

**Research Article**

**Application of analytic hierarchy process and geographic information system techniques in flood risk assessment: a case of Ofu river catchment in Nigeria**

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**Abstract:** Flood risk assessment of Ofu River Catchment in Nigeria was carried out by integration of thematic maps in ArcGIS 10.2.2. Analytic Hierarchy Process (AHP) was applied in the decision making and ranking of flood causative factors before their integration for development of hazard map in ArcGIS. The social and physical vulnerability of the catchment were considered in the development of the vulnerability map. The flood risk map was developed as a product of the hazard and vulnerability map. The results showed that the land areas within the Very High and High Risk zones were respectively 163.07 km<sup>2</sup> and 392.63 km<sup>2</sup> with Igalamela/Odolu Local Government Area (LGA) accounting for about 62% and 31% respectively. A total of 19, 034 and 47,652 persons are respectively at very high and high risk of flood within the catchment. Oforachi community in Igalamela/Odolu LGA and Ejule Ojebe Community in Ibaji LGA both in Kogi State are respectively at Very High and High Risk of Ofu River flood. High Impacts were recorded by about 35% and 52% of Oforachi Community during the 1995 and 2000 historical flood events. A watershed management plan is therefore required to prevent the serious damage experienced in previous flood events.

**Keywords:** *analytic hierarchy process, flood, hazard, multi-criteria evaluation, risk, vulnerability*

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**Introduction**

There is a consensus of opinions among researchers that flood is one of the most devastating, frequently occurring and costliest natural hazards in the world, responsible for more than 30% of all geophysical related hazards, accounting for about 31 % of economic losses globally and adversely affecting more people than any other natural hazard (Nwafor, 2006; Ajin et al., 2013; Adebayo and Oruonye, 2013; Obeta, 2014, Komolafe et al., 2015). Flood generally refers to the inundation of areas of land which are normally dry. Among many other causes, the inability of a river channel to carry discharge volumes beyond its carrying capacity often results in the flooding of nearby lands which in most

cases have catastrophic effect (Jeb and Aggarwal, 2008; Olajuyigbe et al., 2012). This has been the case of Ofu River catchment in Nigeria where the inability of the river to contain the volume of discharges in the peak of the rainy season has consistently resulted in the flooding of surrounding communities for over two decades now (Alfa et al., 2018). Notwithstanding this long disaster within the catchment of Ofu River, this study appears to be the first time the Flood Risk assessment will be carried out in this sub-basin.

While flood risk assessment and flood risk mapping are not new, the methods adopted over time seem to be constantly evolving. Among the methods that have found very wide application in flood risk studies is the application of Multi criteria Evaluation (MCE) and Geographic

Information System techniques. According to de Brito et al. (2016), application of MCE in flood risk management accounted for over 82% of all published peer-reviewed papers between 2009 and 2015. Amongst these techniques, they reported that Analytic Hierarchy Process (AHP) dominated the studies. This points to the fact that these techniques have been proven over this period to be effective tools in flood risk studies. Similarly, the application of Remote Sensing (RS) and Geographic Information System (GIS) techniques have also found wide application in flood risk mapping as opposed to the traditional manual methods (Komolafe et al., 2015). For instance, Daffi et al. (2014) carried out the flood inundation mapping of the Dep River Basin in North central Nigeria using ArcGIS 9.3 in combination with HEC-RAS and HEC-GeoRAS. They obtained the depth and velocity of inundation which were used to classify the hazard level of the flood. Similarly, Jeb and Aggarwal (2008) applied RS and GIS techniques to map the flood inundation extent of River Kaduna within Kaduna metropolis. They combined the Digital Elevation Model (DEM) with flood stage data results obtained from Gumbel's Extreme value distribution model to estimate the extent of flood inundations in different flood return periods. Ojigi et al. (2013) also delineated and mapped the historic 2012 flood in some parts of North-Central Nigeria. A

combination of imageries obtained from RADARSAT, Infoterra SAR, SPOT-5 as well as Shuttle Radar Topography Mission (SRTM) Digital Terrain Model (DTM) were used to map the flood extent of the event. These all attest to the fact that GIS and RS techniques have been proven to be better alternatives for flood risk mapping.

The aim of this study therefore was to apply AHP and GIS techniques to carry out flood risk assessment of Ofu River catchment in Nigeria.

