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An Integrated Approach to Modelling of Flood Hazards in the Rapidly Growing City of Osogbo, Osun State, Nigeria

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Abstract: In recent times, the swift and uncoordinated urban expansion in the medium sized city of Osogbo has increasingly encroached on the environmental sensitive areas. This uncoordinated exploitation of the ecological fragile areas for urban development has triggered urban flooding, which poses serious threat to human lives and properties in the city. This study therefore utilized geospatial technologies to generate flood hazard model for medium sized cities in developing countries in general and Nigeria in particular with a view to identifying hotspots and providing measures to forestall flood occurrences. The study used Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM), Landsat 7-2000 and Operational Land Imager 8 (OLI)- 2015 images. Multi-criteria evaluation method was used to derive the physical characteristics of watersheds from the data to delineate the areas vulnerable to flooding. Flood inundation characteristics were simulated using Hydrologic Engineering Centre-River Analysis System (HEC-RAS) model with GIS interface and found discharge of over 500 m^3/s for the 100-year profile period to be high, given the size of the analyzed basin (207.41 km^2). The flood hazard map showed that 3.92, 103.38 and 100.11 km^2 were least, moderately and highly vulnerable areas respectively. Most prone areas were built-ups with high impervious surface in the basin area where floodplain traversed high and moderate vulnerability zones. The study advocates consistent use of dynamic model within GIS for floodplain delineation and management planning to reduce the flood hazards.

Keywords: Flood Hazard Model, Geospatial Technologies, Medium Sized Cities, Flood Vulnerability, Multi Criteria Decision Analysis, Flood Inundation, GIS

Introduction

Flood is defined as extremely high flows or levels of rivers, lakes, ponds, reservoir and any other water bodies whereby water inundates outside the water body area (Marfai, 2003). It also occurs when sea level rises extremely or above coastal lands due to tidal seas and sea surges. In many regions or countries, floods are the most damaging phenomena with adverse impacts on the social, economic and environmental conditions of a given territory (Smith and Ward, 1998). Over the years and in almost every part of the world, excessive rainfalls due to climate change have resulted in flooding, which has claimed several lives and properties (Komolafe *et al*., 2015a). With the recent projections in the world's urban population from 2.8 billion in 2000 to 5 billion and a triple urban land cover by 2030 (Komolafe *et al*., 2017; Hoeppe, 2016; Muis *et al*., 2015; UNISDR, 2013), more people and assets in the coastal and floodplain areas will be more exposed and vulnerable to the risk of flood hazards whenever extreme events occur (Dutta *et al*., 2013; Herath and Wang, 2009; James and Hall, 1986;

Muis *et al*., 2015). United Nations reported a 35% increase in flood economic risks, driven by the increasing people's exposure and economic assets in the last decades (UNISDR, 2013). In Nigeria, according to EM-DAT database, floods account for highest disaster losses (Komolafe *et al*., 2015a) and with the potential increase in the rainfall intensity due to climate change it is expected that many river basins in the country will experience flooding. Hence, the need for more evaluation and analysis of floodplains in the country in order to delineate vulnerable areas for flood risk reduction plans (Komolafe *et al*., 2017).

Osogbo and its environs are areas traversed by several streams and river Osun, one of the most prominent river basins in Nigeria. The river cuts across the State capital as one of its tributaries as well as main source of drainages in the State. Recent predictions by the (NHSA, 2016) have suggested heavy rainfalls in all the prominent river basins in Nigeria, which might result in flooding. These impending floods are expected to affect some states in the country, including the study area. Therefore, information on the potential river flood characteristics such as spatial distribution, magnitude, extent, flood depth, velocity at different occurring instances and the vulnerability of the exposures are needed in decision making against disaster preparedness. The use of computing flood hydraulic property is needed for floodplain evaluation and natural phenomenon simulation. Several studies pertaining to the flood hazard problem have been done using remote sensing and GIS (Adegoke and Sojobi, 2015; Komolafe *et al*., 2015a). Nevertheless, researches on the integration of GIS and hydrologic modelling have not been comprehensively done in the area. Hydrologic/hydraulic modelling of flood enables integration of basic hydrological and physical components such as rainfall, infiltration, channel flows, evaporation, nature of soil, roughness, hydraulics etc., which determines the propagation of flood waves (Chen *et al*., 2009; Chia *et al*., 2015; Chormanski *et al*., 2011; Dewan, 2013; Herath *et al*., 1992; Hoeppe, 2016; Jonkman *et al*., 2008; Podhorányi *et al*., 2013; Salimi *et al*., 2008; Townsend and Walsh, 1998).

Applying GIS techniques, flood visualization can be easily generated, which could be useful for flood mitigation and planning of the basin area (Horritt and Bates, 2002; Komolafe *et al*., 2015a; 2015b; 2017; Mohammadi *et al*., 2014). Hydrology Engineering Centre River Analysis System and its ARCGIS plug in models are very useful and have the capability for generating flood delineation and estimating hydraulic parameters. The study therefore attempted to produce a flood hazard model of Osogbo town with a view to identifying hotspots and providing measures to forestall flood occurrences. To this end, the study assessed land use land cover changes in the study area, examined the socio-economic and environmental impacts of the hazards on the study area, generated flood risk and vulnerability maps as well as flood hazard models of the area using the factor criteria such as soil, elevation, rainfall and land use; slope and drainage density of the basin and finally modelled river hazards by producing a river model of the main drainage channel in the area in order to predict its tendency to flood in the future.

Study Area

Osogbo is the capital city of Osun state. It is located within latitudes 7°42'06.00"N and 7°51'33.00"N and longitudes 4°27'52.00"E and 4°38'30.00"E (Fig. 1). It is easily accessible from any part of the state due to its central nature. The capital city shares boundary with Ikirun, Ilesha, Ede, Egbedore and Iragbiji. It is located in South-western part of Nigeria. With a population of about 250,951 in 1991, Osogbo has since witnessed tremendous population growth with population of 288,455 according to the 2006 population census with annual growth rate of 2.8%. Geologically, the study area lies largely within the Precambrian Basement Complex of South-western Nigeria and belongs to the Pan African mobile belt east of West African Craton. The major rock groups in the study area are migmatite complex (including banded and auguen gneisses as well as pegmatites) and meta-sediments (consisting of schist, quartzite and amphibolites in places). The dominant basement rocks in Osogbo area are schist and migmatite, associated with quartzite ridges forming the characteristic undulating terrain. Greater proportions of the soils are ferruginous tropical red soils (laterites) associated with Basement Complex terrains (Tijani and Omodera, 2009). The drainage pattern is moderately dense and dendritic, dominated by Osun River and its tributaries, which are largely controlled by the structural trends within the Basement Complex terrain. With an average elevation of about 336 m above mean sea level, the relief of the area is moderate with low-forested hills (Tijani and Omodera, 2009).

The climate is tropical with an average annual temperature of 26°C. About 1241 mm of precipitation falls annually. The driest month is January. In September, the precipitation reaches its peak, with an average of 2002 mm. With an average of 28°C, March is the warmest month. At 23°C on average, August is the coldest month of the year. The precipitation varies 193 mm between the driest Months. The variation in annual temperature is around 4.6°C.

