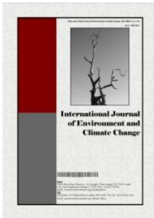

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GIS-Based Climate Change Induced Flood Risk Mapping in Uhunmwonde Local Government Area, Edo State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OAI designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author OFI managed the literature searches and analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Introduction: Flood is one of the climate change induced hazards occurring in most parts of the world. It exposes humanity and many socio-ecological systems to various levels of risks. In Nigeria, extreme rainfall events and poor drainage system have caused inundation of several settlements to flooding. To contain the disaster, risk mapping were among the measures recommended.
Aims: The aim of this paper is to highlight flood risk zones (FRZ) in Uhunmwonde Local Government Area (LGA), Edo State, Nigeria.
Methodology: Flood risk (FR) was mapped using hazards and vulnerability and implemented using geographic information system (GIS)-based multi-criteria analysis analytic hierarchy process (MCA-AHP) framework by incorporating seven environmental and two socio-economic factors. Elevation, flow accumulation, soil water index of wettest quarter, normalized difference vegetation index, rainfall of wettest quarter, runoff of wettest quarter and distance from rivers constituted the hazard component while population density and area of agricultural land use was the vulnerability

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layer. The climate change induced flood risk was validated using the responses of 150 residents in high, moderate and low flood risk zones.
Results: The resulting flood risk map indicated that about 40.4% of Uhunmwonde LGA fell within high flood risk zone, 35.3% was categorized under moderate flood risk zone whereas low flood risk zone extended up to about 24.3% of the LGA. The high number of respondents who reported occurrence of flooding with frequency being very often and the fact that flooding was a very serious environmental threat during on-the-spot field assessment validated the generated climate change induced flood risk.
Conclusion: The utilitarian capabilities of GIS-based MCA-AHP framework in integrating remotely-sensed biophysical and climate change related flood inducing indicators with socio-economic vulnerabilities to arrive at composite flood risk was demonstrated.

Keywords: Flood hazard; vulnerability; flood risk; GIS; mapping; uhunmwonde LGA.

1. INTRODUCTION

Flooding has been acknowledged as one of the direct consequences of climate change [1] due to increase in the frequency and intensity of tropical cyclones, hurricanes, typhoons and other moisture-laden extreme weather phenomena [2]. The warmer than normal global temperature [3] is an invitation for increase in convective activities in the earth's atmosphere [4] with resultant increase in the amount and duration of rainfall [5]. Melting of ice caps in the Polar Regions directly linked to global warming and worldwide changes in the level of water in the oceans leading to upsurge in coastal and river flooding have also been documented [3,6,7]. The current worldwide mean annual increase of 3-4mm in water levels in the oceans and the predicted rise to about 15 mm at the end of the present century is also responsible for the frequency and magnitude of flooding [8].

However, a shift in climate has been ascribed to the actions of man which modifies atmospheric processes as well as the noticeable natural spatial and temporal fluctuations in global climatic pattern [3,9]. In contrast, flood or flooding is the accumulation of excessive quantity of water in an area without flowing away easily [10]. In most cases, the accumulation of such abnormal large volume of water in an area that is not usually covered by water is also hampered by poor percolation and runoff [10,11]. At the global, national, regional and local scales, substantial evidence on the climate change induced floods and flooding abound.

Approximately 80% of the world's population spread across just 15 nations which suffer from severe impact of flooding annually. India, Bangladesh and China topped the list while over 167,000 people in the United States of America (USA) are exposed to flooding every year [12]. In 2017, over three billion dollars' worth of properties and cultivated farmland in several places in USA were lost to climate change induced flooding. This was as result of increase in the frequency and intensity of rainfall coupled with increased development in floodplains, increased impermeable surfaces (roads, pavements, and parking lots), destruction of natural areas [13]. In the United Kingdom (UK), two days continuous rainfall in October 2019 similar to the already reported monthly value as a result of successive stormy activities made several locations to be inundated to flood waters [5]. Nigeria occupied the 10th position in terms of food occurrence and vulnerability annually [12].

In climate change debates, flood risk has been conceptualized as the product of three principal components namely: hazard or exposure, sensitivity or elements at risk and vulnerability [6,7,14]. Risk practitioners view risk as the product of the probability of an event's occurrence and its magnitude (i.e., probability × magnitude = risk). However, in environment and development debates, this relationship include an exponent to account for social values or societal impacts (i.e., probability × magnitude *n*), although *n* may be difficult to measure [15]. Also, several efforts have been made to assess climate change induced flood risk both in developed and developing countries. Identifying the environmental factors inducing flood, the elements at risk as well as the strategies adopted by the vulnerable population is particularly essential in flood risk mitigation and contingency planning [16].

Key datasets common in climate change induced flood mapping include elevation, slope, aspect, geology, distance from river, distance from road, distance from fault, soil type, land use and land cover, rainfall, normalized difference vegetation index (NDVI), stream power index, topographic wetness index, sediment transport index and curvature [16-22]. Methodological frameworks include socio-economic, biophysical, and integrated [23]. Manlosa and Valera [24] deployed socio-economic approach to assess micro scale flood damage in a Lakeshore Community of Jabonga in the province of Agusan del Norte in the Philippines. It was found that monthly household income, land area farmed, number of livestock owned, frequency of flood incidence in the homes, flood velocity, and duration of inundation at the work area were the determinants of household flood vulnerability in the hazard zone. This study however neglected the roles of sociopolitical and environmental variables in shaping societal vulnerability.

Udo and Eyoh [25] also used biophysical approach to map river inundation and flood hazard in Edo State. It was found that 25% were very high hazard zones while 30% of the state was classified high hazard places. The lowly hazard areas covered 4354 square kilometers (22.2%) and no hazard covered 8.2% of the study area. Espada et al [26] used integrated framework to assess the vulnerability of core suburbs of Brisbane City, Queensland, Australia to flooding. Findings revealed that 36% (about 813 hectares) and 14% (roughly 316 hectares) of the study area were exposed to very high flood risk and low adaptation capacity, respectively. Geographical information system (GIS), remote sensing (RS), multi-criteria analysis (MCA) and analytical hierarchy process (AHP) have also been deployed in the execution of integrated based flood risk mapping [16-22,25,26].

