Status of flood vulnerability area in an ungauged basin, southwest Nigeria

A. Sobowale[1*], J. A. Oyedepo[2]

(1. *South West Regional Center for National Water Resources Capacity Building Network, Federal University of Agriculture, P.M.B. 2240, Abeokuta 110001, Nigeria*;
2. *Institute for Food Security, Environmental Resources and Agricultural Research, Federal University of Agriculture, P.M.B. 2240, Abeokuta 110001, Nigeria*)

Abstract: Many rivers in Nigeria had been ungauged in the last three decades; this worrisome scenario has impacted negatively on the livelihood of people who live in flood plains. The general lack of up to date streamflow data has made river basin management problematic especially in the area of flood risk management and the development of a real time flood warning system. Flood studies were carried out in the Ogun River Basin in the southwest Nigeria using synthetic data generated by Rainfall-Runoff Modeling using a combination of the Natural Resources Conservation Service (NRCS) curve number model and digital terrain modeling using ArcGIS® 9.3 software to identify vulnerable areas in relation to synthesized flood waves generated from the basin, extent of inundation and ranking of the flash points that was equally done using proximity to hazard source as a criteria. The total area in the basin covered by fresh water swamps, salt marsh, and tidal flats at the lower course of Ogun river is 49 km^2, while the spatial extent of the entire wetland is 556 km^2 accordingly. When a peak flood volume of 4 270 million m^3 generated in September is routed into the fresh water swamp, about 33.4 m of flood depth was left unaccommodated, which will cause inundation of the entire flood plain and severe damage on its path. Over 1.4 million inhabitants were identified to be at risk in the area. When the entire wetland was considered, the flood wave was reduced to an average depth of 8.5 m which is still capable of causing grave damages in the remaining parts of the flood plain. The flood wave was found to have a residence time of about 45 days. Appropriate recommendations were given for practical adaptations.

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1 Introduction

Floods are hydrological events characterised by high surface water discharges and/or water levels. This can lead to inundation of land adjacent to the water body (flood plain). During a flood, streams and channels are unable to convey the amount of water that has been generated through the runoff process. Sometimes water is unable to escape downstream due to high water levels in receiving streams. Consequently there is an overspill of water over the river banks. In general, floods are caused by intense or longlasting rainfall. Occasionally other causes like failure of embankments, landslides, ice jams, ocean surges (tsunami) or human (in) activity also create floods[1,2].

Large-scale flooding is a serious problem in many counties of the world. In Asia, countries such as China and Bangladesh regularly suffered flood[3], while in

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Biography: J. A. Oyedepo, PhD, Environmental Management. Tel: +234 8032485583; Email: Oyedepoja@unaab.edu.ng.

***Corresponding author: A. Sobowale,** PhD, Engineering Hydrologist, South West Regional Center for National Water Resources Capacity Building Network, Federal University of Agriculture, P.M.B. 2240, Abeokuta, 110001, Nigeria. Tel: +234 8062101020; Email: Sobowalea@unaab.edu.ng; rosvik2@yahoo.com.

Europe many countries are at risk. In recent years, Bangladesh (1997), Mozambique (1997), China (1998), Poland (2000), Pakistan (2011), and Thailand (2011) have suffered catastrophic floods. Nigeria is not an exception as the Abeokuta (2009) and Ibadan floods (August, 2011) are still fresh in our minds. There is danger of death and serious damage to the economies in the affected areas. Such flood risk can never be eradicated, but its impacts can be reduced[4-6]. Early warnings and effective management of river basins by informed flood risk managers can help to prevent some of the physical and psychological impacts of flooding.

The apparent increase in the severity of flooding appears to indicate that there are changes taking place in the earth's climate. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR 4) explains that during 1961 to 2003, the average sea level rose by (1.8±0.5) mm per year. While sea level rise varies between regions, Nigeria's entire coastline has been affected by this observed rise[7]. Such a rise has already led to an increase in coastal erosion and exacerbated flooding damages.

The impact of flooding can be decreased if people are aware of an upcoming flood event. This requires hydrological and hydraulic modeling of the basin to develop a flood forecasting system[3,8]. Unlike developed nations, most of the sub-Saharan African nations lack flood forecasting and warning systems; this is the main reason why flood damages in these countries are more or less catastrophic in nature. The general lack of flood forecasting and decision support systems in these affected countries is connected with the lack of adequate stream gauging in the river basins and low capacity for basin modeling in sub-Saharan Africa.

