Flood Risk Mapping Using AHP and GIS- A Case Study of Abuja Municipal Area Council

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Abstract: The study investigated the use of Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) analysis techniques for making public- based flood risk map of Abuja Municipal Area Council. The flood risk vulnerability mapping follows the integration of some flood causative factors such as rainfall distribution, elevation, slope, drainage density, land-use/ land-cover and soil type. The study result showed the percentage impact of the flood causative factors on the study area to be 4.06% for soil type, 26.62% for land use/ land cover, 30.96% for slope, 4.86% for Elevation, 23.03% for drainage pattern, and 10.47% for mean annual rainfall. The result equally showed a Consistency Ratio of 0.012, which showed an acceptable level and hence proves the validity of the proposed methodology. Additionally, the results were validated and confirmed to agree with historical records of flood distribution in the study area. Flood-prone areas of AMAC; Kubwa, Mpape, Wuse Market, Galadimawa roundabout, Gaduwa housing estate, Lokogoma, Light gold housing estate phase 5, and Trade More estate, Airport Road, were superimposed on the developed flood risk map and found to fall under the category of high to very high flood risk areas. This demonstrated the reliability of the considered method. This study is significant in providing procedures and plans through which the government and other relevant agencies will decrease and/or prevent the destructive effects of flood risk and socioeconomic vulnerability in AMAC.

Keywords: *AHP; GIS; AMAC; Flood Risk Map.*

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I. INTRODUCTION

The constant incidence of floods in Abuja Municipal Area Council (AMAC) is a challenge to the inhabitants. Recently, AMAC has witnessed an increase in the frequency of floods, possibly due to rapid growth and urbanization of the area. The frequency of flooding in the area is occasioned by loss of lives and valuable properties, with a lasting impact on the environment. Over the years, various methods and plans to prevent or mitigate the impact of these floods have been adopted. One of the tools needed for the planning is the vulnerability and flood risk map, which will indicate flood-prone areas. Therefore, this study aims to provide a public-based flood map and estimate the flood risk in AMAC.

Flood incidence is a natural phenomenon, and man has lived with it for ages. It is a global phenomenon and not confined to a particular region of the world [1]. Floods have been experienced across Nigeria for many years; however, their impact was not felt due to vast, undeveloped, and unpopulated land, allowing for the waters to spread without causing havoc.

The risk of flood can be assessed using multi–criteria analysis of flood depth obtained through the use of hydraulic and hydrologic models. Example of this methodology is through the utilization of hydraulic and hydrologic models with Multi-Attribute Utility Theory (MAUT) [2] or Analytic Hierarchy Process to estimate the risk of flood [3]; [4]. The multi-criteria analysis process offers an outline that can handle diverse opinions on identification of the parameters of a multifaceted decision problem and establish the elements into a ranked structure to facilitate identification of relationships amongst problem components [5].

Flood is a natural phenomenon nevertheless, it poses a threat wreaking havoc on communities, destroying lives and properties. Flood risk does not seem to abate and will continue to pose a threat to parts of the world due to rise in number of occurrences and severity due to climate change [6].

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In recent times, development in GIS and Remote Sensing has paved way for in-depth understanding of floods. The British Geological Survey, United State Geological Survey (USGS), International Association of Hydrological Sciences (UK), etc. are all involved in flood studies.

GIS is a conventional tool utilized in hydrologic modelling, it enables management, processing, and interpretation of spatial data. Remote Sensing (RS) is a vital tool for instant and efficient data acquisition at specified intervals, covering wide area. GIS allows the integration of remotely sensed data and spatial data forms such as slope maps, elevation maps, and hydrologic variable quantities [7].