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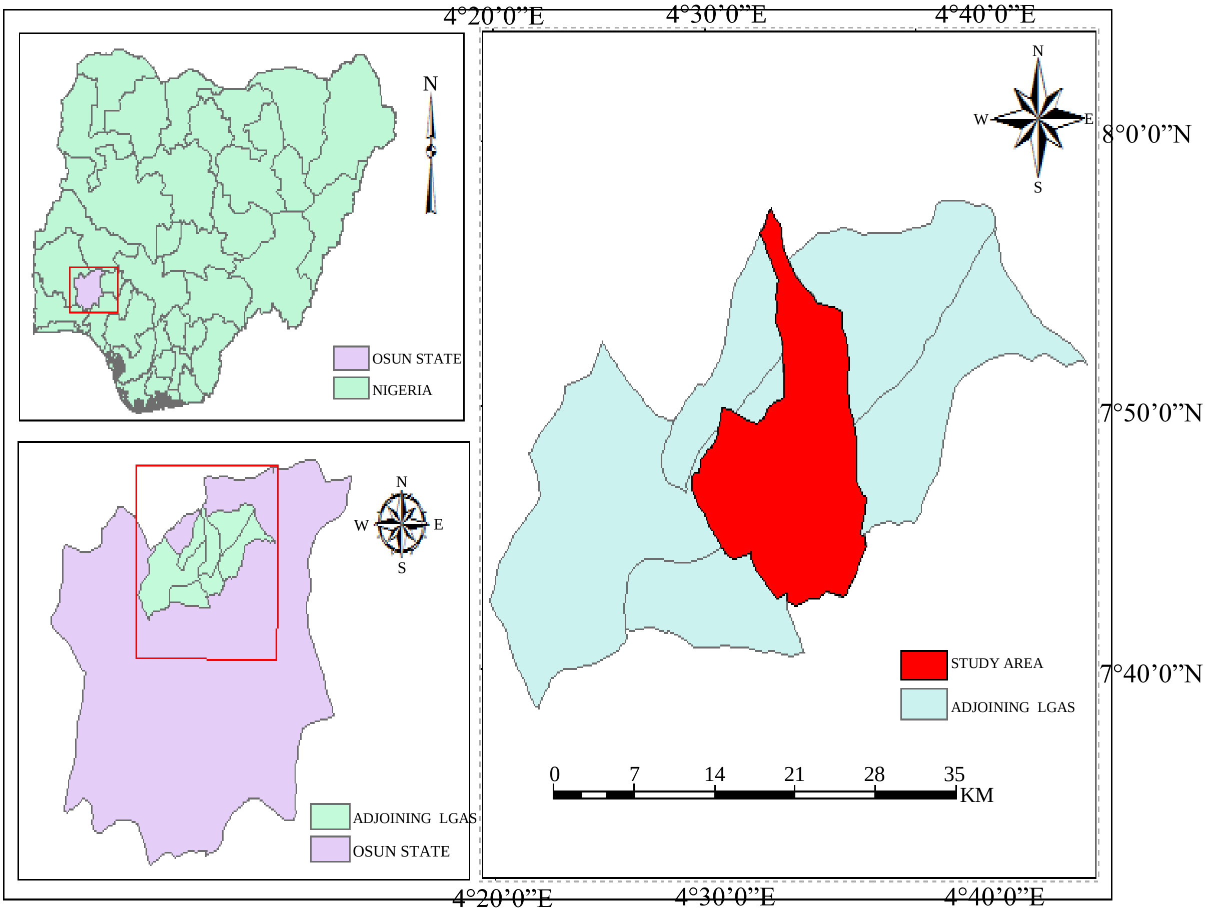

Fig. 1: Map showing study area in regional setting

Materials and Methods

The methodology used in this research is divided into two different stages namely, flood inundation modelling and flood vulnerability assessment. Flood inundation modelling was achieved using integrated GIS-hydraulic model, HEC-GeoRAS 10.1, HEC-RAS 4.1 and HEC-HMS, software developed by the U.S Army Hydrologic Engineering Centre for river analysis and modelling. Some of the output of the stages (HEC-RAS geometry data) acts as input into other processing and analysis stage in order to form a workflow. The flood vulnerability assessment was done using multi-criteria decision analysis with various flood causative factors as inputs.

Flood Inundation Modelling

Catchment's Characteristics Delineation

Prior to the hydrological and flood inundation modelling and analysis, the river basin was delineated on the SRTM-DEM image using ArcGIS-spatial analyst and Arc-hydro tools. SRTM-DEM was acquired from the USGS and DIVA-GIS websites. SRTM data is best used because of its accuracy. It has vertical and horizontal accuracy greater than 10 and 20 m respectively. The elevation ranges from 280 to 420 m. Low areas are mostly prone to flood hazards (Streefland, 2013). Slope of the area (in degrees), basin and contour of the area were also derived datasets from the original DEM and the flow direction raster. In addition, we collected field data using an already calibrated handheld Garmin 72 GPS using The Regional Centre for Training in Aerospace Surveys (RECTAS) COR station to validate the information on the topographic map as well as for geo-referencing purposes. The topographic map scale 1:50,000, 1966 was acquired from the Office of Surveyor-General of the Federation. The Digital Elevation Model was projected from a geographic coordinate system to projected coordinate system (WGS 1984 to WGS 1984 UTM Zone 31°). Using the elevation data as input to ArcHydro software, the river catchment boundary was delineated.

The catchment drainage density of the area was also derived from the drainage line. The line density of each river line was obtained by using the drainage density formula that utilized the size of the basin area (Streefland, 2013). The drainage density, which is the sum of the stream length divided by a basin area, was easily computed for each reclassified basin. It is shown that since both entities are inversely related (Miller *et al*., 2002), large basin areas often have low drainage density while basins with small basin areas have high drainage density characteristic. Channel cross sections were also drawn on the DEM to show the river flow with respect to elevation. Triangular Irregular Network (TIN) was created by converting the DEM to TIN datasets. This is the main data that is needed for the modelling flood and river hazard. Geometric data, which consist of some characteristics of the river, is created from the DTM in form of TIN.

Geometric Data Generation for River Modelling

Geometric data involves the river characteristic property which is mostly physical. Geometric data of the river such as centrelines, banks, cross section used for the modelling of the river and flood hazards were generated using the DEM of the study area and topographic data provided. The geometry file for HEC-RAS contained information on cross-sections, hydraulic structures, river banks, stream centrelines, flow path centreline and other physical attributes of river channels. The pre-requisite data needed for the operation is the Digital Terrain Model in TIN format of the study. It was produced by converting the digital elevation model to TIN using the Conversion tool. The geometric data is required for the river modelling, floodplain mapping and other related operations (HEC-RAS, 2009; Valentin, 2013). These data were generated using the HEC-GeoRAS toolbar in the Arcmap interface. The pre-processing, using HEC-GeoRAS, involved creating these attributes in GIS, followed by exporting them to the HEC-RAS geometry file.

In HEC-GeoRAS, each attribute was stored in a separate feature class called River Analysis System (RAS) Layer. HEC-GeoRAS was used to create a geo-database in which all geometry files created were stored. The geometry files were created by digitizing the DTM of the river created by conversion. The rivers were assigned real names so that tributary could be distinguished from main river course. They were digitized from upstream to downstream. The geometry digitized for the area of study include flow path lines, river or stream centrelines, cross section, bank lines, bridges and culverts. This is so because the main river passes through built-up and developed area.