In recent years, the accuracy of flood forecasting tools has been greatly enhanced with the application of geographic information systems (GIS) in flood risk analysis. The spatial analysis provided by GIS, combined with the temporal analysis provided by hydrological and hydraulic models, would lead to a better understanding of basin behavior and has been used greatly to elucidate flood vulnerability and risk assessment[1,3,9-11]. This approach for the development and management of river basin is still in its infancy in sub-Saharan Africa, especially in Nigeria.

The objective of this research was to evaluate the problem of flooding and flood vulnerability in an ungauged river basin in southwest Nigeria, using a combination of hydrologic simulation and digital terrain modeling.

2 Materials and methods

2.1 Study area

The Ogun River rises in the Iganran Hills (503 m) east of Shaki in the northwestern part of Oyo State, Nigeria and flows southwards for approximately 410 km before discharging into the Lagos Lagoon. Its main tributary is the Oyan River which rises to the west of Shaki and incorporates the Ofiki River. The river basin lies between longitudes 6°33′ E and 8°58′ E and latitudes 2°40′ N and 4°10′ N (Figure 1). The basin area is about 23 700 km^2, occupying parts of Oyo, Ogun and Lagos States[12]. The river basin is predominantly a Precambrian Basement Complex region drained by a system of rivers communicating with the sea through a system of lagoons in the coastal part of western Nigeria. The hydrogeology is generally regarded as comprising poor aquifers because of its limited storage capacity and the low permeability. The area is generally well drained and stream flow responds quickly to rainfall input. The mean wet season rainfall is presently about 1 430 mm in the south and centre, and about 1 185 mm in the north of the basin; the influence of climate change can be readily seen as the increasing rainfall amount and distribution had increased over the basin than that reported by Tahal Consultants (Nig) Ltd[12].

2.2 Data sets and analysis

The methodology used digital elevation data, synthesized direct runoff, and the Forestry Monitoring and Evaluation Coordinating Unit (FORMECU) land-use/land-cover (LULC) data; data from five synoptic and agro-meteorological stations with continuous rainfall records were also used for rainfall-runoff modeling, the Natural Resources Conservation Service (NRCS) curve number model was used to synthesize direct runoff (effective rainfall) in the river basin; the applied curve numbers based on LULC data of the area.

