

Flood Susceptibility Mapping in Asa Local Government Area, Kwara State, using Remote Sensing and GIS Approach

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Abstract: The increasing incidences of flood events in recent times have necessitated the need to come up with an early warning information for flood risk preparedness and reduction. The study aimed at mapping flood susceptibility in Asa Local Government Area, Kwara State, using Geographic Information System (GIS) based multi criteria evaluation approach. The data required for the study include: rainfall amount, soil texture, digital elevation model, distance from stream (euclidean distance) and land use land cover of the study area. Using Analytic Hierarchical Process, flood criteria weights were calculated for the different variables according to their influence on flooding and overlay analysis was employed in analysing the data for the study. The result of the study show there is spatial variation in the level of susceptibility to flood risks in the study area. Thus, the low-risk area covers 16.1% (~222.24 km²), moderate class 28.8% (~398.08 km²), high risk zone occupies 39.5% (~408.70 km²) while the very high-risk zone takes up 25.6% (~354.15 km²) of the area coverage of the study area. Furthermore, the accuracy assessment produced area under the curve (AUC) value of 0.795 (~80%). From the study, it was also discovered that Owode, parts of Afon, Bode, Onikangu, Abule-Alagbede fall within the very high and high-risk flood zones. The map could be a useful tool to decision makers in Asa local government for effective flood management plans.

Keywords: Flood, Flood risk, Multi-criteria evaluation (MCE), Analytical hierarchical process (AHP)

INTRODUCTION

Flooding may be regarded as a period of incomplete or total influx of naturally dry areas from overflow of inland or tidal waters, and from unexpected and rapid deposition of runoff (Jeb and Aggarwal, 2008). According to Ali *et al.*, (2016), floods are among the foremost issues of environmental concern all over the world as it affects man and his immediate environment. Diley *et al.* (2005) estimated that about one-third of the world's acreage are flood prone and this affect about 82% of the world population. Jha *et al.*,

(2012) observed that floods/inundation are the most common and destructive natural disasters which impact seriously upon human lives and properties as well as causes severe economic losses globally.

Flooding is often fluvial, coastal or pluvial in nature, and may occur due to two or more types of floods. Fluvial flood, otherwise referred to as subsurface flood occurs when the river discharge surpasses the size of the river channel. Coastal flooding which is river related is caused by excessive tidal conditions that result from high water levels, wave action and storm surge.

However, pluvial flooding arises when the rate of precipitation out-reach the capacity of storm water drains available to empty the water, therefore hinders the ability of the ground to soak up water (Ball *et al.* 2008).

Pluvial flooding is most often an unusual occurrence especially in places not susceptible to flooding, and apparently without prior warnings, thus it is commonly regarded as 'invisible hazard' (Donald *et al.* 2011). Pluvial flooding is mostly experienced in localities which are characterised by large areas of impervious surfaces and inadequate drainage systems. Hence, as urbanisation rate increases in these localities, the impervious surfaces increases simultaneously. This renders the residents of these areas susceptible to water inundation as natural channels such as streams, rivers and man-made drains are unable to deal with increased runoff from the heavy rainfall (Youssef & Pradhan, 2011).

Flood could be a natural phenomenon caused by storm surges from strong on-shore winds, low atmospheric pressure, and sometimes by earthquakes and volcanoes when they occur under the sea (Udoeka 2002). Furthermore, Okoko (2008) observed that floods may also be caused by human activities on the environment, which destroys the climate system and ultimately lead to the observed global warming. This in turn increases the occurrence and magnitude of weather events such as increase temperature and intense rainfall and windstorms (Parry 2007; Rockström *et al.* 2009).

However, flooding in Nigeria can be linked to high and heavy rainfall which consequently lead to increased run-off. It can also be linked to dam breaks, blockage of river channels, poor land use practices which increases the rate of run-off and decreases the rate of infiltration. Floods can also occur due to human activities such as urbanization, which exacerbates flood risks by reducing infiltration into the ground.