HEC-RAS Modelling

The geometric data created in HEC-GeoRAS was imported into the HEC-RAS software for flood inundation modelling. It is a good practice to perform a quality check on the data to make sure no erroneous information is imported from GIS. Geometric editor was used to perform the quality check. Cross-sections were also edited in HEC-RAS using the graphical cross-section editor.

Information about the river discharge flow was calculated through statistical process of hydrologic model of computing hydrographs using Soil Conservation Service Curve Number (SCS-CN) from rainfall (Adebayo *et al*., 2009; Soulis and Valiantzas, 2012). Flows are typically defined at the most upstream location of each river/tributary and at junctions. Each flow that needs to be simulated is called a profile in HEC-RAS. A simulation was created for each flow regime and exported to GIS to create flood inundation areas as well as floodplain map. Flood extent and depth were computed. Also, flow simulations were computed for four different flood return periods (T = 10, 20, 50 and 100 year periods). Flood Inundation Modelling Methodology Flow was depicted in (Fig. 2).

Flood Vulnerability Assessment

Land use Mapping

Understanding of the surface land use land cover distributions and patterns are essential in rain-runoff modelling, the flood hazards' exposure characterization and vulnerability analysis. In this study, remote sensing images were utilized for extracting the land use of the study area. Landsat 7 image of February 2000 and Landsat 8 image of July 2015 were used for land use land cover study and change detection. The images were acquired from the Earth Explorer website of the United States Geological Survey Agency. False composite image was produced using bands 2, 3, 4, 5 and 6 of the Landsat 8 image. Bands 3, 4 and 5 were combined for the composite image by selecting them in the table of contents. Landsat 7 image bands were also combined for false composite image generation. Different features were identified on the output. The image of the study area was classified into 5 land use and land cover categories namely, built-ups, bare land, vegetation, water body and grassland

Soil and Rainfall Data Processing

Soil data was acquired from the Food and Agriculture Organization (FAO), private data vendor and other soil-related websites. The soil data was converted from vector format to raster format using the Conversion tools in ArcMap. Rainfall data for 2015 was acquired and used to compute seasonal rainfall extent. The data was acquired from Climate Hazards Group Infrared Precipitation's website, with Station data. The rainfall data, as point data, were interpolated using kriging method in order to make them useful at weighting stage as a criterion and to know the extent of rainfall distribution in the study area for the year.

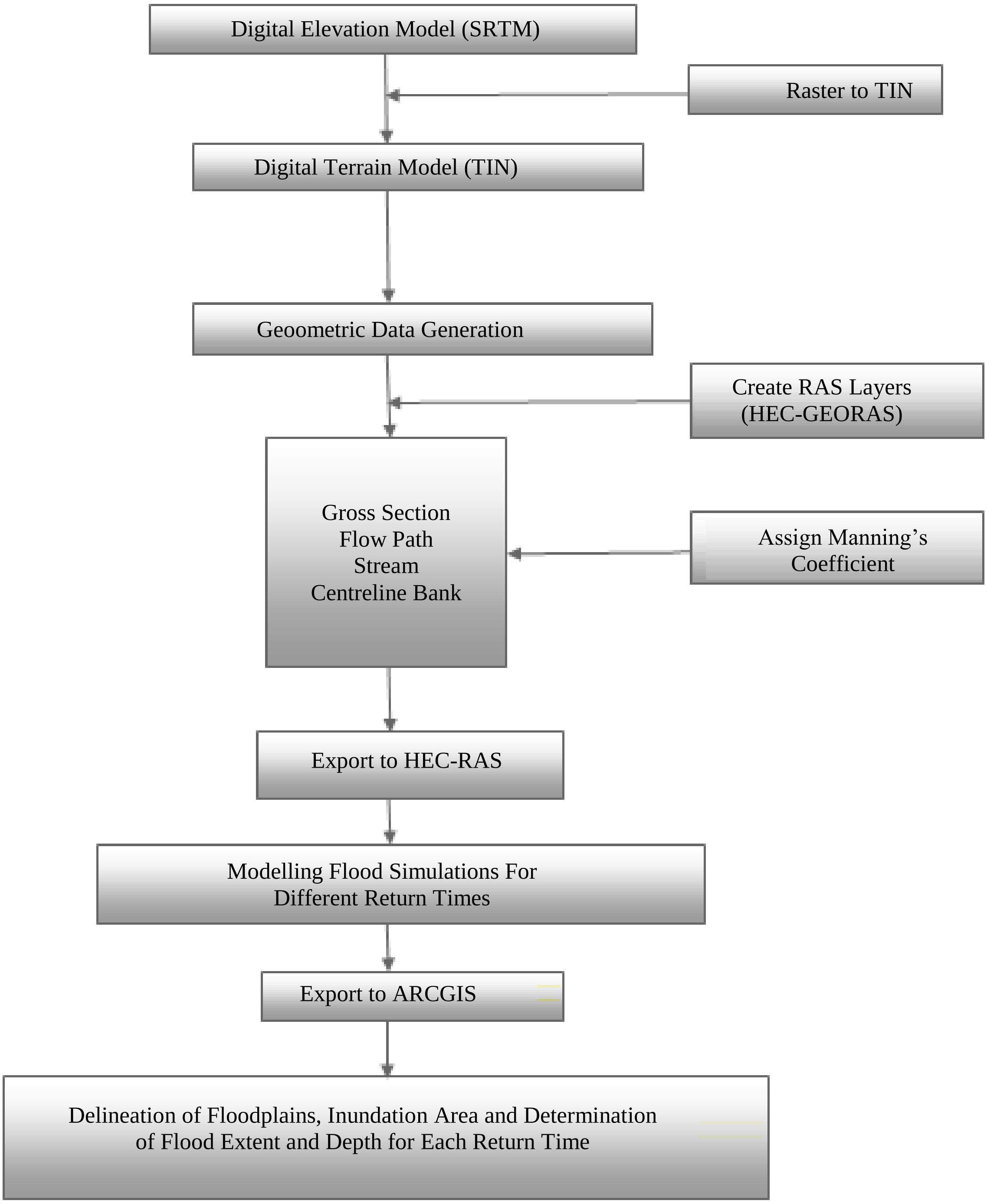

Fig. 2: Flood iundation modelling methodology diagram

Multi-Criteria Decision Analysis

Multi-criteria analysis is applied and integrated with the spatial data in order to describe the causative factors of a phenomenon under concern. In this study, the vulnerable areas were first produced by numerically overlaying soil (Soil with small pore spaces will have less infiltration capabilities because water will only stay at the surface, whereas soil with large pore spaces will have good infiltration capability), slope (Slope is one of the obvious indicators for controlling water flow, run-off is generated at areas with steep slopes but water accumulates at flat areas. This makes the flat areas more vulnerable to flood), elevation (High elevated areas are

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less prone to flood due to the fact that water moves from high elevation to low elevation), land use (Land use and land cover of the area was also considered as it is noticed that impervious surfaces are prone to flood due to low infiltration whereas areas with good vegetation cover and good soil are less prone to flood due to good infiltration). Drainage density The Drainage density (Dd) is the sum of the total length of the streams in the area divided by area of drainage basin, expressed in kilometres. These parameters determine the drainage capacity of the basin due to inverse relationship that exists between them. Thus, the lower the drainage basin areas, the higher the drainage density. This means the drainage is bound to have high surface run off. Reverse is the case in the large drainage basin area. Rainfall is also another major factor. High rainfall intensity i.e., rainfall that exceeds 6 h can cause run- off in high land areas. The selection of these criteria was based on the expert's opinion and availability of data (Table 1).