## Materials and Methods

### Study area

Ofu River catchment lies between latitudes 6° 46' N to 7° 39' N and longitudes 6° 42' E to 7° 21' E (Fig. 1). It falls within the Lower Benue River Basin Development Authority covering parts of Dekina, Ofu, Igalamela/Odolu, Idah and Ibaji Local Government Areas (LGAs) in Kogi State and Uzo-Uwani Local Government Area in Enugu State, within the humid tropical rain forest of Nigeria (Alfa et al., 2018). It falls within the Nigerian Hydrological Zone IVa with mean annual rainfall ranging between 1224 mm and 1800 mm (FMW, 2013) concentrated in one season lasting from April/May to September/October (AR-AR, 2004).

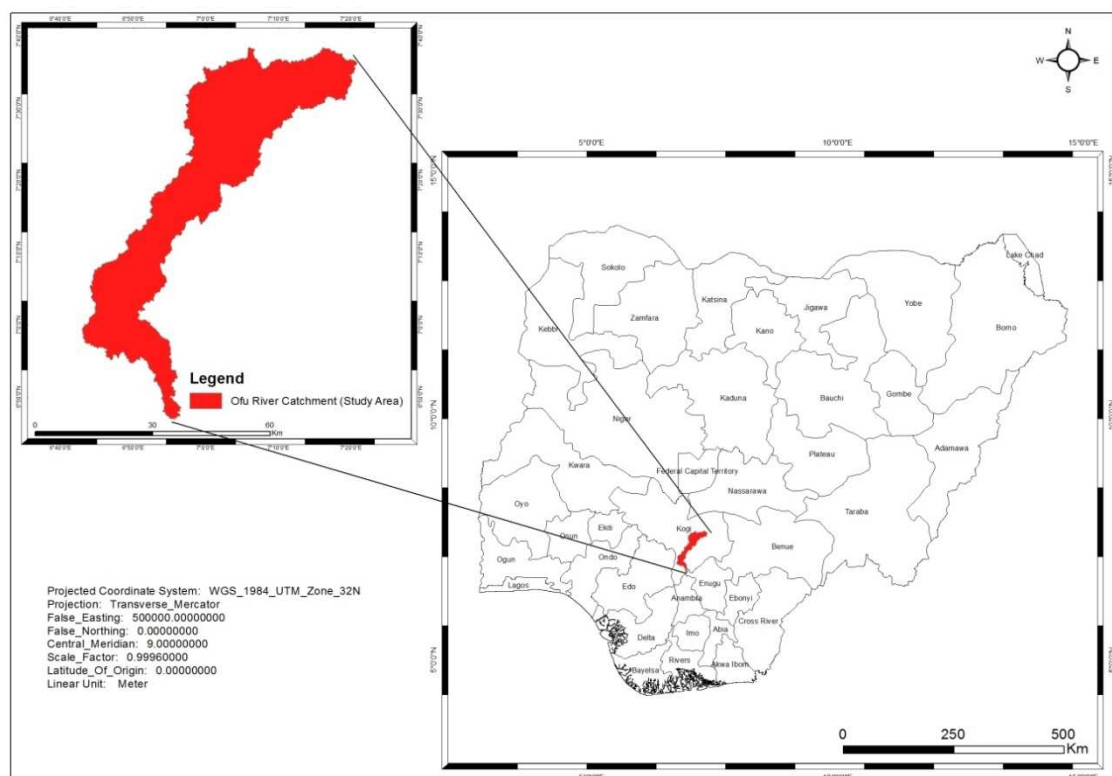


Figure 1. Map Nigeria showing Ofu River catchment

**Generation of thematic maps**

The thematic maps used in this study were those of elevation, slope, proximity (corridor) and soil. The elevation layer was generated using the SRTM DEM of the catchment obtained from the online portal of The United States Geological Services (<https://earthexplorer.usgs.gov>). The elevation information obtained from the field was compared with the maximum stage obtained for Ofu River which served as a guide for the classification of the SRTM DEM as shown in Table 1. The catchment slope on the other hand was obtained in percentages from the sub-mapped SRTM DEM of Ofu River Catchment using the *Spatial analyst surface slope tool* in ArcGIS 10.2.2 and classified based on FAO slope

classifications (Table 1). In order to get the proximity layer, the DEM of Ofu River catchment was first converted to point feature class using the conversion tool in ArcGIS after which the distance of the respective points from Ofu River was calculated using the *Proximity tool* in ArcGIS. The Proximity feature was converted to raster and classified into five domains based on field experience (Table 1). Finally, the soil map of the catchment was extracted from the Digital Soil Map of the World (DSMW) obtained from (<http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116>). The soil types and their respective flood risk classifications are presented in Table 1.