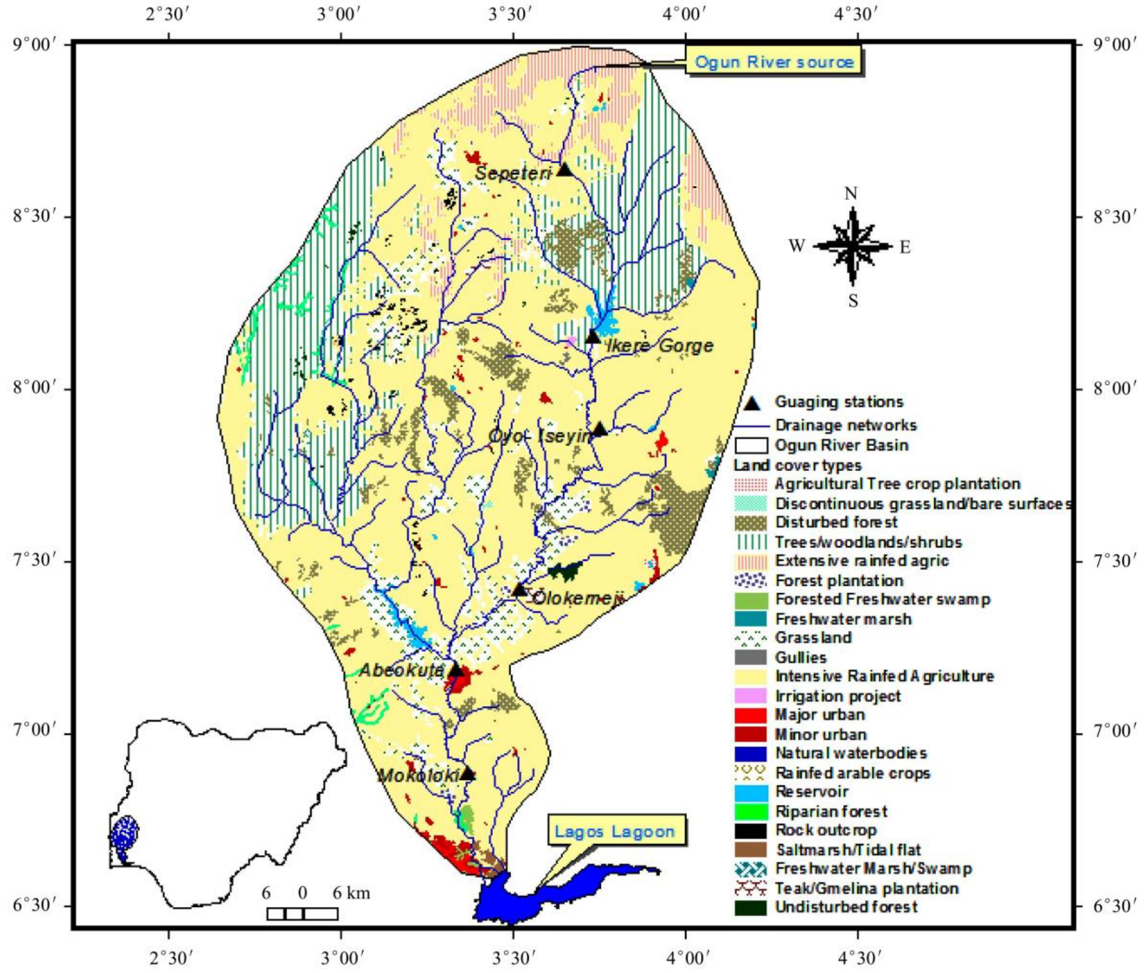


Figure 1 Land use/land cover map of the study area

From the rainfall event as a whole, the depth of excess rainfall or direct runoff (R_d) can be determined, which is usually less than or equal to the depth of the rainfall (P). Likewise, after runoff begins, the additional depth of water retained in the basin (F_a), which is less than or equal to some potential maximum retention (S)[9,10]. There is some amount of rainfall for which no runoff will occur, so the potential runoff is ($P – I_a$). The NRCS model computes abstractions from rainfall[13], the assumptions of the model asserts that:

$$\frac{F_a}{S} = \frac{R_d}{(P - I_a)} \tag{1}$$

where, F_a is depth of water retained in basin, mm; S is potential maximum retention, mm; R_d is depth of direct runoff, mm; P is precipitation depth, mm; and I_a is the initial abstraction from the basin, mm. Initial abstraction was found to be:

$$I_a = 0.2S \tag{2}$$

Therefore,

$$R_d = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{3}$$

Plotting P versus R_d produced curves which were standardized using a dimensionless curve number defined as $0 \le \mathrm{CN} \le 100$. Table 1 presents the curve numbers computed for three categories of antecedent soil moisture conditions: dry (CNI), normal (CNII) and wet (CNIII). From the method of interpolation, equivalent curve numbers were computed using Equations (4) and (5) below.

$$CN(\mathrm{I}) = \frac{4.2CN(\mathrm{II})}{10 - 0.058CN(\mathrm{II})} \tag{4}$$

$$CN(\mathrm{III}) = \frac{23CN(\mathrm{II})}{10 + 0.13CN(\mathrm{II})} \tag{5}$$

Due to the lack of channel characteristics data, a river channel water balance algorithm was used as an alternative to flood routing in order to estimate the flood waves arriving at five existing gauging points (equipment damaged) along the river channel. The river water balance model used for the characterization of the flood in the basin is stated below[14]:

$$Q_d = I_u + R_d - Q_a - S \tag{6}$$

where, Q_d is the computed volume of flood at downstream station, while I_u is the flood inflow volume from upstream station; R_d is the synthesized direct runoff volume generated from the intervening sub basin between upstream and downstream station; Q_a is water abstraction within the sub-basin (dam storage, reservoir evaporation, and water works intake); and S represents the estimated base flow volume at the downstream station. The GIS technology was used to incorporate digital terrain model (DTM) and remotely sensed satellite data with other physical data.

Table 1 Characteristics of sub-basins in the Ogun River Basin

Stream gauging station	Basin area /km^2	Soil type & AMC Group	Land use/land cover	CN (II)	CN (I)	CN (III)	S (II)	S (I)	S (III)
Sepeteri	1 182.2	Clay loam (C)	Intensive agriculture and wood land	74	54	86	3.5	8.5	1.6
Ikere gorge	3 469.5	Clay loam (C)	Intensive agriculture, wood land, disturbed forest	66	45	82	5	12	2
Oyo-Iseyin Road	4 831.6	Clay loam (C)	Intensive agriculture, disturbed forest and grass land	70	49	84	4.3	10.4	1.9
Olokemeji	7 812.8	Clay loam (C)	Intensive agriculture, undisturbed forest and grass land	76	57	88	3.2	7.5	1.4
Abeokuta Bridge	18 812.4	Sandy loam (B)	Intensive agriculture, undisturbed forest	68.5	48	83.3	4.5	10.8	2
Mokoloki	19 737.6	Sandy loam (B)	Intensive agriculture and built up area	68	47	83	4.7	11.2	2

2.3 Land cover classification

The FORMECU LULC data were produced from images of side looking aperture radar in 1995. In order to update the information on the data, the study applied information from a high resolution satellite image and ground truthing exercise. It was important to classify the land use pattern of the river basin since it will give insight to the level of vulnerability of each area within the basin to flooding. What would be impacted can be determined and the best mitigation options to apply can be thought out.