Drogue (2004) observed that in most nations of the world and Nigeria inclusive, incidences of flood have been on the increase, as there have been widespread

flooding incidences across the country which have been towing the world trend. For instance, the World Meteorological Organisation (WMO) in 2004 reported that in the last ten years, hydro-meteorological-related disasters accounted for 90% of natural disasters. Out of which flood disasters top the list as it constituted 37% of the disasters and affected 2.3 billion (56%) of the global population, leading to economic losses estimated at 446 billion US dollar (WMO, 2004). The Emergency Events Database (EM-DAT) (2015) noted that flood have more effect on people than any other types of natural hazards. Similarly, Hallegatte *et al.* (2013) estimated that flood disasters accounted for more than 50% and above 30% of all casualties and global economic losses from natural disasters respectively. In the same vein, Sachs (2006) projected that the mean annual number of people vulnerable to flood will increase from 1 million to 25 million between the years 1990- 2050.

Nigeria has also experienced flood disasters; Eludoyin *et al.* (2007) reported incidences of flood disasters across Nigeria. In Ibadan, for example, there was incidences of flood in 1985, 1987 and 1990. Also, in Osogbo flood disaster was recorded in 1992, 1996 and 2002. Flood cases were similarly reported in Akure in 1996, 2002, 2004 and 2006, respectively. Furthermore, in 2012, more than 20% of the Nigerian population experienced flood disasters which cut across many cities in about 31 states in the country (Oyekale 2013). The flood incident was the most devastating disaster in the country as houses were submerged as an estimated 1.3 million people were displaced leading to death of about 431 people. Moreover, over 1525 square kilometres of farmland were destroyed (MISNA, 2012).

Oriola (1994) opined that flood disasters is quite expected along the coastal regions, however, persistent flood in the hinterland may be worrisome. Nevertheless, flood incidences can be anticipated and avoided, if only the risks of hazard could be addressed through effective preparedness,

forecasting, early warning, and prompt response. However, experience have shown in most developing countries particularly Nigeria that disasters are usually addressed through immediate responses by institutions saddled with the responsibility as accurate and timely information are received to redeem the situation, but as soon as the disaster have been averted, and as time goes by, the need for preparedness isn't a priority thereby leaving the communities unprepared. Thus, predicting the areal extent of flood is a step towards preparedness and a very important approach to flood risk management. Although, there are different approaches (statistical analysis of frequency of flooding, storm monitoring and flood hazard mapping) to prediction of flood, however, the flood risk assessment is the basis for flood management (Sole *et al.*, 2013; Nelson, 2015; Samela *et al.*, 2018).

Nigeria has been experiencing flood incidences which have been claiming lives and properties as well as destroying the environment due to the lack of spatial and synthesized information about the areal extent of flood hazards especially at the flood prone areas. Thus, the application of geographical information system in flood studies cannot be over emphasized. For instance, a lot of studies have been carried out on flood analysis using GIS approach (Ologunorisa & Abawua, 2005; Oriola & Bolaji, 2012; Njoku *et al.*, 2013). However, most of these studies have only been able to classify the flood areas based on their level of severity.

Moreover, experience have shown that Asa local government area is highly susceptible to flood risk, perhaps due to its proximity to rivers and the topography of the location. However, in recent times, the study area has been experiencing increased intensity of rainfall, rapid urbanisation and change in land use. It is against this background that the study adopts the remote sensing and GIS-based multi-criteria decision-making approach in order to assess flood risk in terms of its potential hazard, exposure, vulnerability; and identify

triggering factors to flood risk. Thus, flood susceptibility map of the study area is produced to show the spatial distribution of flood risk along with its level of severity. As such, this study examines flood risk assessment and mapping using GIS and multi decision making approach in Asa local government area of Kwara State with a view of aiding decision making and policy formulation through effective preparedness, forecasting and early warning.

Materials and Methods

Description of the Study Area

The study area is Asa local government area, located in Kwara state (Figure 1). It lies between *latitude* 8°43'01''North of the equator and *longitude* 4°42'60''East of the Greenwich meridian. Asa LGA comprises of several towns and villages such as Ogbondoroko, Laduba, Aboto, Balah, Eyenkon, Pampo, Ogele, Olowokere among others, with Afon being the head quarter. The study area covers an approximate area of 1,286 square kilometres. Asa LGA belongs to the tropical climate region and is characterised by both rainy and dry seasons. The rain season is occasionally preceded by dust storm and this marks the onset of rainfall. Asa LGA experiences double maxima rainfall pattern, with peak periods in June and September, dry spell in July and rainfall cessation in October. The dry season begins in November and ends February and it is usually associated with cold and dry winds (Harmattan). The rainfall ranges from 50.8mm in the dry months and 2413.3mm in the rainy season. Temperature in the study area ranges between 21.1°C to 35°C. The population of the study area according to NPC (2006) is 126,435. The main socioeconomic activities of the people are Agriculture and the principal produce are fish and fish products and major food crops such as yam, maize, cassava, groundnut, cowpea, sorghum, melon, okra, pepper and some leafy vegetables.