Table 1. Classification of elevation, slope, proximity and soil of Ofu river catchment

Class	Elevation (m asl)	Slope (%)	Proximity (m)	Soil Type
VHR	0 – 70	0 – 2 (Flat)	0 – 500 (Too Close)	Clay Loam
HR	70 – 100	2 – 8 (Undulating)	500 – 1,500 (Very Close)	Sandy Clay Loam
MR	100 – 200	8 – 16 (Rolling)	1,500 – 6,000 (Close)	Loam
LR	200 – 350	16 – 30 (Hilly)	6,000 – 20,000 (A bit Close)	Sandy Loam
NR	> 350	> 30 (Mountainous)	> 20,000 (Not Close)	-

Source: Alfa (2018)

**Derivation of criterion weights using the Analytical Hierarchical Process (AHP) and reclassification of thematic maps**

The Analytic Hierarchy Process (AHP) developed by Saaty (1980) for decision making was employed in deciding the respective relative importance of all the thematic maps of flood causative factors. The relative importance of the respective classes within each of the four (4) thematic maps was derived using the process. The derived weights for each of the maps were used to reclassify the maps as shown in Figures 2-5. A comparison of the four thematic maps with each other was also carried out in AHP to determine their relative importance with respect to flood occurrence. The first step was the establishment of the network for the pairwise comparison which was achieved using the four thematic maps as well as their respective classifications. The next step was the generation of the Pair-wise Comparison Matrices of the relative important values. This was determined based on Saaty’s 1-9 scale (Saaty, 1980). The method of Eigenvector estimation was used to estimate respective weights of the various criteria. The pair-wise comparison was checked using the Saaty’s Consistency Ratio, *CR*. *CR* and Consistency

Index, *CI* were respectively calculated using (1 and 2).

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Where, *RI* is the Random Inconsistency Index dependent on the sample size (Saaty, 1980),  $\lambda$  is the average of the value of the consistency vector (calculated factor weight) while *n* is the sample size. The judgment would be accepted for  $0 \leq CR \leq 0.1$  with a value of zero (0) being the most consistent. The summary of the weights derived for each component of the risk class within the thematic layers are presented in Table 2 while the relative importance weight for all thematic layers compared are presented in Table 3.

**Reclassification and integration of thematic layers for production of hazard map**

The four (4) thematic layers produced (Elevation, Proximity, Slope and Soil) were subsequently reclassified into appropriate classes based on the criteria weights derived which in turn were based on the datasets perceived contribution to flood occurrence.

Table 2. Weights for each risk class within the thematic layers

Elevation		Slope		Proximity		Soil Type	
Class	Weight	Class	Weight	Class	Weight	Class	Weight
VHR	35	Flat	36	Too Close	39	Clay Loam	38
HR	31	Undulating	28	Very Close	30	Sandy Clay Loam	29
MR	19	Rolling	20	Close	17	Loam	21
LR	12	Hilly	12	A bit Close	9	Sandy Loam	13
NR	4	Mountainous	4	Not Close	4	-	-
<b>Total</b>	<b>100</b>	<b>Total</b>	<b>100</b>	<b>Total</b>	<b>100</b>	<b>Total</b>	<b>100</b>
<b>CR</b>	<b>0.00</b>	<b>CR</b>	<b>0.00</b>	<b>CR</b>	<b>0.00</b>	<b>CR</b>	<b>0.00</b>

Table 3. Weights for each risk class within the thematic layers

Thematic Layer	Weight
Elevation	29
Proximity	29
Slope	26
Soil	16
<b>Total</b>	<b>100</b>
<b>CR</b>	<b>0.00</b>

This perception was based on field experience and the assessment of their respective measures of association with flood occurrence. The reclassified thematic layers are shown in Figures 2-5. The reclassified thematic layers were integrated in ArcGIS 10.2.2 to produce the flood Hazard map by weighted overlay where each individual's weight was multiplied by the map scores and the results added.