2.4 Digital terrain model

The Global Digital Elevation Model (DEM) data containing the Global Topographic (GTOPO30 global) coverage DEM in IDRISI format (Idrisi32 and IDRISI for Windows) at 30-arc second resolution were largely relied upon to create a DTM of the basin. The GTOPO30 data files were downloaded from the United States Geologic Survey EROS Data Centre, DAAC-GTOPO30 web page at http://edcdaac. usgs.gov/gtopo30/gtopo30.html.

The DEM image was imported into ArcGIS® 9.3 where the elevation values were extracted to points. The points were treated as spot heights which were then interpolated. Deterministic interpolation techniques were used to create surfaces from the measured points, based on the extent of similarity (Inverse Distance Weighted). The deterministic interpolation technique used was the local interpolator which calculated predictions from the measured points within neighbourhoods, which have similar spatial areas within the larger study area. The DTM provided automatic layers for perspective viewing, slope analysis, terrain analysis, hydrograph analysis and flood simulation. It was further transformed into a 3D perspective with the aid of hill shading.

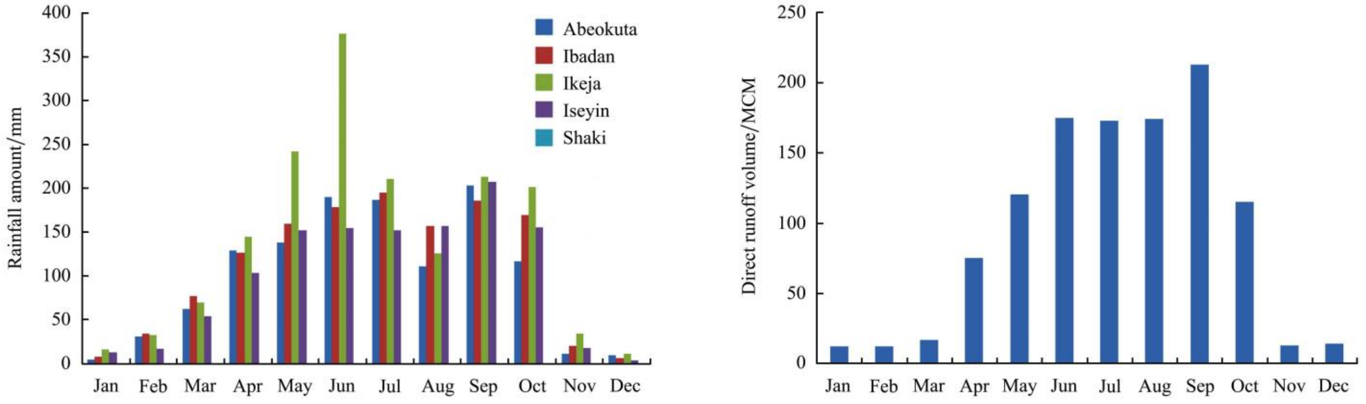
Delineation of the flood prone regions were based on some physical characteristics of flooding such as depth of flooding (m), spatial extent of flood, duration of flood (hours/weeks), frequency of flood occurrence, and relief; the vulnerability factors used include proximity to hazard source, land use or dominant economic activity, adequacy of flood alleviation schemes and perceived extent of flood damage.

3 Results and discussion

Figure 2 presents the 20-year mean monthly rainfall at the five agro-meteorological stations and the synthesized direct runoff at the gauging stations in the basin.