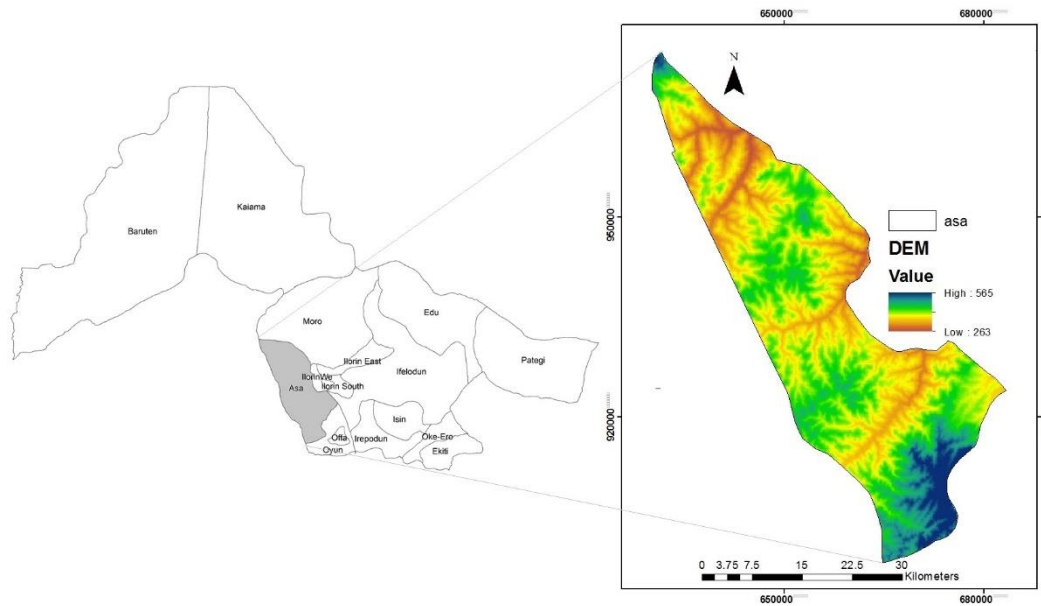


Figure 1: Location of the Study Area in Kwara State (left) and terrain representation of Asa Local Government Area (right).

Data Processing

The study adopted a GIS-based multi-criteria approach for flood risk assessment and ArcGIS version 10.5 was employed. The data required for the study were the flood conditioning variables in figure 2 which include: land use, slope, distance from river, topographic wetness index, soil texture and mean annual rainfall. These data were used to prepare the flood susceptibility map of the study area. The digital elevation model (DEM) was obtained from shuttle radar topography mission (SRTM), soil texture data was gotten from harmonized world soil database, mean annual rainfall data was obtained from world climate data repository (Worldclim.com) and the digital satellite image was gotten from the 2020 (Sentinel-2A) image USGS EROS archive to create the land use land cover map of the study area.

The soil map of the study area was generated by loading the soil data into the ArcMAP work space, the result indicated that the raster of the study area has been classified into four having values of 4, 6, 7 and 9 respectively.

According to the USDA soil texture map, this shows that the available soil textures found

in the study area are loam, silt, sandy clay loam and silty clay loam this was identified in the properties area of the raster in the ArcMAP workspace.

The land use map of the study area was generated using the sentinel 2A image gotten from the EROS archive. The image used for this operation is of the 30m resolution with respective bands 2, 3, 4, and 8. These bands were merged together using the composite band feature on ArcTool box to form one image comprising of all the separate bands. After that, the image was classified (unsupervised classification) using the image classification tool on ArcGIS 10.5 software.

The data layers derived from the digital elevation model include the slope, wetness index, stream order, and the Euclidean distance. In developing the flood hazard layer, data was prepared using topographic layer generated from digital elevation model (DEM). The Slope was the first element generated from the DEM. This was done using the surface tool under the

spatial analyst tool on the arc toolbox on ArcGIS. Distance from river was then generated from the digital elevation model (DEM) using the hydrology tool on the arc toolbox. First the flow direction of the DEM was generated using the flow direction prompt in the hydrology tool. The flow direction as the name implies is used to determine the direction of hydraulic flow on the DEM surface.