The basic principle in MCA is the allocation of weights to various flood hazard, sensitivity and vulnerability indicators based on perceived and established criteria [22]. In MCA, AHP accredited to [27] which involve the use of chain of command configurations in the representation of indicators in addition to prioritizing viable options using expert decisions have been widely used. The AHP framework uses pairwise rating scale ranging from one (equally important) to nine (absolutely more important) in measuring the impact of each indicator to the overall outcome of the phenomenon under study [28].

Flood is one of the environmental problems occurring in most parts of the world. It exposes humanity and many socio-ecological systems to various levels of vulnerabilities. In Nigeria, 35 states including Edo and 380 Local Government Area (LGA) including Uhunmwonde were inundated due to heavy rainfall and poor drainage system in 2018 [29]. The 2019 flooding affected the 36 states and over 124 LGAs rendering 210,117 people vulnerable in addition to 171 deaths while households were rendered homeless [30]. In Uhunmwonde Local Government Area (LGA), several households were displaced leading to the establishment of temporary camp at Egor, the LGA headquarters. The 2020 rainfall prediction by the Nigeria Meteorological Agency (NiMet) showed that the southern parts of Nigeria (where Edo State including Uhunmwonde LGA is located) is expected to have extended period of rainfall [31]. The implication of the 2020 rainfall forecast is increased probability of climate change induced flooding across the zone.

Thus, in order to avert the 2020 flood impact at the present and in the future as well as to contain flooding, the Nigeria Hydrological Services Agency (NIHSA) recommended measures such as flood sensitisation campaigns, flood risk mapping and flood vulnerability studies [29]. Climate change induced food risk mapping in Uhunmwonde LGA is therefore, one of such attempt to respond to the clarion call made by NIHSA. Mapping climate change induced food risk in Uhunmwonde LGA is not only apt but necessary to forestall continued loss of life, properties and biodiversity. This formed the prime motivation for this study in order to support policy and decisions towards a workable flood-based climate change adaptation agenda.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out in Uhunmwonde LGA which is one of the 18 LGAs in Edo State, Nigeria with headquarters in Ehor as depicted in Fig. 1. Uhunmwonde LGA is spatially situated between latitudes 6º14’ 22.207’’ and 6º47’ 2.921’’ north of the Equator and longitudes 5º 36’ 35.761’’ and 6º6’ 37.15’’ east of the Greenwich. Uhunmwonde LGA is bounded in the north by Owan West LGA, in the east by Esan and Igueben LGAs, in the south by Orhionmwon and Ikpoba-Okha LGAs and in the west by Egor and Ovia North-East LGAs. Uhunmwonde LGA extends across a land mass of about 2,056.449 km^2 [32]. Politically, Uhunmwonde LGA is divided into ten (10) electoral wards namely Ehor, Irhue, Igieduma, Uhi, Egbede, Umagbae North, Umagbae South, Isi North, Isi South and Ohuan. Uhunmwonde LGA falls within the tropical/mega thermal climate [33] characterized by two seasons, namely dry and rainy seasons. The dry season usually commences from early November to late March while the rainy season starts from late March to early November. December to February is usually marked by Northeast trade winds which causes harmattan [34]. Climatic data released from nearby station in Nigeria Institute for Oil Palm Research (NIFOR) showed that the mean annual maximum and minimum temperatures (2007 - 2016) in LGA stood at 31.9ºC and 22.2ºC respectively. Mean annual relative humidity at 0900GMT and 1500GMT in the same period stood at about 81.2%, and 67.4% respectively. Mean solar radiation is 352.4gm/cal/cm^2/day while the monthly mean sunshine hour was 4.7.

