two common steps for flood plain mapping; determination of water surface profiles and transfer of water elevation from profiles to maps” (P:488). These methods use the same process to delineate flood boundaries by determining flood elevation at each waterways cross section. However, in this research the following methodological flow chart is used to delineate floodplain area of the study area.

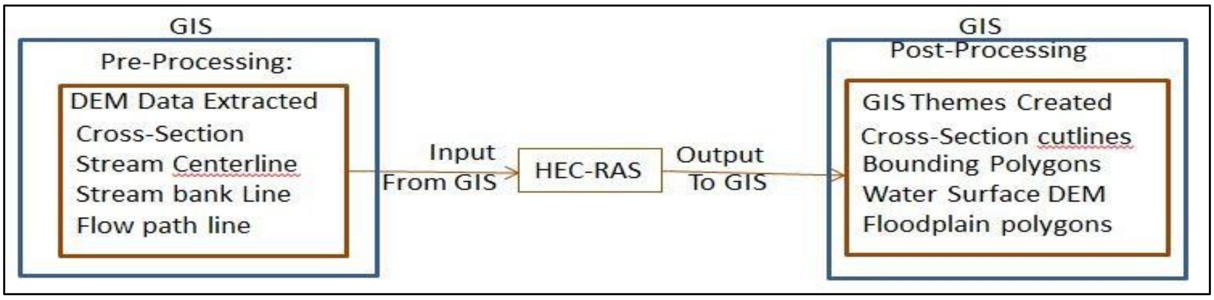


Figure 3: *Model Framework of flood inundation mapping in HEC-RAS and GIS*
Source: *(Kaoje, 2016)*

3.2 Data Input

The main data used in this research are Digital Terrain Model (DTM) and aerial imagery of lansat8 OLI of the study area. Though, floodplain risk mapping strongly requires DEM, DTM or TIN (Triangular Irregular Networks). Aerial images are also useful for identifying features that may affect flood inundation (Schubert, and Sanders, 2012) such as bridges and flood defences systems. The DTM data used in this study are obtained from the Geospatial Lap, Department of Geography Federal University Birnin Kebbi. The data is belief to be generated from SRTM data merge with contours from topographical maps. The data are provided in ASCII file format with a pixel resolution of 15m and 1:10,000 scale raster. A subset area covering the entire Lagos state without any loss of details (data) is extracted from the available DTM datasets. Although, some notable errors exists on the data but they are manageable. Some sink were discovered on the DTM (that are areas with no data), anyway this errors were successfully corrected by using “FILL” tool in ArcGIS.

3.3 Software

This study used two different software application, ArcGIS 10.1 application with HEC-GeoRAS tool extension and HEC-RAS 4.1 software application. These software packages offer better opportunity to perform flood vulnerability mapping and analysis (Alagmand, 2010). ArcGIS 10.1 with HEC-GeoRAS extension was used for pre-processing and post pro-processing for flood inundation mapping. While, HEC-RAS 4.1 software application is used in simulating flood modelling.

ArcGIS 10.1 is a Geographic Information System (GIS) software package developed by the Environmental System Research Institute (ESRI). It gives user environment to interact with Geospatial and Non-Geospatial data and also access to several cartographic and analytical functionalities that allow users to analyze geospatial environment for production of useful information in the form of maps, charts and diagrams (ESRI 2013). The flexibility of Graphical user interface (GUI) of the ArcGIS applications allow users to incorporate additional tools (extensions) that are not originally developed with the software environment (Alagmand, 2010), these permit incorporation of HEC-GeoRAS tools with the ArcGIS that were utilized successfully for a desired end result in flood inundation mapping and analysis. Both HEC-GeoRAS Tools and HEC-RAS application are developed by Hydrologic Engineering Center (HEC) purposely for US Army Corps of Engineer's needs, and are now freely available for use to all users (Kaoje, 2016). The applications can be obtain from US Army Corps of Engineers web page.