The factor criteria were assigned according to the degree of influence on the causes of flood hazards. Ranking method was used to weigh each of the factors based on reclassification using Reclassify tool. The factors were weighed based on the preference and influence of each factor on the study area. The weight values were assigned. Weighted overlay of the raster datasets produced from reclassification was produced. The output map is the flood vulnerability map that shows the flood prone areas (Fig. 3). The assigned weighted influences and their ranks were summarized in the Table 1. The degrees of flood hazard categories were described as a function of the size of the flooding, depth and velocity, rate of flood water rise, duration of flooding, size of population at risk, land use and so on (Blunden and Indraratn, 2000). This is in agreement with Cançado *et al*. (2008) who proposed and concluded that two parameters are used to evaluate the flood hazard in the urban populated area. Water depth and velocity of the flood are most contributing characteristics. Occurrences of flood at depth greater than 1.5 m and a velocity of 1.5 m/s indicate high hazard while flood at depth of less than 0.5 m and velocity of less than 0.5 m/s indicate low hazard possibility (Cançado *et al*., 2008). In addition, the result from each model was integrated to the flood vulnerability map. These results, which are in the form of floods characteristic maps (flood extent, flood depth and flood velocity) are used in the hazard assessment. Hazard map was generated by integrating two factors, namely maximum water depth and flow velocity obtained from the modelling.

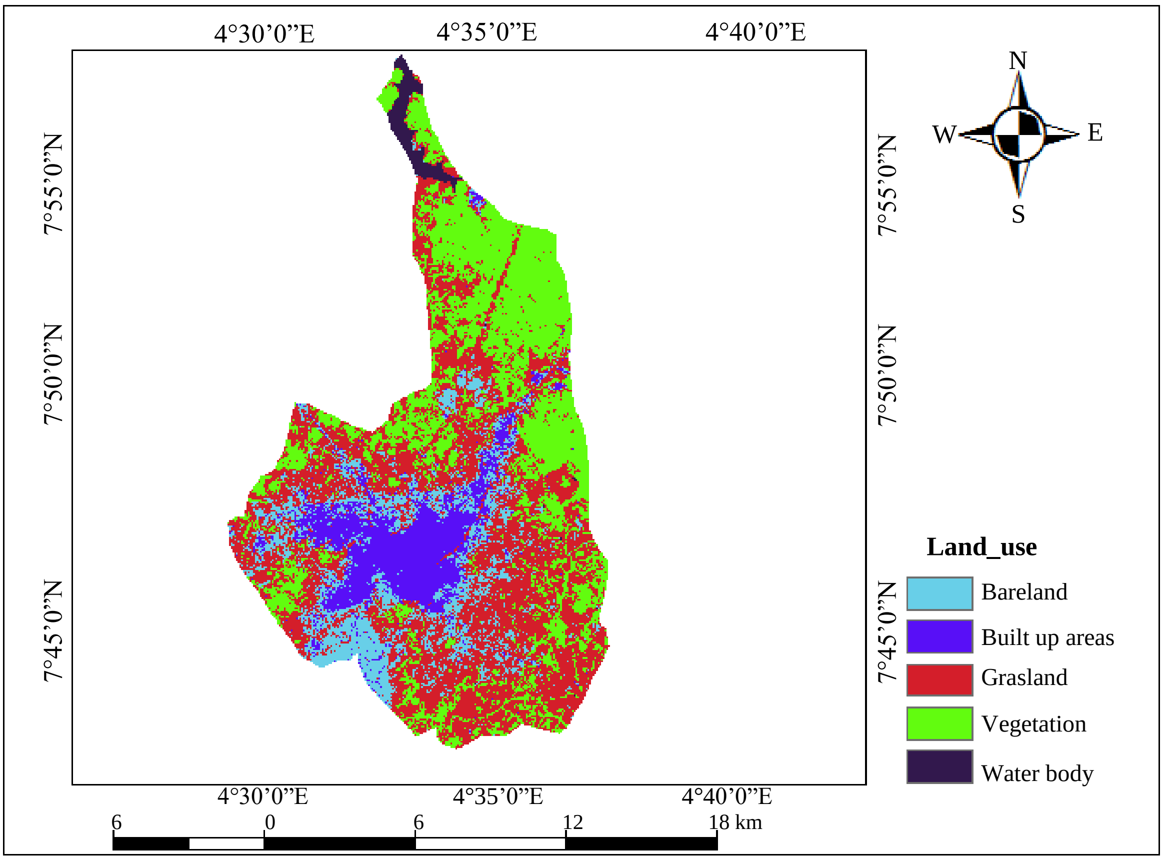

Fig. 3: Land use/Land cover classified Map in January 2000

Table 1: Factor criteria and weighted influences

S/N	Factors	Assigned weight influences (%)
1	Land use	25
2	Rainfall	15
3	Soil data	10
4	Slope	20
5	Elevation	15
6	Drainage density	15
	Total	100

Results and Discussion

Land use/Land Cover Change and Post Classification Results

Table 2, Fig. 3 and 4 showed the predominance of built-up area over other land use/land cover categories by increasing from 24.52 km^2 (11.67%) in 2000 to 78.41 km^2 (37.31%) in 2015 due to increasing demand for housing. The table further showed that vegetation cover reduced from 66.96 to 43.65 km^2 while grassland extent reduced from 86.05 km^2 in year 2000 to 47.27 km^2 in year 2015 respectively. This shows that there are significant developments that have occurred between the periods. This also implies there is a continued demand for more development in terms of residential and industrial land use pattern (Aziz *et al*., 2014). The rate of change per annum between the study years as well as rate of increment was computed. Table 1 showed the annual rate of change for each land use class showed that per year, built up increased by 1.71% annually while water body has little increased change (0.06%). Grassland and vegetation cover decreased annually by 1.23 and 0.74% respectively. This study noticed two major processes of land use/land cover change during the field observation namely conversion and modification. Vegetated and grassland areas were increasingly converted to residential and commercial land uses while riparian vegetaion and parts of flood plain were encroached upon for urban development through modification. This observation agrees with Aguda and Adegboyega (2013) who reported that conversion of non-developable areas narrows down the erosion channels and undermines natural flood control capability of the urban environment.

Furthermore, the change matrix between the two years showed that some areas had also undergone conversion (Table 3). It suggests that the land use categories have been modified indiscriminately. New urban developments have been encroaching on the floodplains. This is in contrast with George (2002) who notes that one of the major principles of planning is to resist developments along the floodplains i.e., river channels. The areas can however, be used as recreational parks and un-improved farmlands. This also includes that housing must not be set on wetlands and should be sited about 100 m away from rivers. The change matrix showed that a greater proportion of vegetation, grassland and bare land had been changed to settlement (built ups). According to Table 3, a proportion of about 28.94 km^2 of grassland and 17.95 km^2 of bare land was observed to have changed to built-ups. Some of these land covers are located on the floodplains. This may be a contributing factor to flood cases in the study area. Land use and floods are closely related; therefore, any changes in the land use, such as urbanization across the catchment's area, may trigger a sequence of flood occurrences (Hadjimitsis, 2012). The current and future development in water resources is very sensitive to land use and intensification of human activities. The implication of the decrease in vegetation cover and increase in built-up impervious area was the reduced infiltration due to the structure of the soil and an increased volume of run-off (1914594 m^3/sec). All these were an indication of increased flood risk in the study area. As shown, the spatial extents of the land cover types and the developed land expansion rates varied significantly over different periods. With a land consumption rate of 0.00066 and due to increased population in the study area (estimated as 315,758), it can be deduced that population growth has really been a driving force to increased built ups in the area. This also affects the modification of land use type into another.