[8], concludes that GIS - based modelling methods to identify flood areas, should be used as an efficient tool within a comprehensive planning process and the use of high-resolution Digital Elevation Models (DEMs) to improve the reliability and correctness of regional flood risk analysis. [9] concludes that flood map developed through the application of RS and GIS can be utilized efficiently in public awareness, rapid response planning and risk management. [10] emphasized the significance of RS and GIS in mapping of flood risk and the simplicity of producing flood risk maps for varying built-up areas and ecological zones in Nigeria utilizing RS data and GIS software, and concluded that rainfall is a significant flood causative factor around the Niger- Benue River basin.

AHP is a universal theory of measurement, it drives ratio scales from both discrete and continues paired comparison. It is widely applied in multi- criteria decision, planning and allocation of resource and in resolution of conflict [11]. A hierarchy of structure representing the problem and a pairwise comparison matrix for establishing relationships is required to model a problem in AHP.

AHP has been used severally in decisions especially in areas of public administration and conflict resolution [12]. The past decades have witnessed significant advancement in the quantity and quality of research in integrating Multi-Criteria Decision Analysis (MCDA) and GIS. The multidisciplinary field of GIS- MCDA has been widely accepted within the GIS community. Quite correctly, the GIS community acknowledged the numerous benefits to be gained by integrating MCDA into a suite of GIS capabilities [13].

[14], observed that AHP is mainly being applied in areas of evaluation and selection. AHP has been applied in engineering, personal and social categories. [15] similarly observed that integrated AHP can be applied to a variety of fields and problems effectively especially in the field of manufacturing and Logistics. [16] conclude that AHP may be an appropriate technique for investigating difference among groups. Furthermore, the analysis of consistency suggests that experts of AHP may have to prepare different model descriptions depending upon the user's background, since the ranking suggest that diverse backgrounds and experience of respondents influenced their judgment.

Usually, hydraulic and hydrologic models were utilized in the assessment of possible locations of flood risk for specific recurrence interval. In essence, these models are based on the balance of the flow and the convergence of water ways. Nevertheless, AHP provides detailed risk index that integrates physiographic pointers with flood prevention measures and flood risk parameters in the field of flood control. The AHP methodology to the assessment of flood risk is relatively inexpensive, easy to use, and allows for interactive use by flood control experts for subsequent development [17].

Integrated application of AHP and GIS in flood vulnerability and risk mapping has been widely applied; this help stakeholders and decision makers in planning and management especially in flood prone areas. One of the numerous applications was studied by [17], for flood risk assessment and flood plain management in Taiwan. [18] developed a flood risk map, utilizing multi- parametric methodology using hydrological, geomorphological and demographic data, for Kosi River basin in the North Bihar plains, east of India.

The AHP method has been used universally in flood risk mapping, susceptibility and impact assessment. For instance, it was utilized in assessing flash flood impact along the coastal city of Jeddah, in Saudi Arabia [19]. This method explores alternative approach for assessment of flash flood impacts aside from the usual method of risk assessment which is founded on assessment of physical parameters such as hydrological, hydrogeological and geographical factors. This study method can provide expert- based judgment to government and institutions with different options for assessing different flood risk levels in accordance with align needs and available resources.

[6] validated the integrated use of AHP and GIS with a reliable accuracy level of 92%. This was verified in methodological overview and case study assessment of municipality of Eldoret in Uasin Gishu County of Kenya. It further asserts that AHP avails the opportunity for the use of an easy and simple method of solving difficult problems in MCDA environment based on experts and users' knowledge and judgment.

In Nigeria, numerous flood studies have been done utilizing the approach of integrating AHP and GIS; it has been established as a significant tool for decision making process, and allows for proficient use of spatial data. One of such studies was the study presented by [20] for the flood vulnerability area analysis of Hadeja- Jama'are river basin.

II. STUDY AREA DESCRIPTION

AMAC is situated in the eastern wing of the Federal Capital Territory (FCT) and comprises of the FCT (Federal Capital Territory) and the FCC (Federal Capital City) has five (5) districts i.e.; Wuse, Asokoro, Maitama, Garki, and Central Area and the newly established districts of Gaduwa, Apo, Lokogoma, Gudu, Durumi, Kaura, Gwarimpa, and Katempe.