The flow accumulation was then determined in order to compute areas with high and low potential for hydraulic

accumulation. Afterwards, the stream order was generated using the flow accumulation and flow direction. The result of this is a four (4) order stream with 4 signifying the highest order and 1 the lowest order. Order 4 signifies the main water body while orders 3 to 1 signifies stream orders that would be created from the main water body. Topographic wetness index (TWI) was generated using variables such as slope, flow direction and flow accumulation. The wetness index can be gotten using this formula.

$$TWI = \ln(\text{flow accumulation scaled} / \tan \text{slope})$$

$$\tan \text{slope} = \text{con}(\text{'slope'} > 0, \tan(\text{'slope'}), 0.001)$$

$$\text{Scaled flow acc} = (\text{flowacc} + 1) * \text{cell size}(20)$$

equation (1)

equation (2)

equation (3)

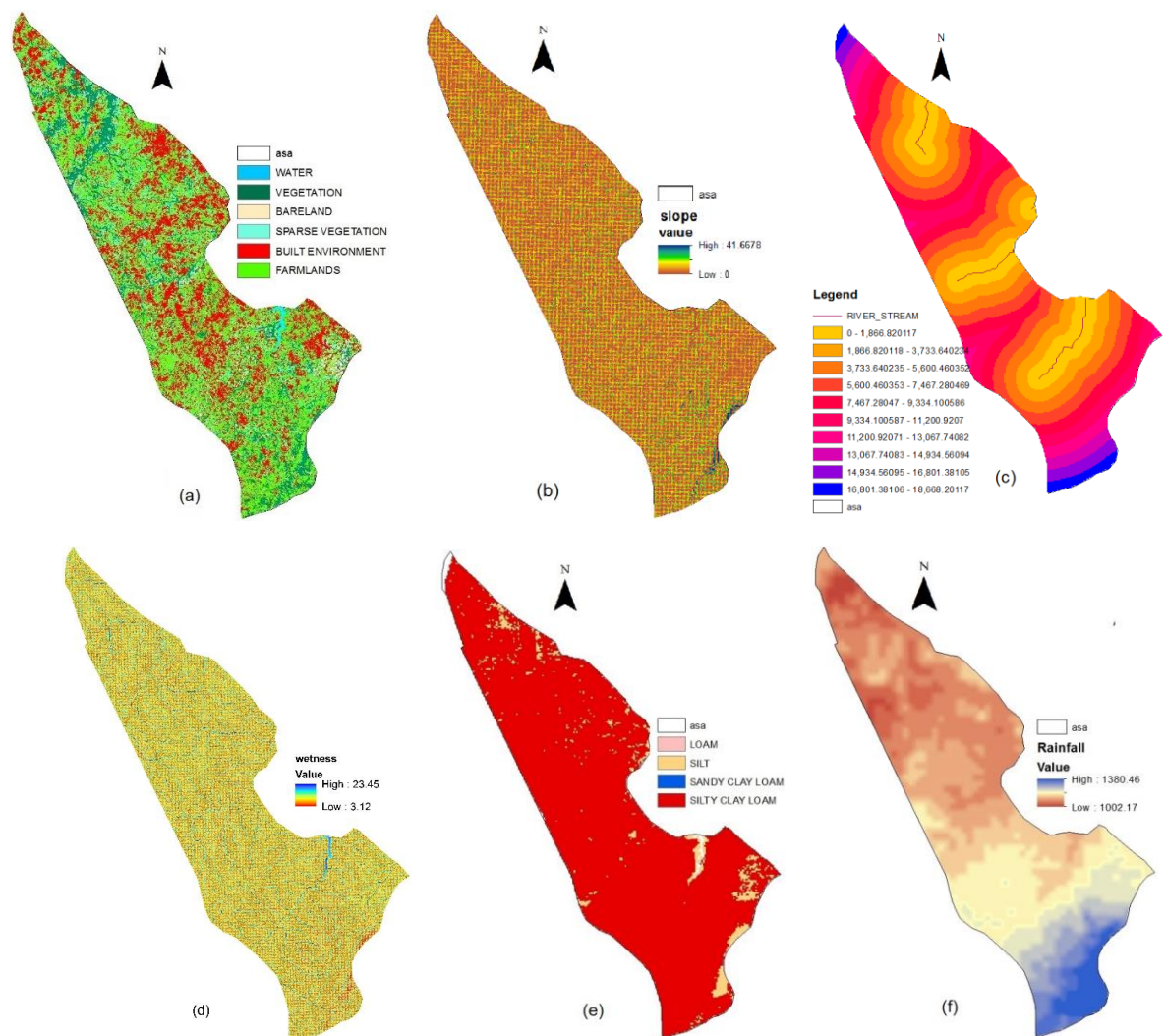


Figure 2: Flood Risk Variables (a) Land use (b) Slope (c) Distance from River (d) Wetness Index (e) Soil Texture (f) Mean Annual Rainfall.

Multi Criteria Evaluation (MCE)

Weighting of Criteria

In this study, multi-criteria decision process using Analytical hierarchy process (AHP) introduced by Saty (2004) was used to determine the weight of each criterion (conditioning factor). An AHP criterion selects the number and names of criteria, after which pair wise comparisons was carried out to calculate priorities using the Analytic Hierarchy Process. The analytic hierarchy process (AHP) weighting method

was applied due to the fact that not all factors influence flooding in the same way and this process helps in decision making by ranking these variables according to the most probable variable that influences the desired result. AHP is a decision support tool that can be used to solve complex decision problems by arranging the factors that are important for a decision (Zaharia, 2017).

The resulting weights are based on the principal eigenvector of the decision matrix as shown in table 1. These resulting weights are based on the pairwise comparisons.

Table 1: Decision matrix, AHP variable weight and influence rating

Pair-wise comparison matrix							AHP weight		
	1	2	3	4	5	6	Variable	Weight (%)	Rank
1	1	0.25	0.50	0.33	0.25	0.50	land use	6.2	6