According to Table 4, the error of commission represents the proportion of incorrectly classified pixels marginally in a row to the total classified pixels in a row. It also represents pixel that belong to another class but are labeled as belonging to the class. For each land use class, the error is being computed to know the extent of wrongly classified pixels in the selected reference. The water body pixels result shows that the error of commission is 0%. This means that in a row, the pixels are correctly classified. The error is also known as error of inclusion. Therefore, it can be interpreted that for bare land pixels, about 35.7% were wrongly included in the classification Furthermore, the error of omission determines the percentage of incorrectly classified pixels in a column. The error represents pixels that belong to the truth class but fail to be classified into the proper class. As shown in the result, the pixels belonging to the built up were not excluded in the classification. This means that the reference points (ground truth points) were correctly sampled but were correctly placed in the classification. Also, for other classes, about 45% of the grassland pixels were also excluded. The error is also known as type II error and is synonymous to the producer accuracy. Both errors show the extent of inclusion and exclusion of pixels incorrectly into their individual land use class. Therefore, the errors can be synchronized with both user and producer accuracies to express the extent of reliability and accuracy for the image classification.

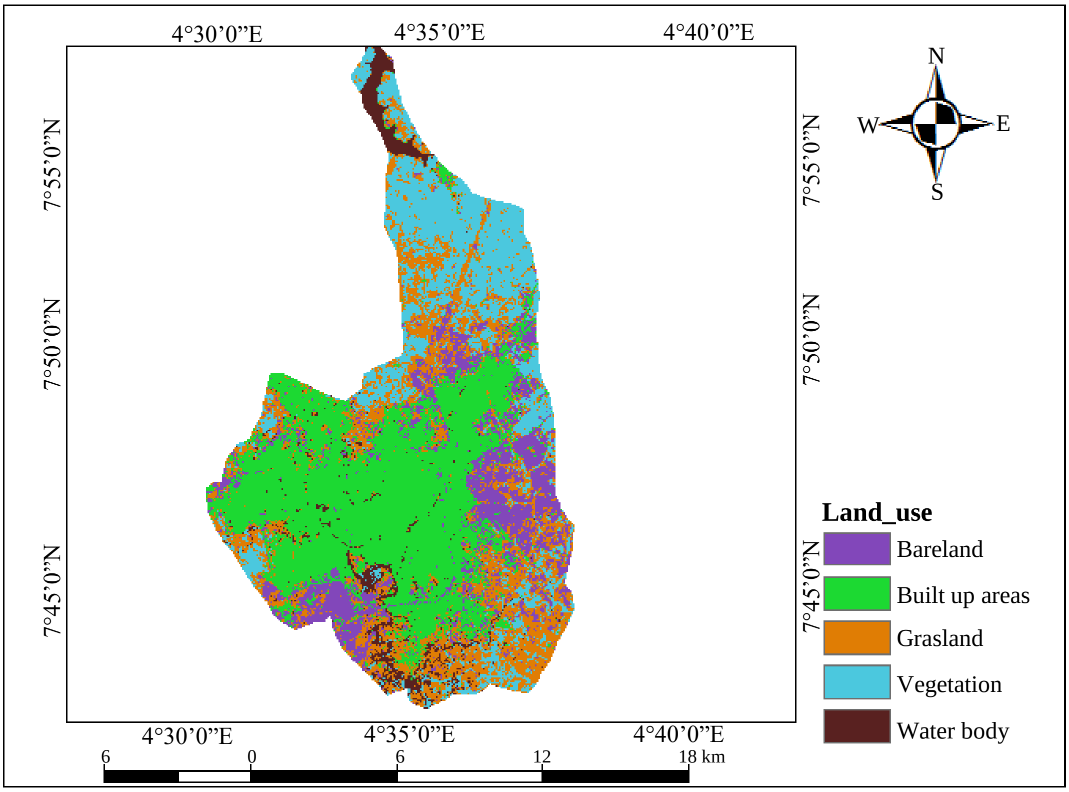

Fig. 4: Land use/land cover classified map in July 2015

Table 2: Land use/land cover change between 2000 and 2015

	LULC (2000)		LULC (2015)		Change between 2000 and 2015		Annual average of change	
Land use class	KM²	%	KM²	%	KM²	%	KM²	%
Water body	3.55	1.69	9.77	4.67	6.22	2.98	0.41	0.19
Built up	24.52	11.67	78.41	37.31	53.89	25.64	3.59	1.71
Grassland	86.05	40.95	47.27	22.49	-38.78	-18.46	-2.58	-1.23
Vegetation	66.96	31.86	43.65	20.77	-23.31	-11.09	-1.55	-0.74
Bare land	29.07	13.83	31.05	14.78	1.98	0.95	0.132	0.06

Table 3: Change matrix between 2000 and 2015

Land use class	Water_Body (KM^2)	Built_Up (KM^2)	Vegetation (KM^2)	Bare_Land (KM^2)	Grassland (KM^2)
Water body	3.45	0.04	0.0081	0.028	0.028
Built up	0.43	23.17	0.0099	0.630	0.270
Grassland	3.23	28.94	6.1700	17.880	29.820
Vegetation	2.33	8.31	37.3300	4.820	14.170
Bare land	0.32	17.95	0.12100	7.690	2.980

Table 4: Accuracy assessment of image classification

Classes	User accuracy (%)	Producer accuracy (%)
Water body	100	90
Built up	90.9	100
Vegetation	100	90
Bare land	64.3	90
Grassland	78.6	55
Overall accuracy	85%	
Kappa coefficient	81%	

Rainfall Data Analysis

Total annual rainfall was used as the value interpolation point with cell size resolution set at 22 m. Figure 5 revealed that the rainfall values ranged between 1260 and 1420 mm of rainfall. With a mean annual rainfall ranging between 1250 and 1300 mm, it was observed that most places on the river plain or flood plain experienced high and low rainfall events. This implies that the areas have varying rainfall events. It was noticed that areas on high elevation such as Igbona, Ayetoro and Ota-Efun were found in the regions of low precipitation regime of about 1350 mm of rainfall while areas such as Rasco, Alekuwodo and Oke-fia recorded high values of rainfall of 1200 mm. It was also observed that varying degrees of slope and elevation precipitated accelerated runoff around river plain/floodplain. This might increase the chance of ccurrence of floods along the floodplain during the peaks of rainy season.

Hydrology and Flood Inundation Results

Delineation of the drainage pattern, basin, slope, flow accumulation and direction, generation of contour and stream order are the resulting outputs from the hydrologic processing. It was revealed that drainage density and basin area were inversely related. Figure 6 showed that most popular places such as Alekuwodo, Oke-fia, Onward Area, Dada Estate, Fagbewesa, Ogo-Oluwa, Ajegunle, just to name a few, were found in the high drainage density zone whereas areas such as Igbona, Ota-Efun and Biket areas were located in medium to low drainage density zones.