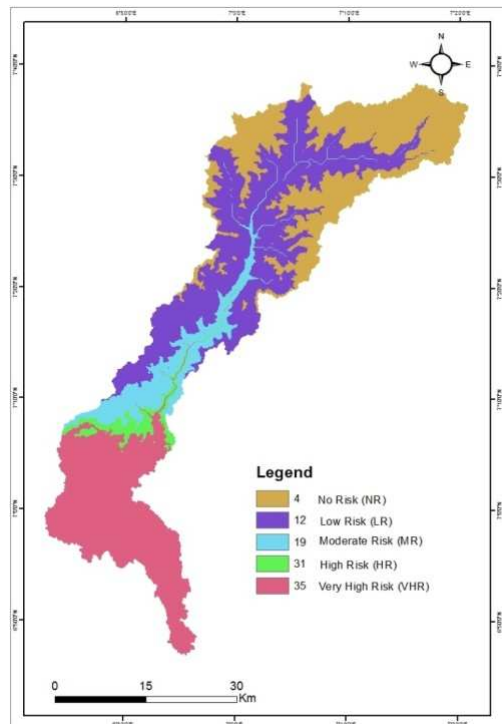


Figure 2. Reclassified Elevation Layer

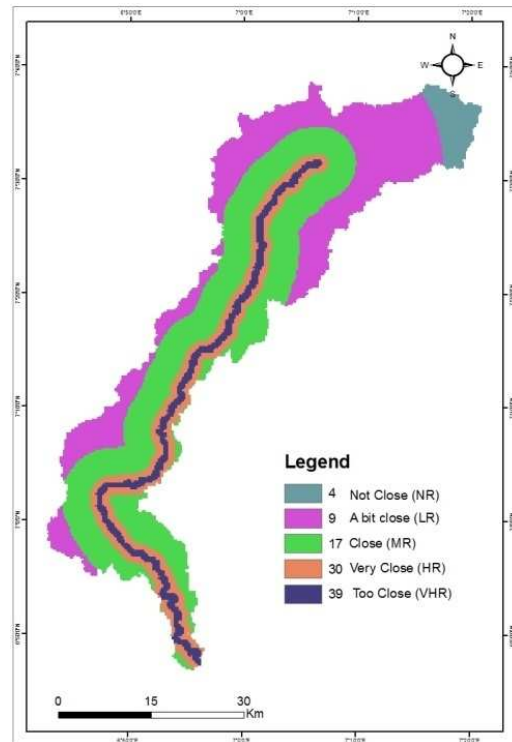


Figure 3. Reclassified Proximity Layer

The flood hazard map produced via the previous operation was then reclassified into five Hazard classes: 'Very High Hazard,' 'High Hazard,' 'Moderate Hazard,' 'Low Hazard' and 'No Hazard.'

**Estimation of vulnerability index and production of vulnerability map**

Physical and social vulnerability were combined to derive the Vulnerability Index and vulnerability map for the study area. The Physical vulnerability was derived based on the location of each point within the catchment in respective hazard zones. The area within the 'Very High Hazard' zone were given a score of 5 while those within the 'High Hazard,' 'Moderate Hazard,' 'Low Hazard' and 'No Hazard' zones were respectively given scores of 4, 3, 2, and 1. The social vulnerability on the other hand was derived based on Age,

disability, gender and economic status. The procedure for determining social vulnerability developed by Cutter et al. (1997) for the South Carolina Emergency Preparedness Division was adopted in this study. The method was developed for vulnerability assessment at County level which is equivalent to the LGA system in Nigeria,

thus making it appropriate for the present study. Using this method, vulnerability weights for ten (10) social classes were derived (Table 4) after which Saaty's Analytical Hierarchical Process (Saaty, 1980) was used to rank all the vulnerability categories (Table 5).