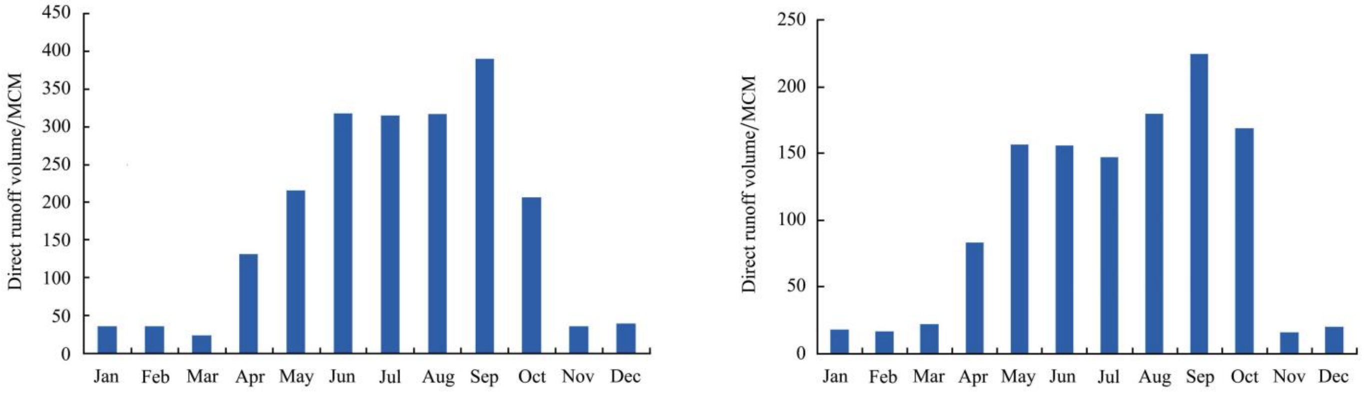
In the past, the rainfall regime in southern Nigeria used to be bi-modal; analysis of the rainfall data showed that it is tending towards a uni-modal regime. This observation may be connected with the problem of climate change leading to increased potential for flooding.

The synthesized direct runoff volume for five stations on the Ogun River is equally presented in Figure 2, there is evidence of strong correlation between rainfall amounts and runoff volume as you move from the northern parts of the basin to the southern part. Worthy of note is the huge amount of water arriving at the Abeokuta station on the river, obviously due to the amalgamation of the Ogun River and Oyan River some few kilometers upstream of Abeokuta city as shown in the satellite image of the river basin presented in Figure 3. It can be seen from Figure 4 that flood waves usually arrive at Abeokuta in June, July, August and September of every year, having direct runoff volume of 4 160 million m^3, 4 180 million m^3, 2 650 million m^3 and 4 700 million m^3, respectively. The sharp drop in August is due to the reduction of rainfall amounts that is locally known as “August break”; despite the reduction in rainfall amounts, the inundation of the flood plain continues as a result of water releases from the Oyan dam which is upstream of the flood plain.



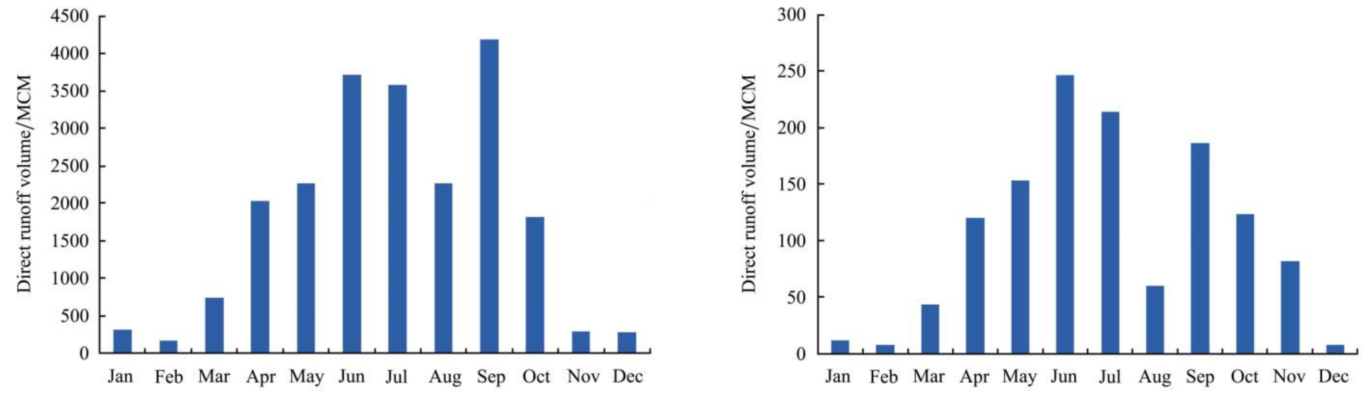
a. 20-Year Mean monthly rainfall in the basin

b. Synthesised runoff at Sepeteri Station



c. Synthesised runoff at Ikere gorge Station

d. Synthesised runoff at Oyo-Iseyin Station



e. Synthesised runoff at Abeokuta

f. Synthesised runoff at Mokoloki

Figure 2 Synthesized direct runoff at five gauging stations in the Ogun River Basin