2	4.00	1	1.00	1.00	3.00	5.00	Rainfall	28.0	1
3	2.00	1.00	1	1.00	4.00	3.00	Slope	25.3	2
4	3.00	1.00	1.00	1	1.00	2.00	DFR	18.9	3
5	4.00	0.33	0.25	1.00	1	1.00	Soil	12.6	4
6	2.00	0.20	0.33	0.50	1.00	1	wetness index	9.0	5

Consistency index:

Source: Authors' Compilation (2021).

Assigning Weight to Sub-criteria

Each of the criteria layer in table 1 (slope, wetness index, distance from river, rainfall, soil texture and land use) were further

reclassified into sub-criteria on a scale of 1 to 5 (table 2) using the reclassify tool in ArcGIS environment. A value of 5 signifies high influence while 1 indicates low contribution to flooding event. The criteria map was reclassified to carry out the weighted overlay operation.

Table 2: Sub-criteria Weighting

Parameters	1	2	3	4	5
Land use	Vegetation	Farmlands	Bare land	Built up	Water
Rainfall	1002.17-1098.60	1098.60-1159.42	1159.42-1217.28	1217.28-1284.03	1284.03-1380.46
Slope	16.67-41.67	8.66-16.67	4.90-8.66	1.80-4.90	0-1.80
Wetness Index	14.28-23.45	11.81- 14.28	10.13- 11.81	7.82- 10.13	3.12- 7.82
Soil texture		Silty clay loam	Sandy clay loam	Silt	Loam
Dist. from River	12811.51-18668.20	8711.83-12811.51	5856.69-8711.83	3001.55-5856.69	0-3001.55

Source: Authors' Compilation (2021).

Weighted Sum Operation

The reclassified data layers (Table 2) and their priority weight (Table 1) were combined using the Weighted Sum operation to produce the flood risk map. The weighted Sum tool is a geo-processing tool that overlays several raster layers, multiplying each by their given weight and summing them together. The priority influence (weight) obtained from the AHP analysis in percentage was converted to decimal which sums up to 1 and was then used for the overlay operation. The AHP process ranks the variables 1 to 6, according to how importantly each contributes to determining the level of risk (Table 1).

The Weighted Sum output was filtered and reclassified into 4 classes (low, moderate, high, and very high) after an overlay analysis has been carried out. This aid in determining the percentage area coverage of the respective class as shown in table 3. Furthermore, the accuracy of the resulting flood risk map was evaluated using the receiver operation characteristic (ROC) curve statistical measure (Idrees & Pradhan, 2016).