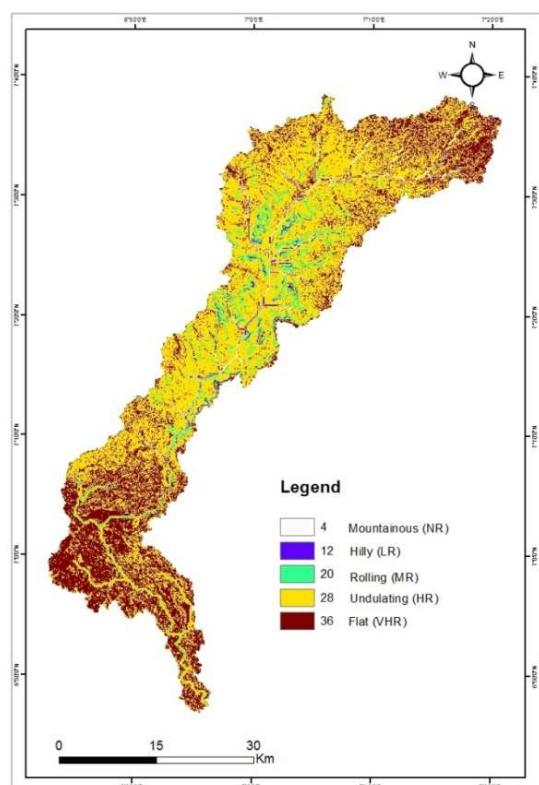


Figure 4. Reclassified Slope Layer

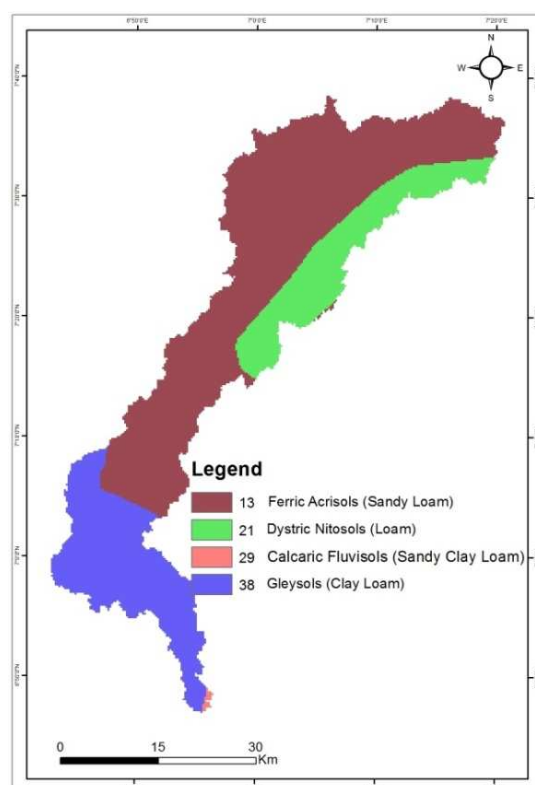


Figure 5. Reclassified Soil Layer

Table 4. Social vulnerability weights for Ofu River catchment

State	LGA	Vulnerability Weight*100									
		Under 15 Years		Above 65 Years		15 – 65 Years		Poverty		Gender	
		WD	ND	WD	ND	WD	ND	In Pov	Ab Pov	Male	Female
Kogi	Dekina	100	100	100	100	100	100	100	100	100	100
	Ofu	55	64	55	64	55	64	64	64	64	64
	Idah	12	10	12	10	12	10	10	10	10	10
	Igalamela/Odolu	30	29	30	29	30	29	29	29	30	29
Enugu	Ibaji	24	25	24	25	24	25	25	25	25	25
	Uzo-Uwani	1	1	3	2	2	2	1	1	1	1

The vulnerability classes are WD15 (under 15 years with disabilities), ND15 (under 15 years with no disabilities), WD65 (above 65 years with disabilities), ND65 (above 65 years with no disabilities), WD15\_65 (between 15 - 65 years with disabilities), ND15\_65 (between 15 – 65 years with no disabilities), InPov (In pov), AbPov (Above Poverty level), Male and Female. The

Table of vulnerability weights for all social classes saved in Comma delimited format (CSV) in Microsoft Excel 2007 was joined to the Catchment shape file divided by LGAs. The respective weights of the social classes were used to derive the vulnerability raster surfaces using the conversion (from polygon to raster) tool in ArcGIS.

The physical vulnerability and the ten (10) social vulnerability maps were integrated to produce the final flood vulnerability Map. This was done using the weighted Sum tool in the Spatial Analyst Tools in ArcGIS 10.2.2. The weights derived for each category was used at this point for the integration. The final Vulnerability Map was first converted to float by dividing by the maximum value using the Raster Calculator in Spatial Analyst (Map Algebra) tool. Thus the final Flood Vulnerability Map was produced with 1 as the maximum value. Similar to the hazard map, it was reclassified into five (5) vulnerability classes: ‘Very High Vulnerability’, ‘High Vulnerability’, ‘Moderate Vulnerability’, ‘Low Vulnerability’ and ‘No Vulnerability’.