Slope is a measure of steepness or degree of inclination of a feature relative to the horizontal plane. They are expressed as degree, percentages or ratio (Geokov, 2014). The slope computed is measured in degrees. The result also showed that steepness ranged from 4° to 9° while gentle slope of the terrain ranged from 0° to 4°. It was observed that areas such as Alekuwodo, Gbomi, Old Garage/Rasco area and Oke-fia were located on gentle slope while Fagbewesa, Orita-Sabo, Egbatedo and Gbemu areas were situated on a moderate slope. In addition, it was noticed that Ayetoro, Igbona, Ota-Efun, Biket and Agunbelewo were areas located on steep to very steep slope range (Fig. 7). It may be recalled that runoff water flows faster in steep slope than gentle slope (Streefland, 2013). Hence, areas around the gentle slope may be prone to flood occurence. Therefore, high river density coupled relatively gentle or flat areas and low elevations are an important part of watershed characteristics affecting aspects of run-off. A watershed is like a basin-like landform defined by highpoints and ridgelines that descend into lower elevation and stream valleys. It is an area of land that contains a common set of streams and rivers that drain into a larger body of water (Palaka and Sankar, 2016). In relation to slope and elevation of the area, the factors increase flood tendency in the area since the watershed characteristics favours its occurrence (Aderogba, 2012).

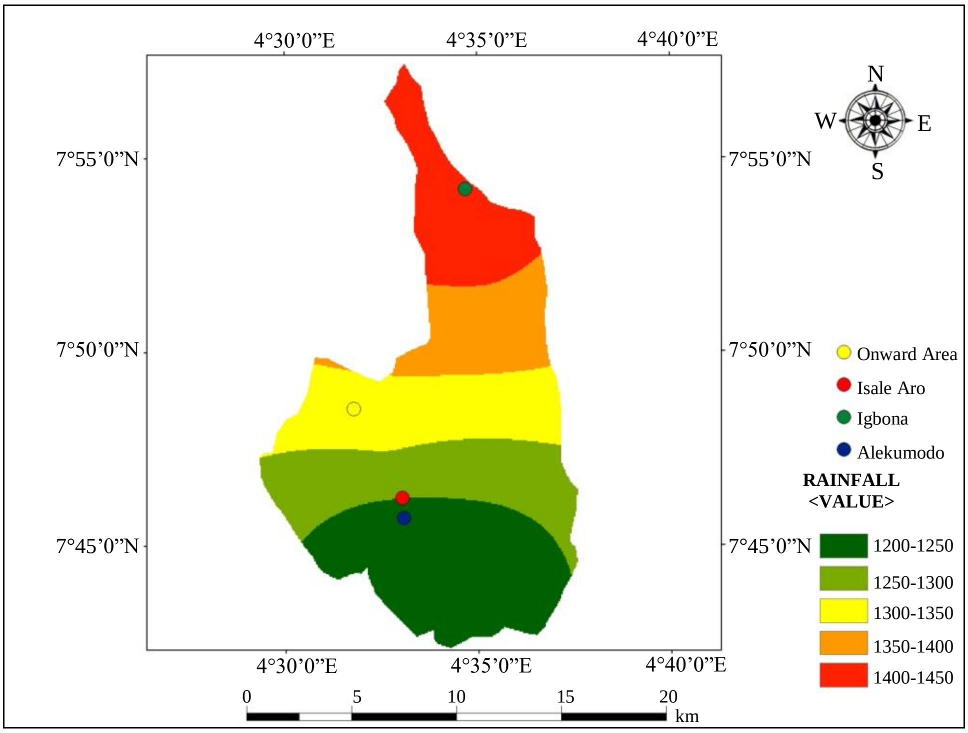

Fig. 5: Rainfall distribution in the study area

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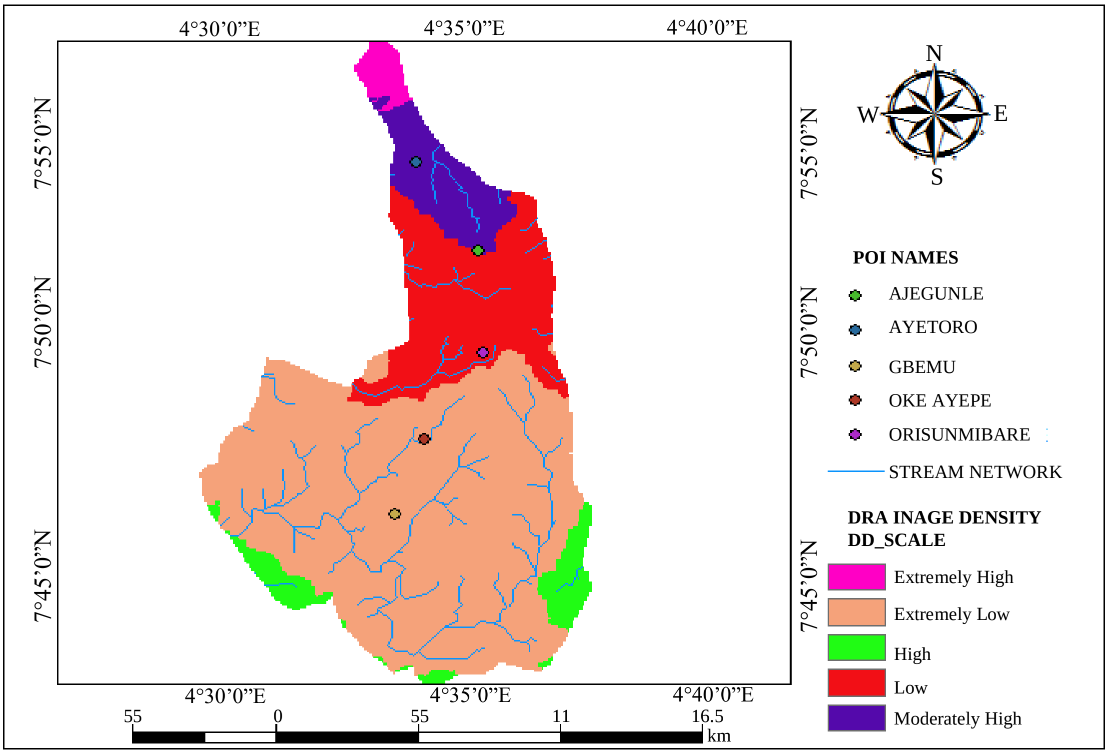