4. Result and Discussion

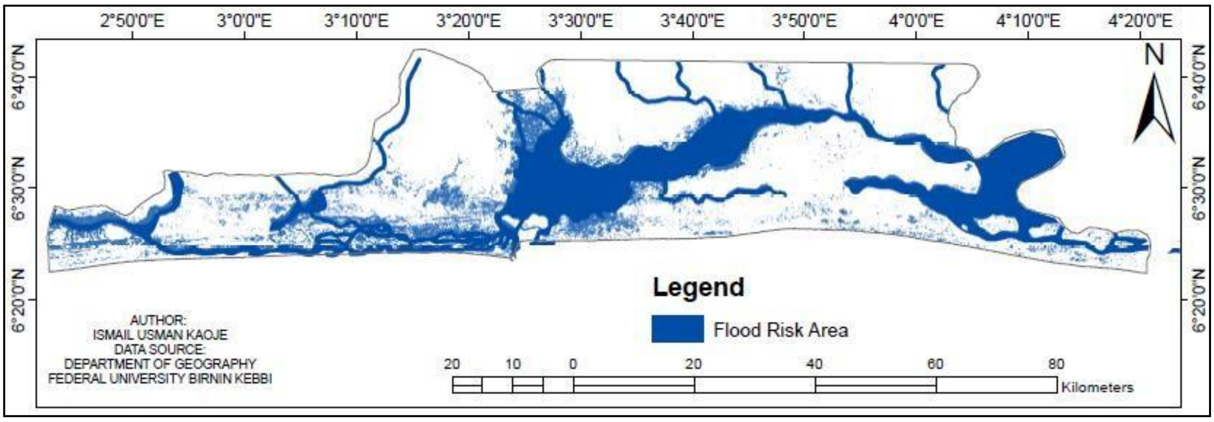
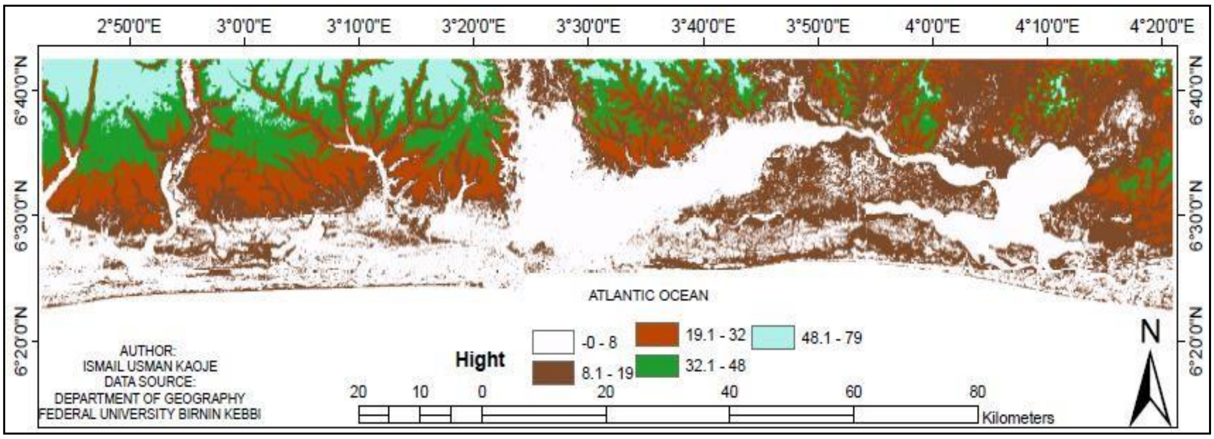


Figure 4: *Flood vulnerability map of Logos*

Figure 4 shows the flood vulnerability map of Lagos generated using the combination GIS techniques and RAS packages. The flood risk depicted shows areas that have 1 % probability of flood occurrence in 100 years. These are areas where waters from rainfall and other forms of precipitation will run to and be accumulated. Water body areas are also shown on the map as flood vulnerable areas. It has been observed that most of water body areas are less than 5 meters above sea level, for this reason all areas that are less than 5 meters above sea level are also included and depicted as flood vulnerability areas on the map.

The flood vulnerability map clearly shows that flood vulnerable areas of Lagos are found around the major waterways (Lagos lagoons and creeks) this is because most of the streams and rivers in and around Lagos empty their waters in the lagoons and creeks then to the Atlantic Ocean. Lagos topography is one of the main factors that significantly influence flooding within the flood vulnerability areas. Conner, (2002) stated that "topography of an



area strongly determines the characteristics and behaviours of surface water balance" (Kaoje, 2016 pp: 144). In an event of flood occurrence, land surfaces that are lowland and relatively plain within the topography are more likely to be affected.