Table 5. Overall weights for all vulnerability maps derived by AHP

Social Class	Weight*100
WD15	13
ND15	12
WD65	13
ND65	11
WD15_65	10
ND15_65	7
Inpov	10
Abpov	7
Male	7
Female	10
<b>Total</b>	<b>100</b>
<b>CR</b>	<b>0.00</b>

**Production of flood risk map and flood risk assessment**

The flood Risk map,  $R_m$  was produced as a product of the Hazard map,  $H_m$  and the Vulnerability map  $V_m$  (Baas et al., 2008; Eleuterio, 2012). The multiplication was done using *Raster calculator* in Map Algebra Spatial Analyst tool in ArcGIS 10.2.2. The Flood Risk map for 2018 was then produced and reclassified into five risk zones (‘Very High Risk’ ‘High Risk,’ ‘Moderate Risk’, ‘Low Risk’ and ‘No Risk’) based on natural breaks (Cutter et al., 1997). The flood risk raster map was converted to vector (polygon). The total land area enclosed by different risk zones was calculated using the *Calculate Geometry* tool in the attribute table of the risk polygon. The flood risk polygon was also overlaid on the Catchment shapefile to identify the distribution of the respective risk zones by LGAs. It was also overlaid on the Land use/ land cover raster for the catchment (Alfa et al., 2018) in order to extract

the respective land uses affected by different degree of risks.

**Assessment of extent of damage of the 1995 and 2000 flood events**

In order to assess the damage extent (Impact) of the 1995 and 2000 flood events which are the most severe in recent history within the study area, a cross-sectional study was conducted among 325 household heads in Oforachi Community between September and October, 2016 using quantitative methods of data collection. The choice of Oforachi was informed by the fact that it is the only community within the ‘Very High Risk’ zone in this study. All household heads or representatives who have lived in the community for a minimum of 16 years and consented to participate in the study were included in the study population, otherwise, they were excluded. The sample size estimator, a program developed by The Research Advisors (2006) for different Population sizes and different levels of confidence based on the method (3) of Krejcie and Morgan (1970) was used to determine the sample size of 320 which was rounded up to 325 for ease of proportionate distribution within the respective settlements in the Community.

$$n = \frac{X^2NP(1 - P)}{d^2(N - 1) + X^2P(1 - P)} \quad (3)$$

- Where, n = Sample Size,
- $X^2$  = the table value of chi-square for 1 degree of freedom at the desired confidence level.
- N = the population size,
- P = the population proportion and
- d = the degree of accuracy expressed as a proportion.

A two part semi structured interviewer administered questionnaire was used to assess the impacts of the 1995 and 2000 flood events. The first part contained socio-demographic information of the respondents while the second part contained questions designed to assess the impacts of the respective historical flood events. A total of 22 responses (11 positive and eleven negative) were used. The positive responses were given a score of 1 while the negative ones were given a score of 0. A total score of 0 was regarded as no impact, scores greater than 0 but less than or equal to 2.75 (25%) as low impact, scores greater than 2.75 (25%) but less than 5.5 (50%) as moderate impact, scores greater than 5.5 (50%) but less than or equal to 8.25 (75%) as high impact while scores greater than 8.25 (75%) was regarded as very high impact.



## Results and Discussion

### Flood hazard, vulnerability and risk assessment

The output flood hazard and vulnerability maps are shown in Figure 6. The hazard map in Figure 6 shows that a total of 259.81 km<sup>2</sup> was within the Very High Hazard zone, while 269.52 km<sup>2</sup>, 214.10 km<sup>2</sup>, 552.94 km<sup>2</sup> and 298.75 km<sup>2</sup> were respectively in the High, Moderate, Low and No Hazard zones of the catchment. This implies that the area with the Very High Hazard zone have a very high potential of being affected by a flood disaster (Ajin et al., 2013, Daffi et al., 2014). The vulnerability map in Figure 6 on the other hand shows that only 0.78 km<sup>2</sup> were at a Very High Vulnerability, while 60.49 km<sup>2</sup> was at High Vulnerability. Meanwhile, the Moderate, Low and No Vulnerability zones cover 208.18 km<sup>2</sup>, 613.22 km<sup>2</sup> and 698.05 km<sup>2</sup>. The vulnerability is often a reflection of the exposure, susceptibility and resilience (Balica et al., 2009). The flood risk map obtained as a product of flood hazard and vulnerability is presented in Figure 7. The details of the land area within each risk zone, the respective land cover types within the respective risk zones as well as the distribution of the risk zones by LGAs are presented in Tables 6 and 7.