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AMAC is situated between Latitude 8o 40’ and 9o 20’ North of the Equator and Longitude 6o 40’ and 7o 40’ East of the Greenwich meridian. The FCT has an area of approximately 8000 Sq. Km and the FCC occupies about 250 Sq. Km with inhabitants of about 778, 567 for AMAC.

AMAC experiences an average annual rainfall of 1,650mm, about 60% of the annual rains falls between the months of July to September. A vital climate characteristic of the area is recurring incidence of thunder lightening, storms, strong winds and high rainfall intensity. A noticeable difference between the lowest and highest elevation within AMAC is clearly observed; the highest elevation is 213.3 m to the north (which is largely urbanized) and 142.2 m to the south (which is largely rural) of the FCT. The famous Aso Rock, Katempe Hill and Asokoro outcrops are located in AMAC.

In recent times, some districts within the AMAC have been ravaged by flood, with attendant significant loss of lives and property. A recent flood at Lokogoma led to the loss of three lives in August, 2017 as a result of heavy rainstorm, an entire stretch of about twenty (20) housing estates ware also affected by the flood, destroying valuable assets. Most areas within the six (6) area councils have been experiencing varying levels of flooding and often lead to loss lives and valuable properties. The flash flood at Lokogoma and Galadimawa have led to destruction of assets and displaced families from their homes and livelihoods. The central part of Abuja, particularly the Central Business District (CBD), Utako, Jabi, amongst ware also affected by heavy rainfall resulting in flash floods, which often leads to the disruption of traffic, commercial activities and destruction of essential road infrastructure in area.