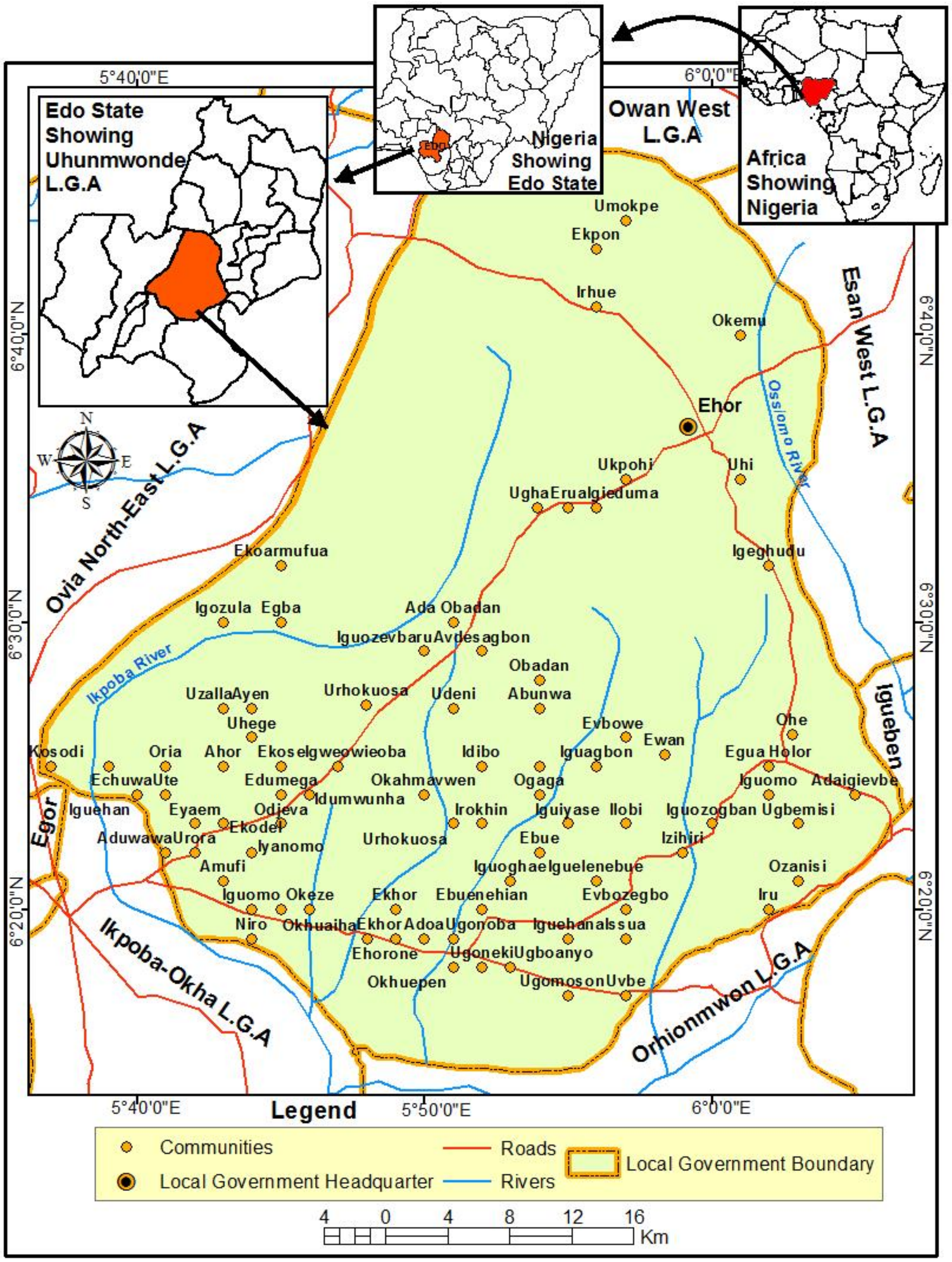


Fig. 1. Uhunmwonde LGA in the State, National and Continental Context

The area receives rainfall throughout the year with annual rainfall range of 1172mm and 2127.2mm and these were recorded against the year 2016 and 2011 respectively [35]. The rainfall pattern in Uhunmwonde LGA is characterized by double maxima as observed from the ten year data. The first peak is recorded in July while the second peak is in September after a short dry season (August break) in August. These climatic elements are critical and could drive the community to various levels of risks and vulnerabilities to flood in event of slight change in time and space. The relief of Uhunmwonde LGA is low lying situated within the Benin lowlands with a sandy coastal plain and alluvium clay with some hills in the north and eastern parts [36].The United States Geological Surveys (USGS) 30 X 30 meters resolution digital elevation model (DEM) of Uhunmwonde LGA shows that the highest elevation range is between 118 – 127 meters while the lowest elevation range is between 31 - 66 meters above the mean sea level (MSL). Uhunmwonde LGA is drained by two important rivers namely Rivers Ikpoba and Ossiomo with their tributaries. These rivers flow from the northern part of the LGA towards the southwest. The drainage pattern has the potential of aiding flood risk in Uhunmwonde LGA due to seasonal overflow of its channels during peak periods.

Apart from climate, another vital environmental factor in flooding globally is the nature of the soil. There are two principal soil groups found in Uhunmwonde LGA namely, acrisols (AC) and nitisols (NT). In general, acrisols are soils characterized by the possession of an argic B layer having exchangeable capability of cation of ≤ 24 cmol(+) kg^{-1} with a saturation level (by NH_4OAc) ≤ 125 cm of the plane. There is conspicuous disappearance of the E layer in this soil type which is unexpectedly superimposed on a gradually permeable layer. Haplic sub-category of acrisols are not sturdily humic but it is noted with relatively low ferric characteristics and deficient in plinthite and gleyic features around 125 cm and 100 cm from the top soil [37]. Another group of soil that dominates the study area is the nitisols with colouration varying from darkish-red to murky red which usually.

This soil group has an estimated mean depth of 150 cm from the surface. Nitisols are tightened intensely to the subsurface layer dominated by clay and distinguished by polyhedric blocky configuration basics with glossy ped facade [37]. This soil association is very widely formed and predominantly intensely disintegrated, rough and principally acidic in nature with substantial quantity of humus necessary to support plant growth. The significant level of organic materials of soils in this group is traceable to frequent decay of plant and animals in the area [38].

The major means of socio-economic livelihoods in Uhunmwonde LGA are closely related to that found in normal semi-urban areas in Nigeria [33]. However, with a large expanse of landmass, farming is the leading source of livelihood in Uhunmwonde LGA. Farming is the chief source of raw materials for secondary/tertiary industries within and outside the study area [39], key employer of labour and chief supplier of over 70% of the food consumed in households [40]. Other livelihood options include trading, logging, hunting, processing of agricultural products, carpentry, bricklaying and other forms of salary jobs or service provision [33]. Major crops include yam, cassava, maize, plantain, banana and coco yam, plantation crops in the area are rubber and cocoa while melon, okra, peppers and other crops are grown in smaller quantities [41].

2.2 Datasets and Sources

Datasets used include administrative maps, elevation, flow accumulation (FA), soil moisture of wettest quarter (SMWQ), normalized difference vegetation index (NDVI), rainfall of wettest quarter (RWQ), runoff of wettest quarter (RWQ) and distance from the rivers (DFR) constituted which constituted the hazard component while population density (PD) and agricultural land use (ALU) was the vulnerability layers. The administrative maps include that of Edo State (for insert purpose) and Uhunmwonde LGA was sourced from Edo State Geographic Information Systems [42] archive. Elevation, FA (derived from elevation), NDVI and RWQ were remotely sensed data sourced from METEOSAT Earth Observation Satellites launched by EUMETSAT (Network of 31 European National Meteorological Services) Satellite Application Facility on Climate Monitoring (CM SAF) [43].

Another remotely sensed data was SMWQ (0-40 cm) and was downloaded from the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) website (https://disc.gsfc.nasa.gov/datasets/FLDAS_NOAH01_C_GL_MC_001/summary?keywords=FLDAS).

Empirical reports as well as detailed information concerning the accuracies, consistencies, quality checks and algorithms of these remotely sensed datasets can be found in the works of [44-46] among others. Also, DFR was extracted from the administrative map of Uhunmwonde LGA, RWQ was downloaded from http://worldclim.org, PD was retrieved from [32] while ALU was sourced from the global gridded dataset of the extent of irrigated land [47]. Apart from the administrative maps which were in hard copy other datasets were in gridded digital formats with spatial resolution ranging from 30meters to 0.1 x 0.1 degrees.

2.3 GIS Data Capture and Flood Risk Database Creation

This section describes data capture processes which facilitated the creation of database used for flood risk mapping in ArcGIS 10.1 environment. The administrative map of Edo State was imported in ArcGIS 10.1, georeferenced with latitude-longitude geographic coordinate system (GCS), vectorized using on-screen digitization and classes which formed attribute data was created. Clip algorithm was executed in order to subset Uhunmwonde LGA out for map compilation as seen in Fig. 1. Based on [16,17,25 and 48], 2km buffer around all the rivers and streams traversing Uhunmwonde LGA was generated using multiple ring buffer algorithm in Spatial Analysis Extension of ArcGIS 10.1 which produced the DFR layer.