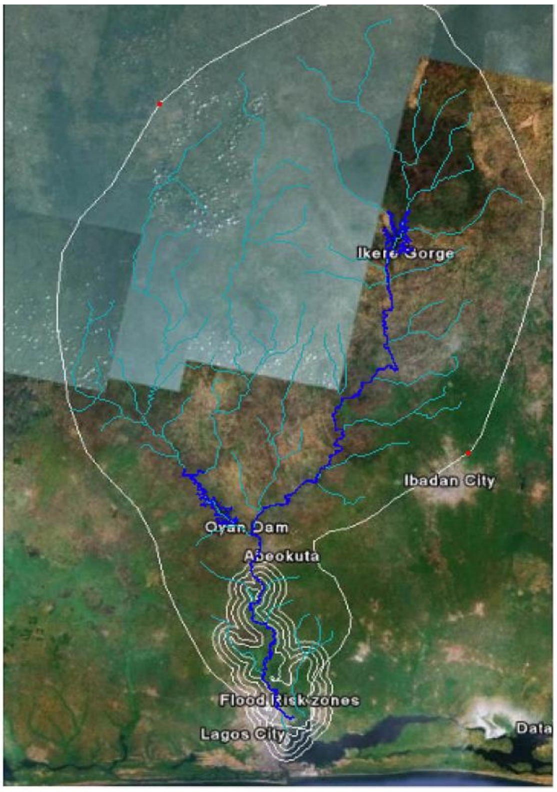


Figure 3 Satellite image of the Ogun River Basin showing stream networks and urban centres

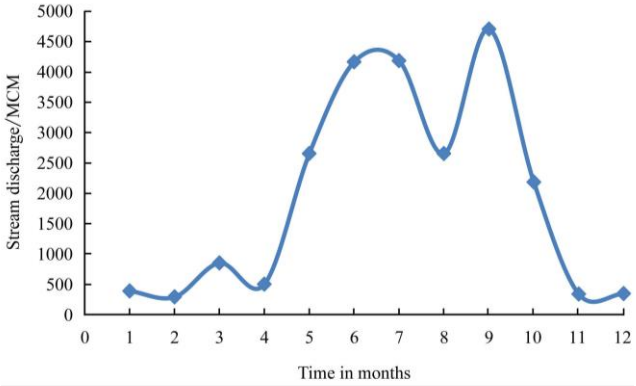


Figure 4 Hydrograph of direct runoff at Abeokuta station

The DTM generated for the basin is presented in Figure 5, the model revealed that there are three distinct toposequence along Ogun river from its source in Ago fulani in Oyo state; namely, upper, middle and lower course of the river. There are very few natural sinks (depressions) all over the entire basin, meanwhile with a depression-less digital elevation model, the natural troughs or flood plains become obvious at the lower course of the Ogun River as shown.