Fig. 6: Drainage density of basins in the study area

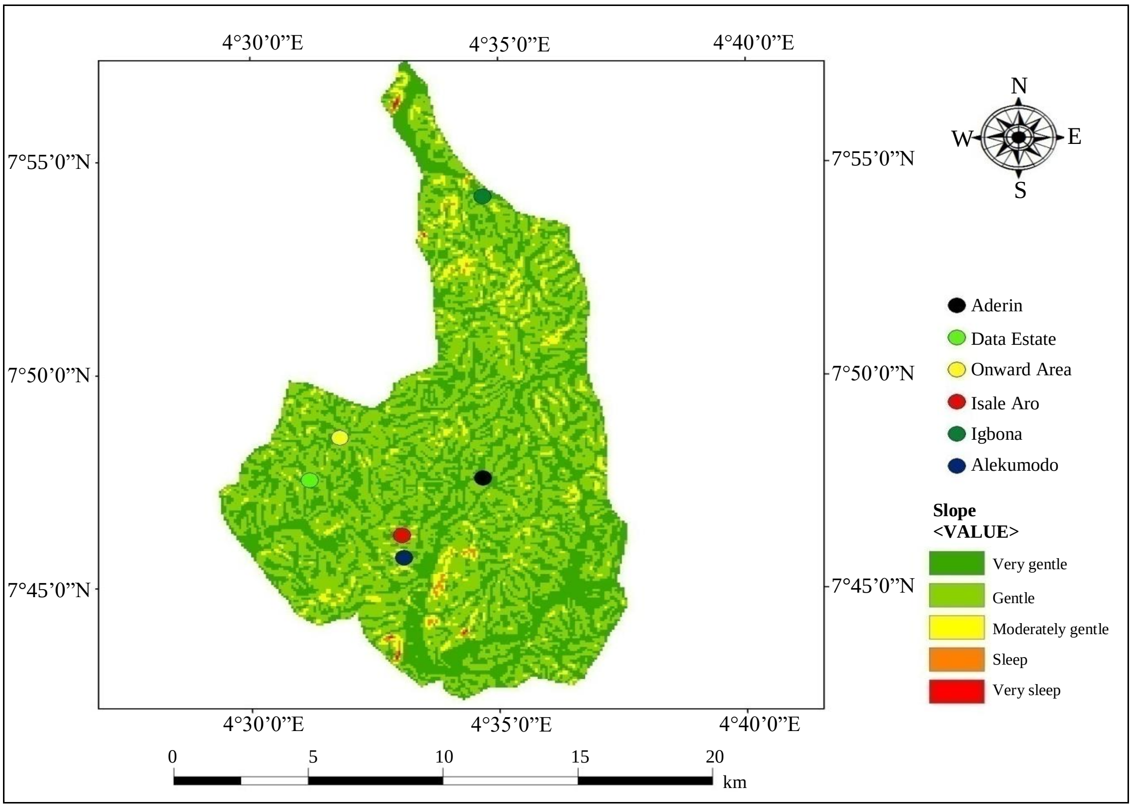

Fig. 7: Rainfall and slope map

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Total velocity at probability of 0.1% which was a 10-year flood return period as illustrated in Table 4a, 4b and Fig. 8 was at 0.87 m/s. Total peak discharge flow for this return period at channel level was at 198 m^3/s. For 20-year return period, total velocity was 1.07m/s while peak discharge flow was 356 m^3/s. Also, the peak river discharge for the 100-year profile period was highest at 1373 m^3/s. Considering the size of the analyzed basin (207.41k m^2), discharge of more than 500 m^3/s was considered to be very high for the 100-year profile period. The classification of flood depth areas indicated that 42% of the total flooded areas had water depth greater than 5 m. This illustrates that the total area under the water depth of more than 5 m increases considerably with the increase in the intensity of flooding. The delineated floodplain constituted up to 5% of the study area. Mostly, prone areas were vegetation sites and built ups. The basin slope ranged from 0.9° to 3.6°, revealing how gentle or flat the area was. The water depth and mean velocity were calculated for a given cross section using the energy conservation equation. HEC-RAS also calculated the water levels' variation along the channel and the water level values were overlaid on a Digital Elevation Model (DEM) of the area to get the extent and flood depth using GIS.

A brief comparison between Table 3a and 3b showed that conveyance level of water was high at right channel overbank. When considering upstream level, the velocity of water increased twice the value at 10 year return period. Also, the maximum channel depth for the 100-year period was about 10.86 m. This is in agreement with Aderogba (2012), in a similar research, reported a flood depth of 9.73 m. This implies that an increment in return periods affect flood depths which accounts for more damages.

Flood Vulnerability Map

Figure 9 showed that largest places in extent of vulnerability were moderately and highly vulnerable to flood areas. Most places such as built ups, bare land and grassland close to drainage system in the study area were extremely vulnerable. This can be used as an add-up estimate of the number of people affected and property worth that was damaged (Orimoogunje *et al*., 2016) and flood extent. Specifically, approximately 4 km^2 of the total area under study was less vulnerable zone while about 100 km^2 were highly vulnerable to flooding. Places such as Alekuwodo, Rasco, Oke-fia and Dada Estate areas were found to be in the highly vulnerable category while Igbona area was least vulnerable to flood. The results of the study have been validated by the occurence of devastating floods precipitated by torrential rain of 12th and 13th September, 2016, which affected areas like Rasco, Oke-Onitea, Fiwasaye, Gbomi, Iludun and Testing Ground (Nigerian Tribune, 2016). Meanwhile, the Nigeria Meteorological Agency (NIMET) has identified Osun State as one of the flood-prone areas. The NHSA (2016) has also predicted flash flood and overflow of the nation's rivers in Ogun-Osun, CrossRiver, Anambra-Imo, Sokoto-Rima, Niger and Benue. Despite usual preemtive measures (in form of dredging of waterways and channels in Osogbo) taken by the Osun State in particular, the flash flood recorded in Osogbo culminated in loss of properties worth several millions of Nigeria Naira.