Conversely, all the remotely sensed data which came in gridded .ncdf formats were all converted to Environmental Systems Research Institute (ESRI) grid formats using ArcGIS 10.1 multidimention algorithm. In order to extract the numerical values from the remotely sensed gridded data, 5,000 random points at mean distance of 10meters were automatically generated using ArcGIS 10.1 spatial analyst extension-based random point algorithm. The 5,000 random points generated were to facilitate smooth qualitative flood hazard and risk mapping. These random points were used in extracting the numerical values from the remotely-sensed gridded data using batch operation-based extraction algorithm in ArcGIS 10.1. Thereafter, following [49] framework, the extracted values were interpolated using inverse distance weighted (IDW) algorithm in ArcGIS 10.1. The resulting IDW-generated flood hazard layers were reclassified into three distinct classes using equal interval classification system.

2.4 Flood Hazard Mapping

This study applied GIS-based MCA-AHP to map climate change induced flood hazard in Uhunmwonde LGA. This was preceded by application of batch operation in the reprojection of all the layers from GCS to Universal Transverse Mercator (UTM) Zone 32 North and

Table 1. Flood Hazard Datasets Ranges, Ranks and Weights

S/No	Flood Hazard Datasets	Ranges	Ranks	Weights
1.	Rainfall (mm)	1064.0 – 1085.2	Low	1
		1085.3 – 1103.5	Moderate	2
		1103.6 – 1121.8	High	3
2.	Soil Moisture of the Wettest Quarter	183.2 - 194.3	Low	1
		194.4 - 205.8	Moderate	2
		205.9 - 227.6	High	3
3.	Distance from the rivers (meters)	4001 – and above	Low	1
		2001 – 4000	Moderate	2
		Less than 2000	High	3
4.	Runoff of the wettest quarter	150.2 - 167.7	Low	1
		167.8 - 178.8	Moderate	2
		178.9 - 193.5	High	3
5.	Flow Accumulation (dimensionless)	Less than 900	Low	1
		901 – 1802.6	Moderate	2
		1,802.6 - 2,704	High	3
6.	Elevation (meters)	33.1 - 86.4	High	3
		86.5 - 113.0	Moderate	2
		113.1 - 127.1	Low	1
7.	NDVI	Less than 0.2	Very	3
		0.2- 0.4	Moderate	2
		0.4 and above	Low	1

resampling to the pixel resolution of 30 x 30 meters to correspond with the resolution of the DEM used. The MCA-AHP framework involved the categorization of the entire seven factors into three hazard classes with each class ranked according to the estimated significance for causing flooding. The ranges distinguishing each factor including their respective ranks and weights are presented in Table 1. Spatial Analyst Extension of ArcGIS 10.1 and raster calculator tool thereafter provided the algorithm to create and execute map algebra expressions using the seven climate change induced flood hazard factors. The Single Output Map Algebra is mathematically expressed using the formula in equation 1:

$$\sum_{j=1}^{n} H = CjXj \qquad (1)$$

Where H is the Flood Hazard Index; Cj is the factors that instigate flood; and Xj is the parameter associated with each factor which in this case is the determining weights. However, among all the datasets, RWQ was given the highest rank and weight (Table 2) due to the fact that most flood events normally occur after a long and persistent rainfall while other factors were given equal weight. The final output of flood hazard index map was reclassified into three (3) hazard categories namely: Low, Moderate and High.

Table 2. Flood Hazard Determinant and Rank

Flood Hazard Factors	Rank	Weights
Rainfall intensity	3	0.3
Soil water index	1	0.112
Distance from rivers	1	0.112
Runoff	1	0.112
Flow accumulation	1	0.112
Elevation	1	0.112
NDVI	1	0.112
Total	**10**	**1**

2.5 Flood Vulnerability Mapping

It is vital to note that vulnerability in risk management refers to the degree to which an area, people, or physical structures or economic assets are exposed to loss, injury or damage caused by the impact of a hazard. The socio-economic factors used in this study as vulnerability layer were PD and ALU. The 2019 projected population figures were linked to the communities in their respective locations in the map and thus creating points feature and values were interpolated to have a smooth surface using IDW technique. Agricultural land use of Uhunmwonde LGA was clipped out from Nigeria ALU database and reclassified. The ranges, ranks and weights of PD and ALU are presented in Table 3. Raster calculator tool also provided the framework for mapping the two vulnerability variable to climate change induced flooding. Population density was given 60% while ALU was weighted 40% to arrive at the final output of flood vulnerability index map. The flood vulnerability layer was also reclassified into three vulnerability categories namely Low, Moderate and High.

2.6 Flood Risk Mapping and Determination of Areal Coverage

The potentials for possible disaster are often referred to as risk. It is the likely things that would be destroyed in any hazard. In this study, Raster Calculator tool also provided the algorithm to create and execute Map Algebra to model flood risk. This involved the combination of flood hazard index map and flood vulnerability index map on a ratio of 50%: 50%. The final output of flood risk map was reclassified into three risk categories namely Low, Moderate and High. This study also attempted the determination of the areal extent of flood risk in Uhunmwonde LGA to aid decision. Thus, the areal extent covered by each hazard, vulnerability and risk levels (classes) was calculated as the product of data

Table 3. Flood vulnerable datasets ranges, ranks and weights

S/No	Flood hazard datasets	Ranges	Ranks	Weights
1.	Population Density	380 - 864	Low	1
		865- 1,328	Moderate	2
		1,329 - 2,049	High	3
2.	Agricultural Land Use	Non Agricultural Land	Low	1
		Agricultural - Single Crops	Moderate	2
		Agricultural - Multiple Crops	High	3

pixel resolution (pixel area) and class count. All the datasets were resampled to the pixel resolution of 30 x 30 meters to correspond with the resolution of the DEM used. This yielded a pixel area of 900 m^2 and this value was multiplied by individual class count as provided in ArcGIS 10.1 Layer Properties. The resulted values were converted to square kilometers (km^2).

3. RESULTS AND DISCUSSION

In an attempt to determine the spatial extent of climate change induced flood risk in Uhunmwonde LGA, GIS technique was deployed. With the mapping capability of GIS, complex analysis were carried out with available data. The MCA-AHP based map algebraic framework of several biophysical and socio-economic factors revealed remarkable spatial pattern and coverage. This resulted in climate change induced flood hazard (Fig. 2), flood vulnerability (Fig. 3) and flood risk (Fig. 4) zones in Uhunmwonde LGA.