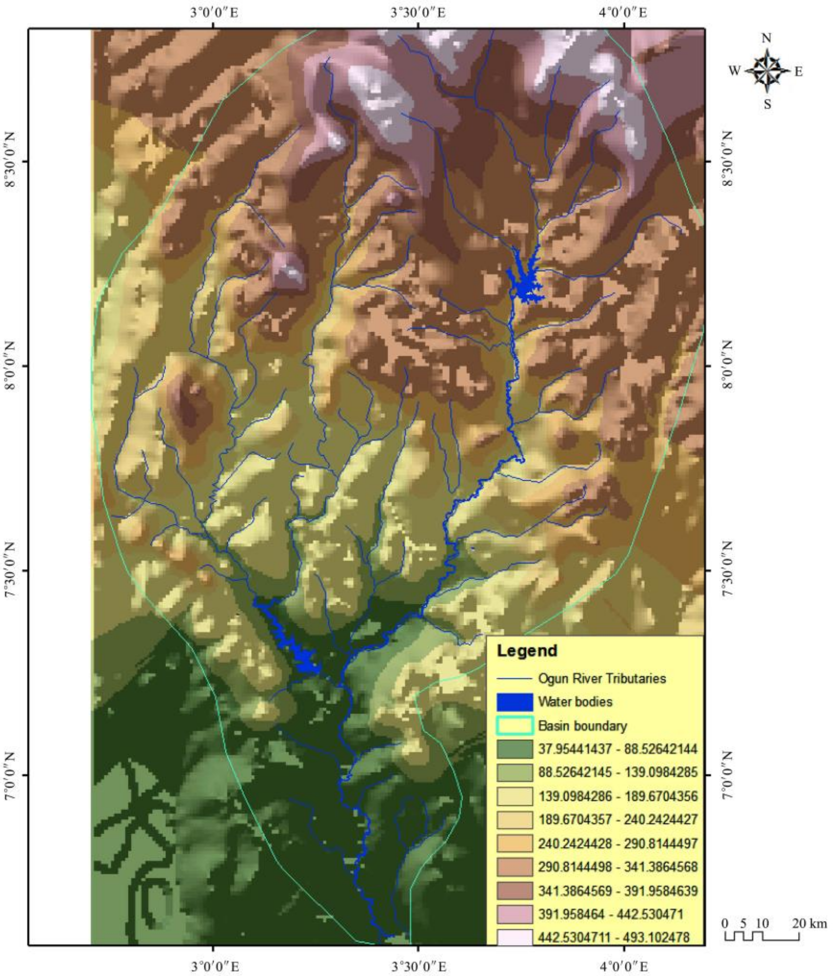


Figure 5 Digital terrain model (DTM) of the Ogun River Basin

The total area in the basin covered by fresh water swamps, salt marsh, and tidal flats at the lower course of Ogun river is 49 km^2, while the spatial extent of the wetland from the DTM is 556 km^2 accordingly; when a peak flood volume of 4 270 million m^3 generated in the month of September is routed into the natural depressions of the fresh water swamp, about 33.4 m of flood depth was left unaccommodated which will cause inundation of the entire flood plain causing severe damage on its path.

When the 33.4 m flood depth was routed into the natural wetland, only 29.95 m of flood waters were accommodated leaving a balance of 8.5 m, which is still capable of causing grave damages in the remaining parts of the flood plain. The flood wave was found to have a residence time of about 45 days after which it begins to recede.

The various elements are considered to be vulnerable to flood damage, including residential areas, agricultural lands, riparian forest and grassland (biodiversity), human population and infrastructures. As earlier stated, several factors were used to assess flood vulnerability, but only analysis based on proximity to hazard source and land use is presented in this paper. The other factors used to develop a flood risk index for the basin include adequacy of flood alleviation schemes and perceived extent of flood damage. The result of that analysis will be published in the second part of this paper.

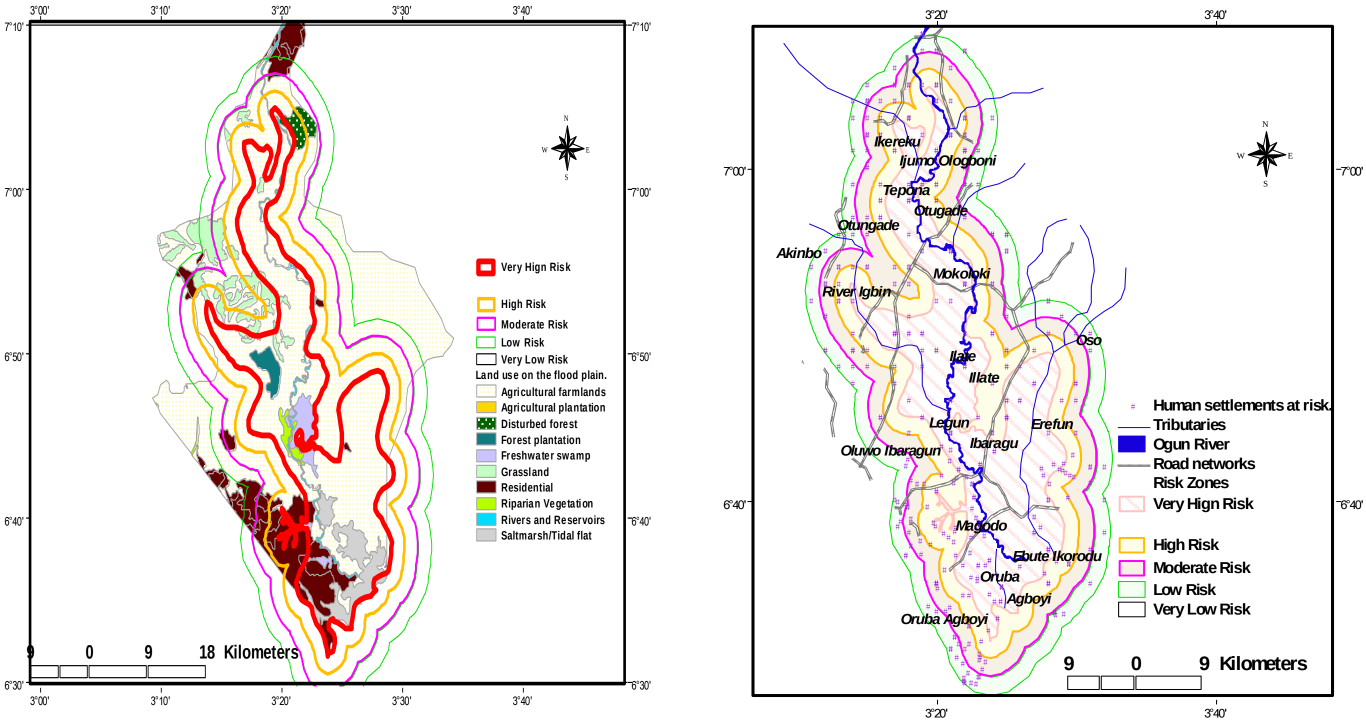
The land use map draped over the relief (hill shade) of the basin reveals the incursion of human activities on the natural buffer zones in the basin. At several positions where human residence are found along the water course, there has been gross violation of the 200 m river bank protection zone law. The spatial extent of vulnerable elements is presented in Table 2; areas within the wetlands were found to be at very high risk, a flood depth of 8.5 m will create catastrophic damages; about 377 336 persons are directly at risk while over 43 km^2 of residential area are highly vulnerable including buildings and its contents. In terms of food security, the annual damages to agricultural lands cannot be accurately estimated; about 395 km^2 of agricultural land and its cultivated crops are at very high risk. The damage to biodiversity will be so enormous considering a total of 79 km^2 area of both riparian forests and grassland in the flood plain. The highest population at risk was found in the buffer zone occupying a distance of 0-2 000 m away from the wetland, this area is also highly vulnerable going by the spatial extent of the residential areas found in the zone; the implication is rapid urbanization within the flood plain without due consideration for potential flood damages.