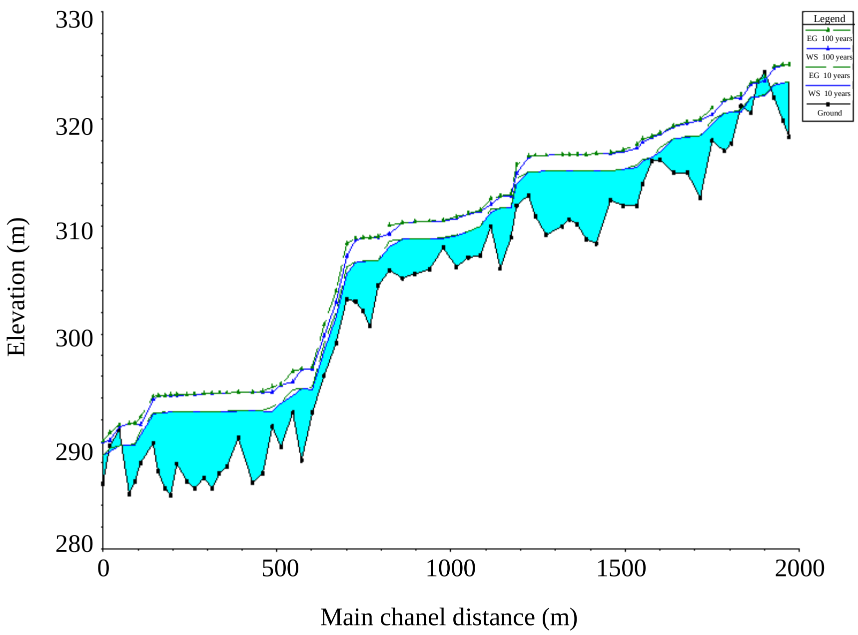

Fig. 8: Water surface profile for both return periods

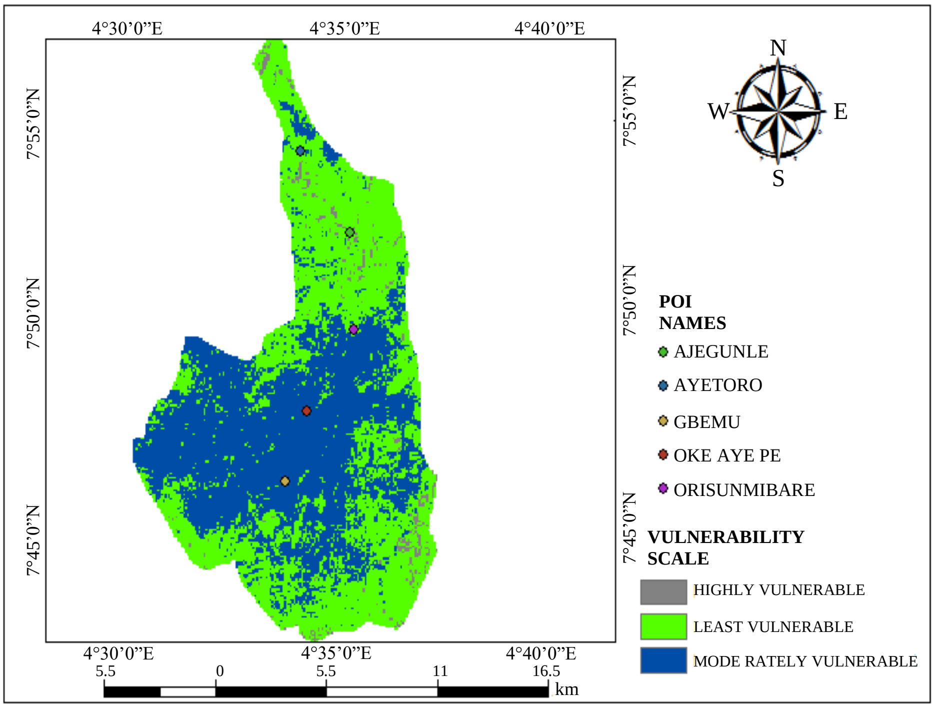

Fig. 9: Flood vulnerability map

Table 4a: Cross section table output for 10 and 100 years profile

E.G. Elev. {m}	323.46	Element	Left OB	Channel	Right OB
Vel head {m}	0.000000	Wt n.Val	0.050	0.035	0.050
W.S. Elev. {m}	323.460000	Reach Len {m}	186.380	184.32	171.040
Crit W.S. {m}		Flow Area {m^2}	268.890	1102.78	3566.500
E.G. Slope {m/m}	0.000012	Area {m^2}	268.890	1102.78	3566.500
Q Total {m^3/s}	880.000000	Flow {m^3/s}	17.410	201.94	660.640
Top Width {m}	1523.350000	Top Width {m}	292.480	430.53	800.330
Vel total {m/s}	0.180000	Avg Vel {m/s}	0.060	0.18	0.190
Max Chl Dpth {m}	9.210000	Hydr. depth {m}	0.920	2.56	4.460
Conv. Total {m^3/s}	256948.500000	Conv. {m^3/s}	5084.300	58965.10	192899.200
Length Wtd {m}	175.800000	Welted Per. {m}	292.510	430.75	801.960
Min Ch El {m}	318.290000	Shear {N/m^2}	0.110	0.29	0.510
Alpha	1.060000	Stream power {N/m s}	89597.230	0.00	0.000
Froln loss {m}	0.010000	Cum volume {1000m^3}	7311.330	14584.25	7703.390
C and E loss {m}	0.000000	Cum SA (1000 m^2}	3139.000	6239.15	3172.700

Table 4b: Cross section table output for 10 and 100 years profile

E.G. Elev. {m}	325.12	Element	Left OB	Channel	Right OB
Vel Head {m}	0.0100000	Wt n.Val	0.050	0.035	0.050
W.S. Elev. {m}	325.1100000	Reach Len {m}	186.380	184.320	171.040
Crit W.S. {m}		Flow Area {m^2}	847.220	1813.240	4887.210
E.G. Slope {m/m}	0.000031	Area {m^2}	847.220	1813.240	4887.210
Q Total {m^3/s}	2709.820000	Flow {m^3/s}	151.730	749.920	1808.170
Top Width {m}	1644.490000	Top Width {m}	413.630	430.530	800.330
Vel total {m/s}	0.360000	Avg Vel {m/s}	0.180	0.410	0.370
Max Chl Dpth {m}	10.860000	Hydr. Depth {m}	2.050	4.210	6.110
Conv. total {m^3/s}	488052.700000	Conv. {m^3/s}	27326.500	135064.600	325661.500
Length Wtd {m}	176.720000	Welted Per. {m}	413.670	430.750	803.610
Min Ch El {m}	318.290000	Shear {N/m^2}	0.620	1.270	1.840
Alpha	1.090000	Stream Power {N/m s}	89597.230	0.000	0.000
Froln loss {m}	0.010000	Cum Volume {1000m^3}	12768.600	25136.790	13698.080
C and E loss {m}	0.000000	Cum SA (1000 m^2}	4047.300	7595.090	4522.270

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Conclusion

A hydraulic model, like any other model, is intended to be a realistic representation of the physical processes over time in a river channel or flood plain and gives decision makers indication of the outcome for different options. The hydraulic model usually has the capacity to analyze, to predict and to solve environmental problems without taking into consideration the geographical prospective. Under these circumstances, GIS becomes a valuable tool and it notes that there are strong grounds for believing that GIS has an important function to play because natural hazards are multi-dimensional phenomena which has a spatial component.

This study has clearly shown that integration of GIS techniques and application of HEC-RAS are very effective in flood inundation and vulnerability modelling. The integration of remote sensing and Hydro-Dynamic model (HEC-RAS) has successfully simulated flood hazard modeling. The river channel spread over parts of the floodplain was successfully modelled through HEC-RAS. The software models the floodplain in one dimension. The selected river channel passes through the main town of Osogbo. This integrated approach will further improve understanding of the flood characteristics in the study area and extension guide in the flood risk analysis in other river basins in the country. By using capabilities of the HEC-RAS, several river cross sections have been identified which cannot contain discharge that is likely to come for return period of 10, 20, 50 and 100 years. One of the most important results of HEC-RAS simulation is preparing different water surface profiles of different T-year floods. These tools could reasonably separate high hazard from low-hazard areas in the floodplain to minimize future flood losses. Flood risk mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily read, rapidly accessible charts and maps that can facilitate administrators and planners to identify areas at risk and prioritize their mitigation and response efforts. It is also demonstrated that most of the low lying area is submerged at different peak discharges. Structural remedial measures are suggested in order to prevent flood effect in low lying areas up to some extent. The poor drainage condition in the lower river basin which houses the river and its banks particularly in the high to very high flood hazard risk zone have to be improved. In view of this, land use has to be changed and be properly managed in order to minimize the flood hazard during the main rainy season.

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Author’s Contributions

Suleiman Abdul-Azeez Adegboyega: Responsible for the conception and designing of the article.

Oluchi Christiana Onuoha: Carried out acquisition of data, Analysis and interpretation of data.

Komolafe Akinola Adesuji: Coordinated the analysis and interpretation of data.

Ayo Emmanuel Olajuyigbe: Reviewing of the article.

Adebola Abiodun Olufemi: Carried out Image processing and information extraction as well as interpretation of data.

Matthew Olomolatan Ibitoye: Coordinated GIS Applications and provided guidance in the acquisition of data.

Ethics

The research has been conducted in an ethical and responsible manner and in strict compliance with all relevant legislation. The article submitted for publication is original, is not plagiarised has not been published elsewhere. We, authors of the article, shall be collectively responsible for the submitted and published work.

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