The flood hazard map (Fig. 2) clearly showed that high flood hazard category spanned across an estimated area of 866.23 km^2 which is about 43% of Uhunmwonde LGA. Spatial coverage of moderate flood hazard was about 721.04 km^2 (35.8%) while low flood hazard zone was 426.03 km^2 representing about 21.2% of Uhunmwonde LGA. The pattern of flood hazard found seems to be influenced by the closeness to rivers and water bodies despite the fact that rainfall was given the highest weight. The underlying principle is that as rivers and streams receives higher than normal recharge through excess precipitation, the carrying capacities of these natural water channels is overstressed resulting in water overflowing their banks and spilling to adjourning areas. This result corroborates earlier findings by [17,25,48] who reported that flood hazard, vulnerability and risk reduces as one move farther away from water bodies.

Similarly, vulnerability is the propensity or predisposition to be adversely affected by climate-related hazards, physical events or trends or their physical impacts [7]. Flooding is climate-related hazard and induced vulnerability (Fig. 3) which was a combination of two socio-economic indicators namely population density and ALU clearly showed that high flood vulnerability category spanned across an estimated area of 576.33 km^2 which was about 28.7% of Uhunmwonde LGA. Spatial coverage of moderate flood vulnerability was about 560.55 km^2 (27.8%) while low flood vulnerability zone was 876.42 km^2 representing about 43.5% of Uhunmwonde LGA. It may therefore be inferred that about 29% of the population in Uhunmwonde LGA are highly vulnerable, 28% are marginally vulnerable while 44% are lowly vulnerable to climate change induced flooding. This finding also implied that in event of higher than normal rainfall in the area, about 57,633 hectares of cultivated farmlands would be highly inundated by flooding. This certainly will lead to wide spread and devastating destruction of crops and attendant food security challenges. In 2012 flooding, about 7 million people were affected in across Nigeria, 597,476 houses destroyed, 2.3 million people displaced and 363 death were reported. Also, several farmlands and means of livelihood, animals and biodiversity were also gravely impacted [50].

In contrast, the overall climate change induced flood risk (Fig. 4) which was a combination of flood hazard and vulnerability clearly showed that high flood risk zone spanned across an estimated area of 813.18 km^2 which is about 40.4% of Uhunmwonde LGA. Spatial coverage of moderate flood risk was about 710.59 km^2 (35.3%) while low flood risk zone was 489.52 m^2 representing about 24.3% of Uhunmwonde LGA. Related spatial trend in flood risk had earlier been reported by [16,19,22]. For instance, 7% of the study area fell under 10years flood risk probability map, 16% for 50 years likelihood and 22% for 100 years flood possibility in Kadalundi River Basin [19]. The flood risk map compiled by [51] also demonstrated that high risk zone spanned across 22,654 km^2, medium risk zone (44,923 km^2) whereas low risk zone extended about 5198 km^2 of the study area.

However, in the absent of an already established model in the study area to validate the compiled climate change based flood risk, field visits was undertaken to 10 communities (5 from high risk zone, 3 from moderate risk zone and 2 from low risk zone).This was to investigate the occurrence, frequency and seriousness of flooding in their areas. A total of 150 residents who have resided in the area between 5 to 20 years were orally interviewed. As seen in Fig. 5, 46 respondents in the high risk zone (HRZ) agreed that flood has been occurring in the community while 4 said “No”. In the moderate risk zone (MRZ), 39 residents said “Yes” while 11 responded “No”. In contrast, 27 respondents said “Yes” whereas 23 responded “No” in low risk zone (LRZ).