The results presented in Table 6 reveal that 163.07 km<sup>2</sup> are at a Very High Risk of flood, 392.63 km<sup>2</sup> are at a high risk of flood while 116.82 km<sup>2</sup>, 255.27 km<sup>2</sup> and 653.70 km<sup>2</sup> are at moderate, low and no risk of flood respectively. The result further shows that built-up area accounts for 36.68 % of the Very High Risk zone and 52.35% of the High Risk Zone putting 19,034 and 47,652 persons at Very High and High Risks respectively. This calls for serious concern for an emergency mitigative measures as well establishment of awareness systems to prevent the catastrophic effect of this flood disaster. Similarly, Igalamele/Odolu LGA is the most at risk of flooding within Ofu River catchment. This is revealed by the fact that 62.86% and 31.33% of the Very High and High Risk zones respectively fall within the LGA. It can be seen that Oforachi in Igalamele/Odolu LGA is the only notable community within the Very High Risk zone while Ejule-Ojebe in Ibaji LGA is the only notable community within the High Risk zone. As a result, an assessment of the impact of the 1995 and 2000 flood events which are the most severe in recent history was carried out at Oforachi and the results are presented in Table 8.

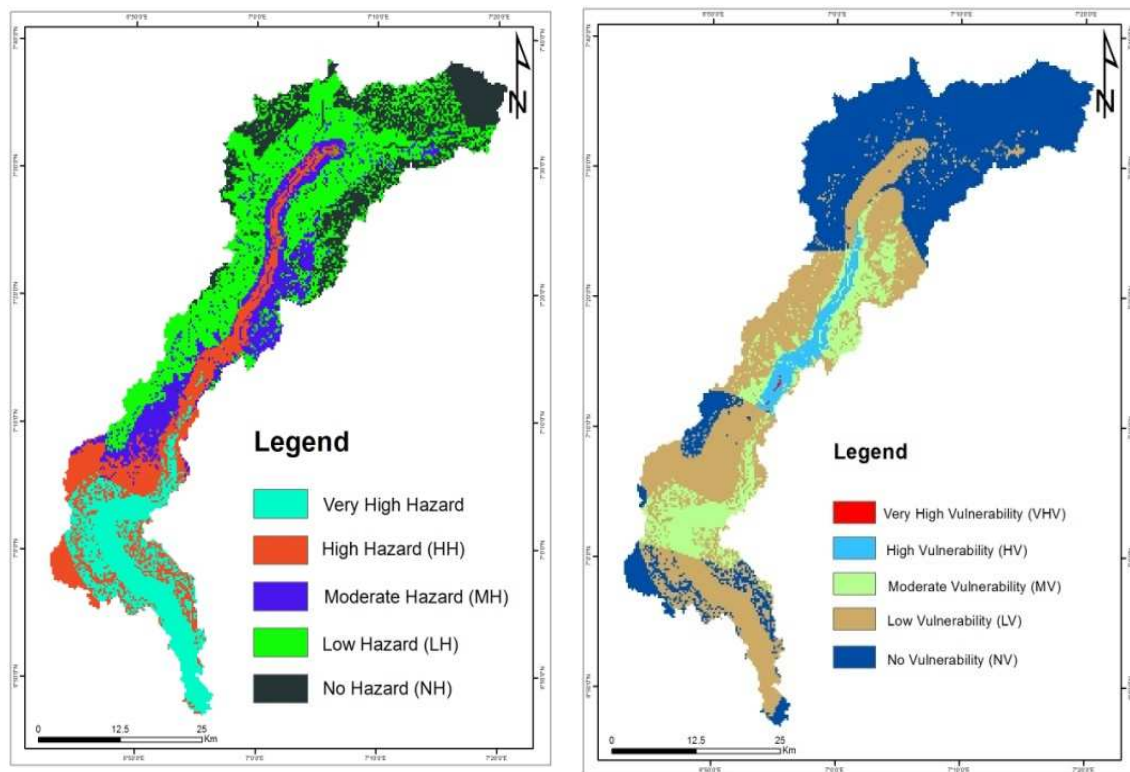


Figure 6. Flood hazard and vulnerability maps of Ofu River catchment, Nigeria

Table 6. Land cover and population at varying degree of risk

Risk Class	Total Land Area (km <sup>2</sup> )	Land Area by Cover Types (km <sup>2</sup> )						Population at Risk	Notable Communities
		Vegetation	%	Bare Ground	%	Built-up	%		
VHR	163.07	97.54	59.81	5.39	3.31	59.81	36.68	19,034	Oforachi & scattered settlements
HR	392.63	165.98	42.27	19.62	5.00	205.56	52.35	47,652	Ejule-Ojebe & scattered settlements
MR	116.82	65.14	55.76	9.06	7.76	42.19	36.12	13933	Scattered settlements
LR	255.27	157.11	61.55	13.14	5.15	83.24	32.61	44245	Scattered settlements
NR	653.70	367.93	56.28	73.74	11.28	208.11	31.84	91996	Ajaka, Araba, Adiele, Ajieru, Ajiyolo & scattered settlements