Results and Discussions

Applying the six flood conditioning variables and their degree of influence determined using multicriteria analysis, the resulting flood risk map (Figure 3) was

generated. The map is categorised into four vulnerability classes: low, moderate, high, and very high-risk zones based on their inherent characteristics. The study adopted the natural break classification scheme (low, moderate, high, and very high-risk zones) used by previous studies (Poli and Sterlacchini, 2007; Khosravi et al., 2016b) to group data according to flood susceptibility.

Analysis of the contribution of each variable weighting (Table 1) has shown that rainfall ranks first with 28%, followed by slope (25%), distance from river (19%), and soil texture (12%) in the second, third, and fourth position. Topographical wetness index and land use accounted for the least contributing factors with priority weight of 9% and 6% respectively. In other words, the result of the study revealed that rainfall amount and slope percent has the highest degree of influence on flooding event in the study area.

This result support the findings of previous studies (Termeh *et al.* 2018; Hong *et al.* 2018a; Dano, 2021) that rainfall and slope percent are a very important factor which determine flooded locations. This implies that, it is not all the flood conditioning factors that have the same degree of influence on flood events. That is to say, not all factors influence flooding events the same way. Thus, identifying the factor(s) with the most probable influence will aid in planning, decision making and flood management.

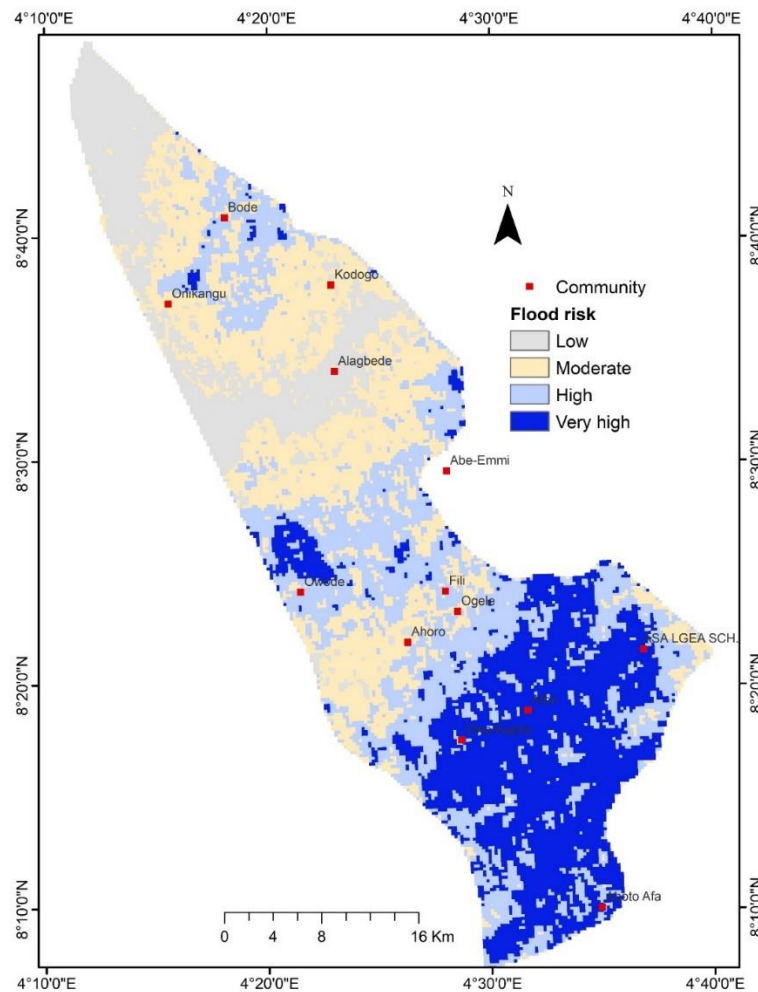


Figure 3: Flood risk map of Asa Local Government Area, Kwara State.

Source: Authors' Compilation (2021).