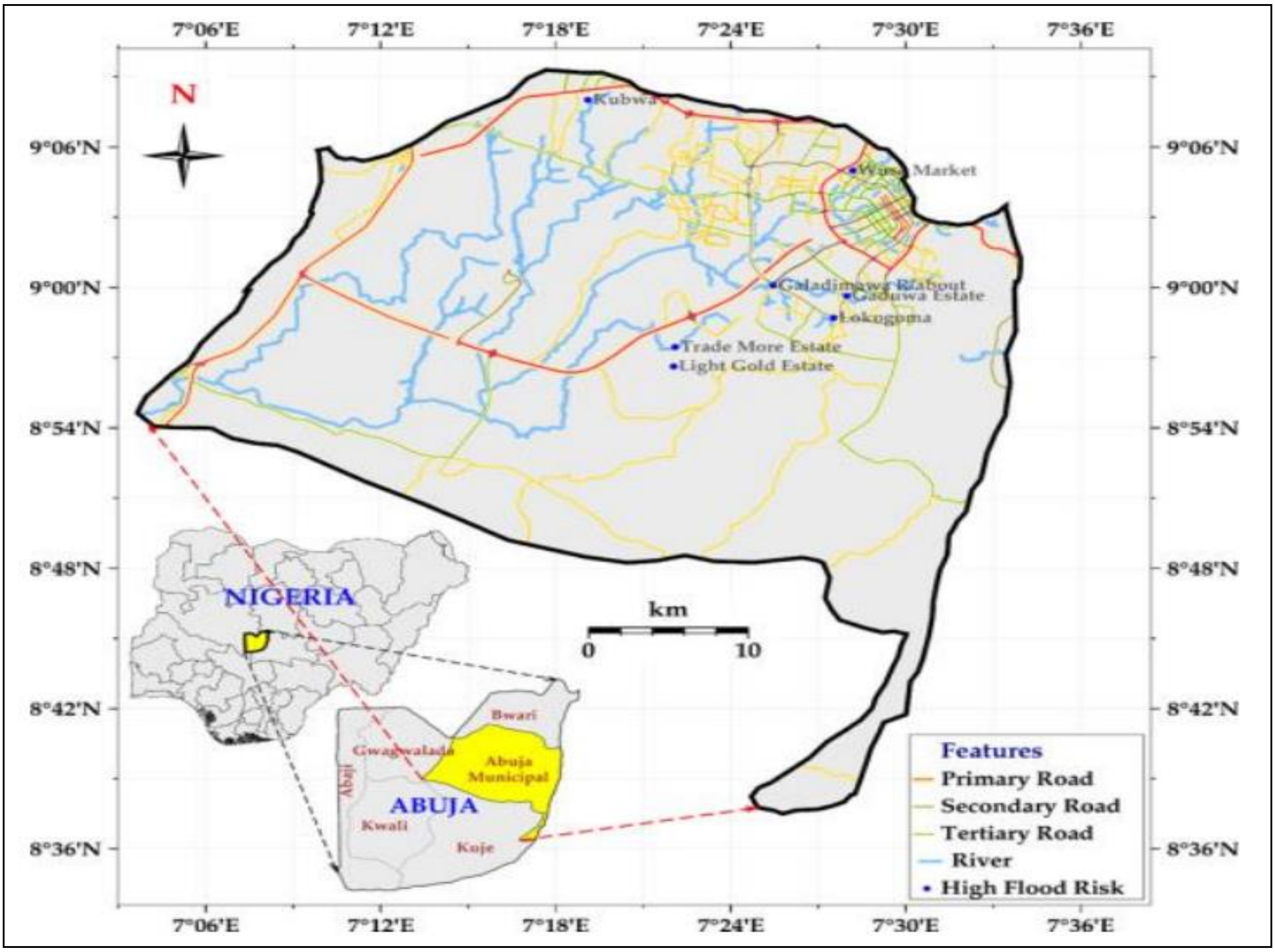

Fig 1 Location Map of the Study Area- AMAC.
(Source: OSGOF)

III. METHODOLOGY

An integrated GIS and multi-criteria decision-making methodology was utilized in this study for flood risk assessment. The method is based on the spatial integration of selected flood causative factors, namely soil type, land use and land cover, slope, elevation, drainage pattern, and mean annual rainfall. AHP method was chosen as the weighting criterion. ArcGIS software was used in this research to create the spatial layers required for the development of the flood risk map. Figure 2 below gives a general overview of the research process and method.