Table 7. Distribution of respective risk zones by LGAs

Risk Class	Total Land Area (km <sup>2</sup> )	Land Area by LGAs (km <sup>2</sup> )											
		Dekina	%	Ofu	%	Igalamela/Odolu	%	Idah	%	Ibaji	%	Uzo-Uwani	%
VHR	163.07	0.54	0.33	59.60	36.62	102.31	62.86	0.17	0.11	0.13	0.08	0.00	0.00
HR	392.63	18.94	4.84	107.03	27.35	122.56	31.33	0.33	0.09	142.40	36.40	0.00	0.00
MR	116.82	53.26	45.75	0.29	0.25	56.78	48.77	0.00	0.00	0.55	0.47	5.55	4.77
LR	255.27	1.27	0.50	184.46	72.74	0.79	0.31	2.83	1.12	64.01	25.24	0.24	0.10
NR	653.70	586.73	90.25	34.04	5.24	29.31	4.51	0.00	0.00	0.00	0.00	0.00	0.00



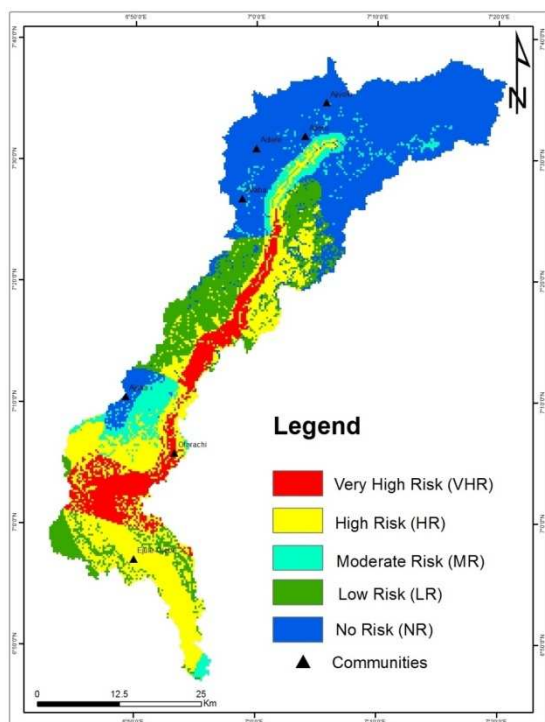


Figure 7. Flood risk map of Ofu River catchment, Nigeria

Table 8. Impacts of the 1995 and 2000 flood event in Oforachi community in Kogi State

Characteristics	Frequency	Percentage
<b>Have ever experienced flood</b>		
Yes	197	60.62
No	128	39.38
Total	325	100.00
<b>Affected by 1995 flood event</b>		
Yes	126	63.96
No	71	36.04
Total	197	100.00
<b>Impact of 1995 flood event</b>		
Moderate Impact	13	10.32
High Impact	113	89.68
Total	126	100.00
<b>Affected by 2000 flood event</b>		
Yes	189	95.94
No	8	04.06
Total	197	100.00
<b>Impact of 2000 flood event</b>		
Moderate Impact	21	11.11
High Impact	168	88.89
Total	189	100.00

In agreement with the risk analysis done previously, the results in Table 8 show that 113 persons representing 89.68% of those affected by the 1995 flood, 57.36% of all those ever affected by flood in the community and 34.76% of the total households surveyed had high impact of the 1995 flood event. The situation is even more serious with the 2000 flood events. 168 persons representing 88.89% of those affected by the 2000 flood event, 85.28% of all those ever affected by flood and 51.69% of the households surveyed. In both cases, no loss of lives or physical injury to humans was recorded. But various degrees of losses such as building collapse, loss of livestock, loss of crops amongst others were top among the damages experienced.

### Conclusion

This study concludes that about 163 km<sup>2</sup> of the entire catchment of Ofu River is at a very high risk of flood disaster while about 392 km<sup>2</sup> is at high risk of flood disaster. Oforachi in Igalamela/Odolu LGA in Kogi State is the main community at a very high risk of flood within the catchment of Ofu River. While the very high and high risk zones span across the four LGAs that make up the catchment, Igalamela/Odolu LGA is the most at risk of flood disaster accounting for over 62% and 31% of the very high and high risk zones respectively. An appropriate watershed management plan that will include optimum management of the flood plains, emergency preparedness and early warning systems is urgently needed. This is believed will reduce the current high flood impact within the communities.

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