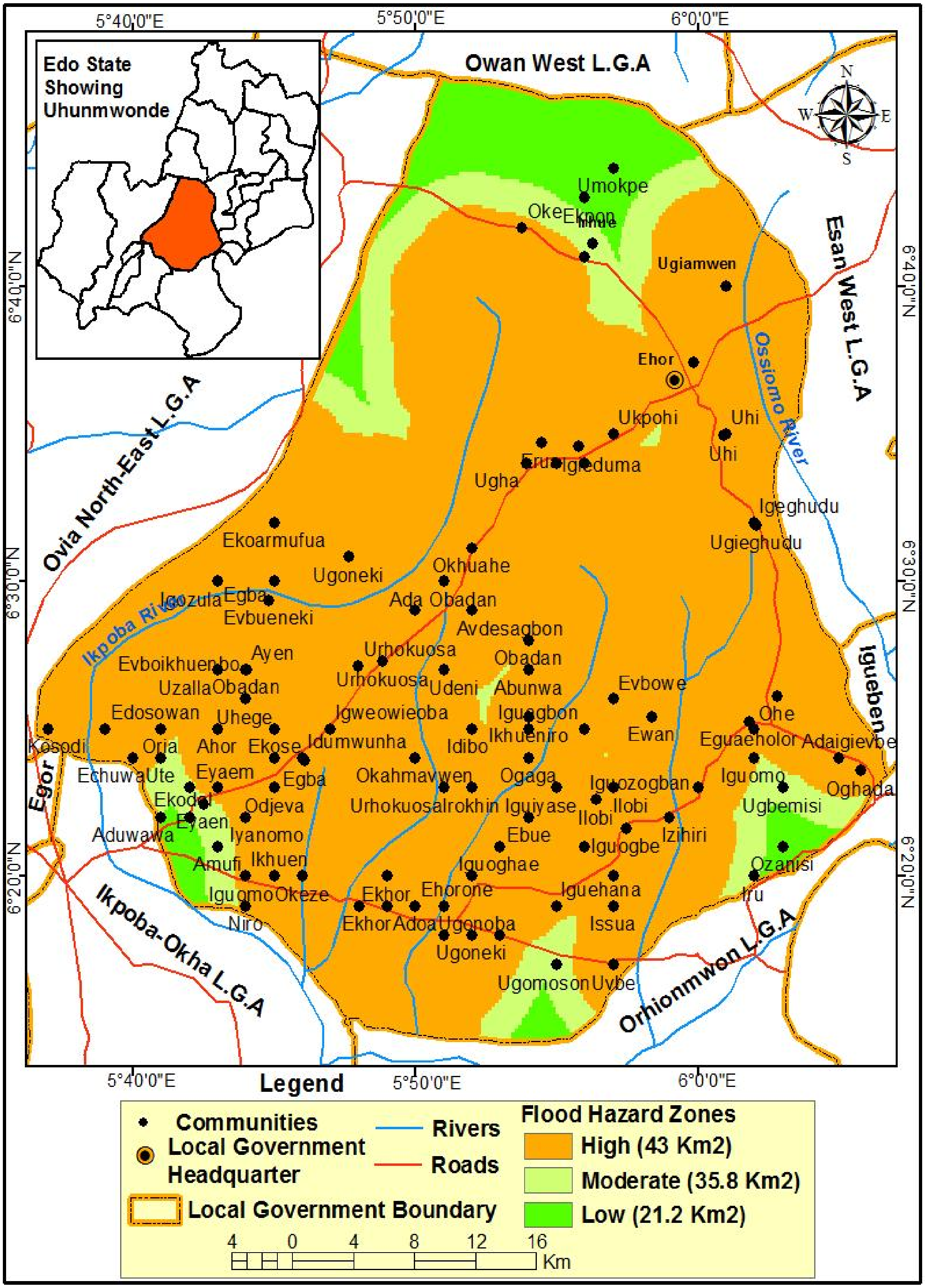


Fig. 2. Flood Hazard Zones in Uhunmwonde LGA

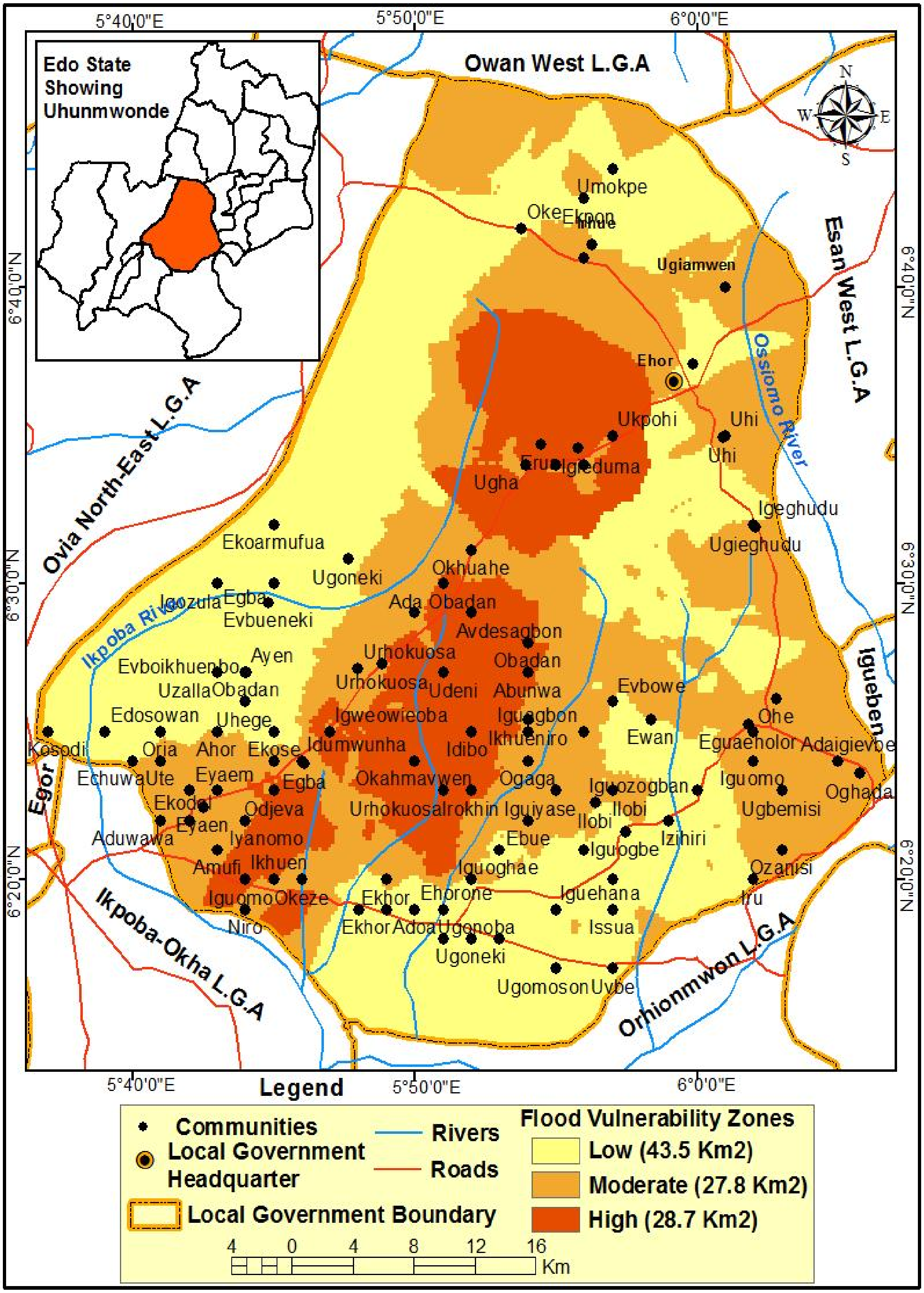