Table 2 Vulnerable elements within the flood plains of Ogun River Basin

Distance to hazard source/m	Vulnerability	Land area threatened /km^2				Population at risk*	Infrastructure at risk (Roads)/km
		Residential	Agricultural land	Riparian forest	Grassland		
Within wetland	Very high risk	43.0	395.0	8.0	9.6	377 336	33.2
0 – 2 000	High risk	44.3	284.0	-	8.4	389 384	45.0
2 000 – 4 000	Medium risk	21.0	174.2	5.5	25.1	184 459	30.2
4 000 – 6 000	Low risk	23.7	102.2	-	10.5	208 245	22.1
> 6 000	Very low risk	33.4	184.2	1.3	11.0	293 952	40.0

Note: *Based on an estimated 8 789 persons/km^2 derived using Lagos and Ogun state population data.

Figure 6 presents the flood hazard map of the floodplains of Ogun River, showing the spatial extent of vulnerable areas with varying risk levels. Figure 6a shows the threat to agriculture and biodiversity while Figure 6b shows the vulnerability of human population and infrastructure. It can be seen from Table 2 that over 170 km of trunk roads are at risk of annual damage. Estimating the cost of potential damages is indeed a daunting task which requires careful analysis; this is the reason why a flood risk index is very necessary to be considered in the Government's decision on whether they should pay compensation for annual losses in the basin from the National Emergency Relief Fund. This and others are also presented in the second part of this paper. The total human population at risk in the floodplain is 1 453 376 persons; these constitute a grave risk in the area. It is well documented in literatures that this area is fast becoming a major component of the Lagos Mega city development, the implication is that both Lagos and Ogun state governments must work together to develop a joint master plan for the area. The increasing human settlement within the natural wetland indicated a competition for space with the fresh water swamps in the area; ground truthing exercise confirms this as several areas has been sand filled giving rise to buildings and factories.



a. Agriculture and biodiversity

b. Human settlements and infrastructure

Figure 6 Flood hazard map showing elements at risk in the flood plain

4 Conclusions and recommendations

Flood modeling and vulnerability assessment have been carried out in the ungauged catchment of the Ogun River Basin in southwestern part of Nigeria. The lower Ogun River in the catchment receives an enormous discharge of water which is increasingly becoming unmanageable due to excessive negative anthropogenic activities close to the river. Although hydrological analyses show that the basin is quick draining in the upper regions, the analysis of the direction of flow reveals that all water goes into the flood plain at the lower course, and where an excess flood depth finds no natural harbor, the effect could be devastating. It is recommended that strict adherence to the 200 m setback rule should be enforced in the rapidly urbanizing areas along the river course. It will also be useful to carry out some urban renewal to remove encroaching human residence along the river banks. More green belt zones should be established to preserve the biodiversity.

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