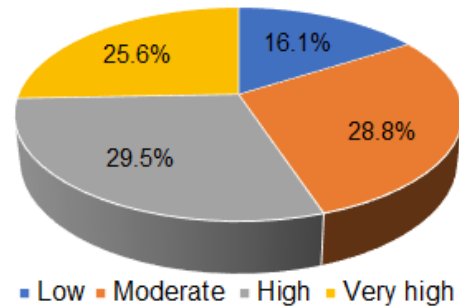
The vulnerability map reveals that the southern part of the Local Government Area is most susceptible to flooding (very high risk) compared to the mid-section categorised as high risk. In contrast, the northern section of the study area is predominantly detected to be moderately to low degree of risk. This implies that there is spatial variation in incidences and degree of susceptibility to flood risk in the study area.

Also, quantitative analysis in terms of the area coverage of each class is presented in Table 3. It is shown that the low-risk class covers 16.1% (~222.24 km²), moderate class 28.8% (~398.08 km²), high risk zone occupies 39.5% (~408.70 km²) while the

very high-risk zone takes up 25.6% (~354.15 km²) of the area under investigation. In addition to the area coverage, reliability of the resulting map was evaluated using the area under the ROC curve (AUC). The test show that the map yielded overall accuracy with AUC value of 79.5%. This value of 0.795 (~80%) is reliable and permissible according to past studies (Yesilnacar, 2005; Idrees & Pradhan, 2016; Sajedi-Hosseini *et al.* 2018b) which posit that an AUC value of 80% or N0.8 is good, permissible and appropriate in prediction accuracy. As such, the study applied it in the assessment of flood susceptibility.

Table 3: Area Coverage of Flood Risk Class

	Class	Area (Sq km)
1	Low	222.24
2	Moderate	398.08
3	High	408.70
4	Very high	354.15



Source: Authors' Compilation (2021).

The analysis of flood risk entails the features of the elements at risk. Elements at risk involves the human system, the environment (built and natural) that are at risk of flood in a given area. Such elements can be regarded as the vulnerable elements which are exposed to flood. Examples of these elements include the population, buildings, infrastructure and economic activities among others. These elements are faced with adverse effects of flooding like fatalities, injuries, psychological stress, destruction of buildings and inventory, interruption of traffic or business and pollution of soils, respectively. Since the data containing these elements at risk were not readily available at the time of this study, the areas that fall under the different risk zones were used to classify the elements at risk. Essentially, it was observed that communities in the southern parts of Asa Local Government Areas such as Bode, Onikangu, Owa-kajola, Afon, Owode, Ogele, Aboto, Eiyenkorin, Dadi, Aladere Mogaji, Gbabu, Aiyekoto, are vulnerable to flooding (Figure 3).

Furthermore, the result of the study as indicated in table 1 and 2 showed that rainfall has the highest degree of influence to flood event in the study area. Moreover, the rainfall map of the study area in figure 2 show that the southern part of the study area receives the highest amount of rainfall, thus, the communities in these areas are more susceptible to flood events and hence regarded as very high and high risk zones;

unlike the mid-section and the northern area of the study area regarded as the moderate and low risk zones which receives lesser amount of rainfall. In addition, figure 3 show the result of the overlay analysis that was carried using several raster layers such as rainfall map, land use, slope among others to produce the flood risk map categorised these areas accordingly.

Specifically, communities that fall within the very high- and high-risk zones include Owode, some parts of Afon, Bode, Onikangu, Abule-Alagbede. Communities that fell within the moderate risk zones includes; some parts of Afon, Ahoro, Ogbondoroko, Ogele, Lajiosun, Kodogo-Alagbede and Filli. Communities within the low-risk zones include Ladi, Alata and Aboto-Afa among others.

Conclusion

Flood risk mapping with the use of GIS and multiple criteria analysis is very vital for highlighting areas that are at risk of flooding. It assist stakeholders such as policy makers, hydrologist, planners in decision making so as to remain focus on specific areas in order to perform further detailed assessment of flood risk (e.g., through the use of hydrological and hydraulic models). The use of AHP method in assigning weight to the contributory factors of flooding was exceptional as it enabled the comparison of the different factors that contribute to floods (pair wise comparison) before the assignment of weight. The study however, recommended that an up-to-date disaster

management database should be developed in order to provide early warning systems especially in areas that fall within the high flood risk zones. This will help the evacuation of people in order to prevent loss of lives and properties. Furthermore, planners should endeavour to factor in flood risk during Environmental impact assessment (EIA) to ensure that there are enough drainages that can withstand heavy and prolonged downpour to mitigate damage to lives and properties.

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