Fig. 3. Flood Vulnerability Zones in Uhunmwonde LGA

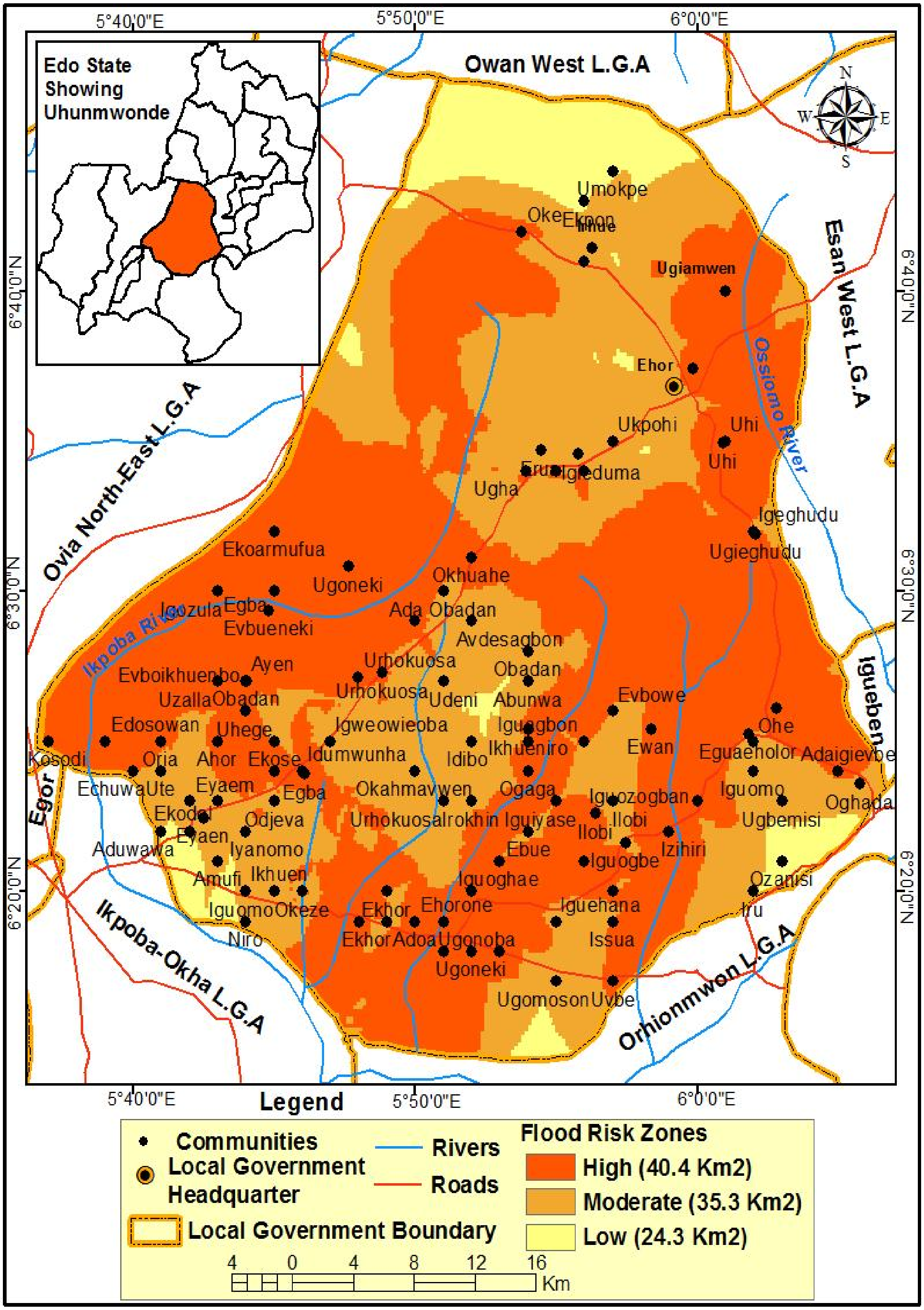
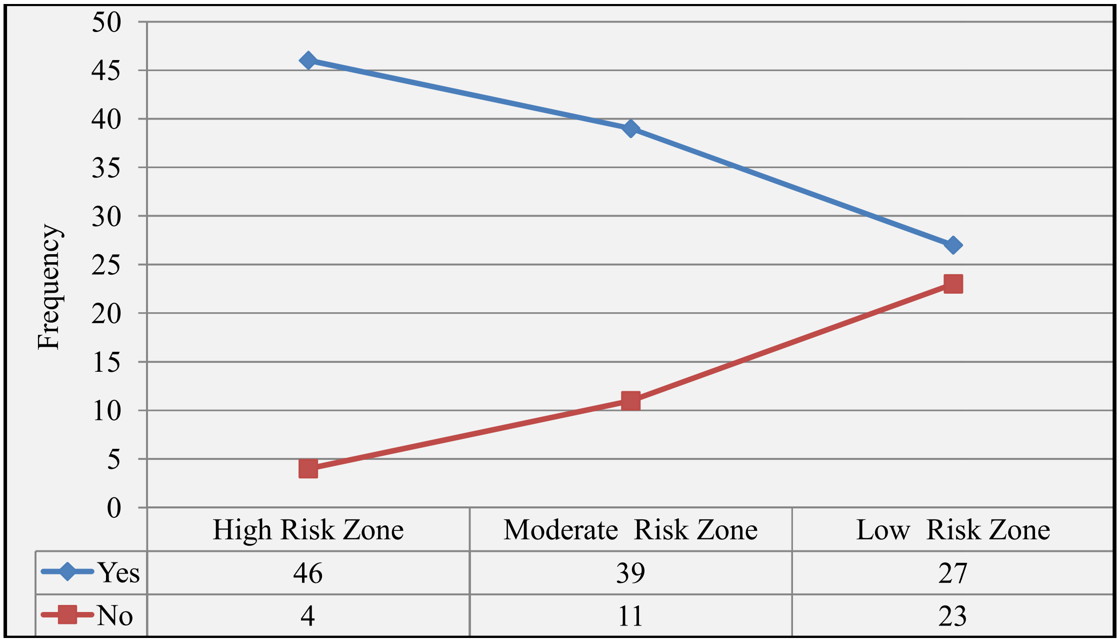
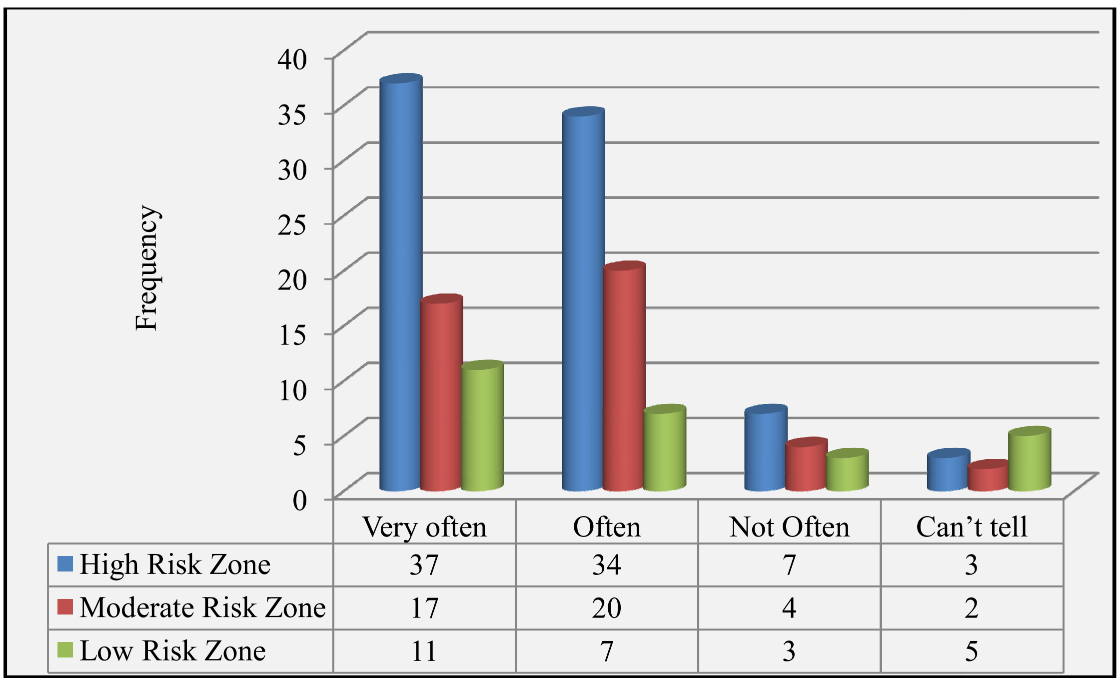