Figure 5: *Relief map of Lagos*

Figure 5 is the topographic map of Lagos which is generated from the DTM data that was utilized in this research. The topography of Lagos reveals the pattern of the city terrain which is relatively flat in the centre and it also has few meters high above sea level especially in the southeastern areas. Lagos has the lowest elevation of -0 meters and the entire terrain is between 0 to 79 meters above sea level. The elevation increases in height as it moves from south to north and the highest elevation is found in the north-western part with 79 meters above sea level. Even though there is no record of tidal flood occurrences in recent years, the topographical arrangement of the city shows that the city lies within tidal flood risk areas. Since Lagos is a coastal area, risk of flooding from the Ocean has always been significant. And the effects of climate change are expected to make the situation worse.

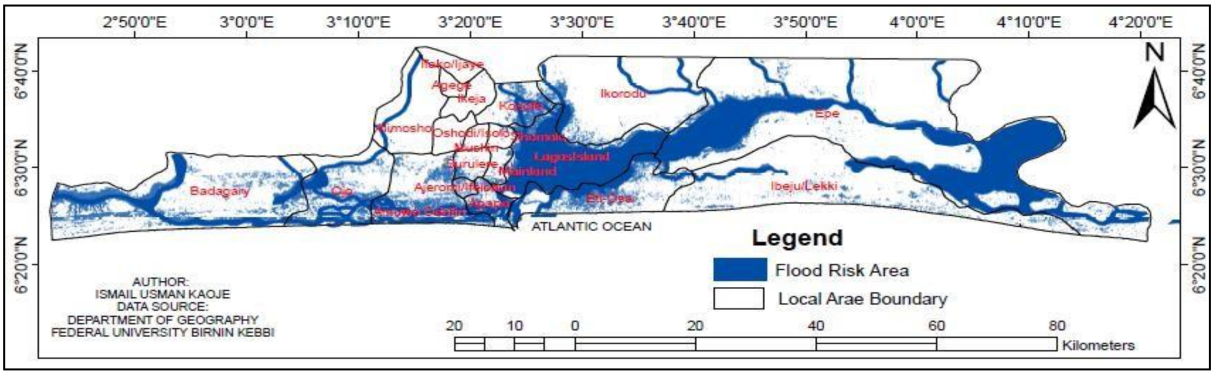


Figure 6: *Flood vulnerability extend in local areas*

As shown in figure 6: Lagos State has 20 local government areas. Out of these areas, it is only Agege and Ifako local areas that are not at risk of flooding. The two local areas are outside the extent of flood vulnerability extent. However, the most vulnerable local government area is Lagos-Island with about 98% of it total land area at risk of flooding. According to findings of this research a total of **1,144** km^2 that is **29.8%** of the total land area of Lagos is vulnerable to flood occurrences. Table 1: explains the vulnerability percentage of flooding in each local area.

Table 1: *Flood vulnerability extend in local areas of Lagos*

LOCAL AREA	Land Area KM^2	Flood Risk Areas KM^2	Flood Risk %
Agege	16	0	0%
Ajeromi/Ifelodun	11	3.3	30%
Alimosho	149	11.8	7.9%
Amuwo Odofin	175	73.5	42%
Apapa	42	28	67%
Badagary	498	139	28%
Epe	1212	441	36.4%
Eti-Osa	182	51	28%
Ibeju/Lekki	464	51	11%
Ifako/Ijaye	33	0	0%
Ikeja	46	0	0.002%
Ikorodu	372	22	6%
Kosofe	74	36	49%
Lagos-Island	241	236	98%
Mainland	22	3.7	17%
Mushin	17	0.7	4%
Ojo	181	39	22%

Oshodi/Isolo	38	0.7	2%
Shomolu	18	2.5	14%
Surulere	30	5	17%
Total	**3,833**	**1,144**	**29.8%**

5. Conclusion

The flood vulnerability map generated in this research shows areas that have 1 % probability of flood occurrence in 100 years. The maps are generated using ArcGIS 10.1, HEC-RAS 4.1, and HEC-GeoRAS software packages. In most developed countries such as UK and US flood maps are common and available for use in planning and for insurance policies (National Academy of Sciences 2007). However, if such maps are produce for Nigeria and other countries that such maps are not available, it will help to make decision on flood disaster planning.

Lagos state bordering the Atlantic Ocean in the South also increases the risk of tidal flood. Therefore, this research recommends that the need to establish an emergency response unit or design a system around the city that can be used as emergency response units in case of any occurrences of tidal flood. The need for this is necessary, especially when considering some unpredictable tidal flood hazards that occur in some part of the world which result in huge loss of human lives and properties. Example of these kinds of flood is 2004 Tsunami that causes huge flooding along the coastal areas of Indonesia and some Asian countries (Fagherazzi, and Du, 2008).

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