Fig. 4. Flood RiskZones in Uhunmwonde LGA



	High Risk Zone	Moderate Risk Zone	Low Risk Zone
Yes	46	39	27
No	4	11	23

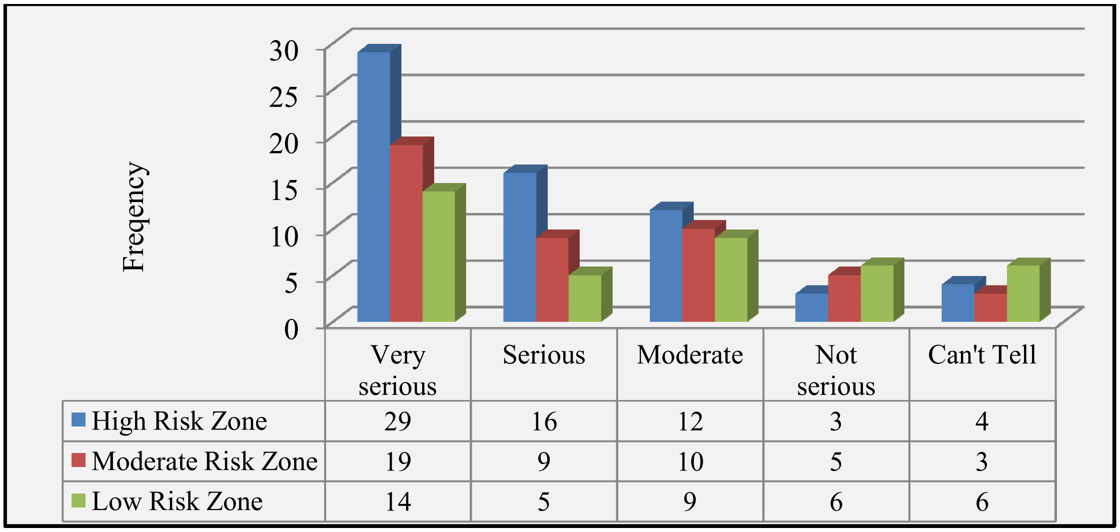
Fig. 5. Occurrence of Flood in Uhunmwonde LGA



	Very often	Often	Not Often	Can't tell
High Risk Zone	37	34	7	3
Moderate Risk Zone	17	20	4	2
Low Risk Zone	11	7	3	5

Fig. 6. Frequency of Flood in Uhunmwonde LGA

In terms of frequency, the field check as seen in Fig. 6 showed that 37 respondents in HRZ alluded that flooding has been occurring *very often*, 17 in MRZ and 11 in LRZ. The number of respondents which reported *often* was 34 in HRZ, 20 in MRZ and 7 in LRZ whereas 7 respondents reported not often in HRZ, 4 in MRZ and 3 in LRZ. In contrast, 3 respondents reported *can't tell* in HRZ, 2 in MRZ and 5 in LRZ.



	Very serious	Serious	Moderate	Not serious	Can't Tell
High Risk Zone	29	16	12	3	4
Moderate Risk Zone	19	9	10	5	3
Low Risk Zone	14	5	9	6	6

Fig. 7. Seriousness of Flood in Uhunmwonde LGA

Besides, the field checks as seen in Fig. 7 showed that 29 respondents in HRZ alluded that flooding in the area *very serious* environmental threat, 19 in MRZ and 14 in LRZ. The number of respondents which reported *serious* was 16 in HRZ, 9 in MRZ and 5 in LRZ whereas 12 respondents reported that flooding severity in the area is *moderate* in HRZ, 10 in MRZ and 9 in LRZ. In contrast, 3 respondents reported *not serious* in HRZ, 5 in MRZ and 6 in LRZ while 4 respondents reported *can't tell* in HRZ, 3 in MRZ and 6 in LRZ.

4. CONCLUSION

The cardinal motivation of study was to explore the utilitarian capabilities of GIS in integrating remotely-sensed biophysical and climate change related flood inducing indicators with socio-economic vulnerabilities to arrive at composite flood risk in Uhunmwonde LGA, Edo State, Nigeria. This was facilitated through the robustness of the GIS-based MCA-AHP which was not only cost-effective and evidence-based but result oriented capable of supporting decisions at all levels. It was found that 43% of Uhunmwonde LGA was under high flood hazard zone, 35.8% under moderate flood hazard while 21.2% was categorized as low flood hazard zone. Similarly, about 29% of the population in Uhunmwonde LGA are highly vulnerable, 28% are marginally vulnerable while 44% are lowly vulnerable to climate change induced flooding.

In contrast, is about 40.4% of Uhunmwonde LGA fell within high flood risk zone, 35.3% was categorized under moderate flood risk zone whereas low flood risk zone extended up to about 24.3% of the LGA. The high number of respondents who reported occurrence of flooding with frequency being *very often* and the fact that flooding was a *very serious* environmental threat during on-the-spot field assessment validated the generated climate change induced flood risk. Among all the indicators, natural water bodies seemed to be the greatest determinants of flood hazard, vulnerability and risk in Uhunmwonde LGA. The study recommended discontinuation of developmental activities including farming along natural water channels and wetlands to reduce flood risks and vulnerabilities. This should be facilitated by an objective delineation of buffer zones and subsequent designation as ecologically protected areas to protect lives and properties in addition to preserving the environment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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