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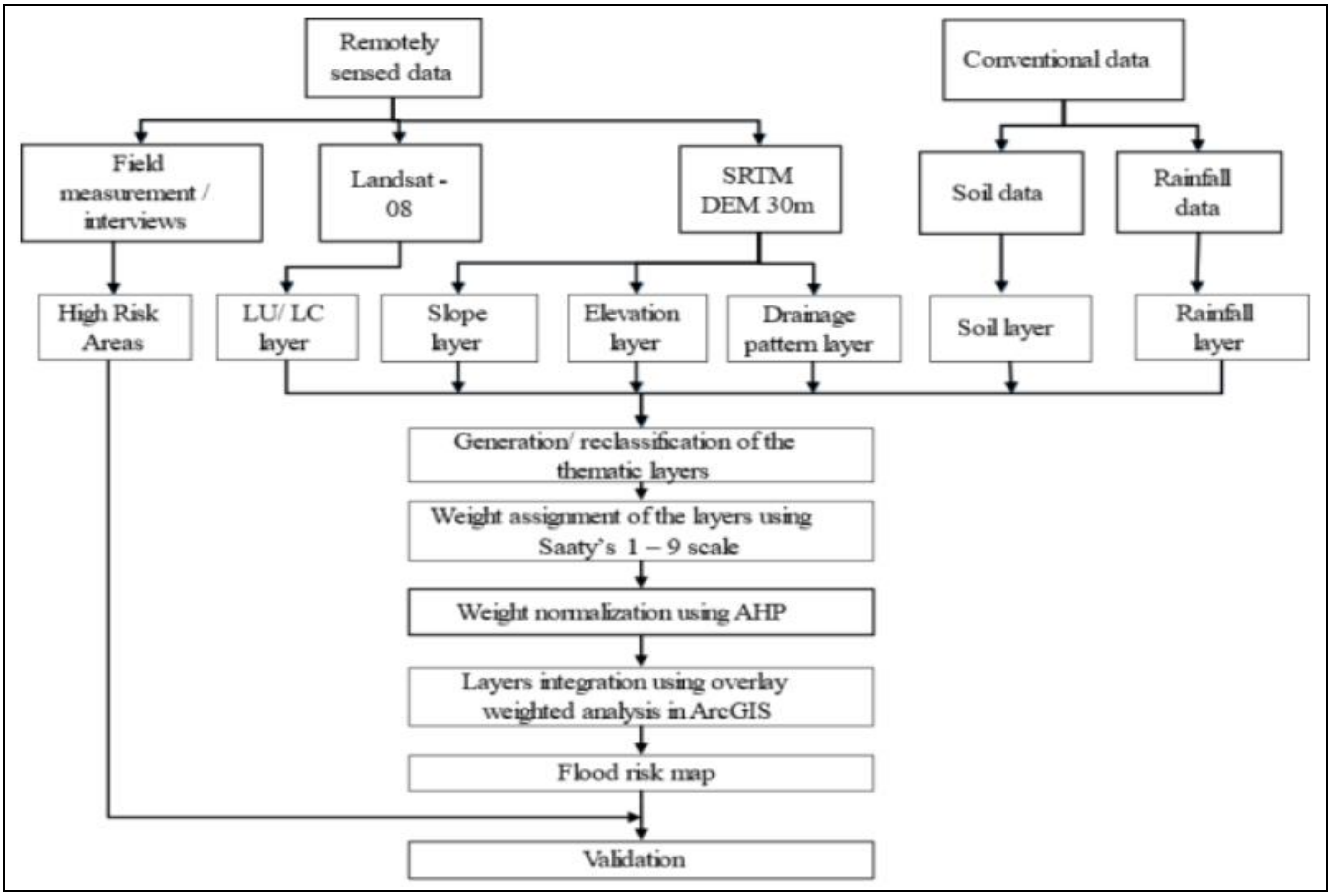

Fig 2 Flowchart for the Development of a Flood Risk Map.

Data is an important component for GIS analysis. The data utilized in this research work for the accomplishment of the stated objectives includes data obtained from RS and meteorological data from meteorological stations. The data types and sources are listed in Table 1.

- *Selection of Flood Risk Factors*

To study the flood risk, flood causative factors and their relations with flooding should be considered [21]; [22]. Different flood causative factors were utilized in past flood risk mapping studies [23]; [24]; [25]. However, there is no definite way of choosing flood causative factors along with their respective influence, experts often choose flood causative factors based on physical properties of the study area. In the current study, six flood causative factors founded on wide-ranging literature review were selected. These factors are rainfall, drainage density, elevation, slope, LU/LC, and soils.

Soil properties are significant in characterizing water holding capacity hence, affect water infiltration [26] and flood susceptibility [27]. Therefore, soil properties were considered as a parameter in this study. When supply of water surpasses the soil's permeation capacity, it flows as runoff on the surface and can result in flooding [28]. The soil map used in this study was obtained from the Geo Network Web Portal for Food and Agriculture Organization (FAO) Soil Map. Moreover, soil types were obtained from the SWAT Soil archive and added to the soil map in ArcGIS 10.5 and geo-referenced to the related UTM projected coordinate system. The soil map was geo-coded to each soil group based on the classes obtained from the SWAT Soil archive and further reclassified and assigned weights. Weights were subsequently allocated to respective soil classes. Soil type with very high likelihood to generate very high flood rate was classed 5, and 1 was allocated to soil class with very low capacity to generate flood.

Land Use and Land Cover (LULC) influences flow concentration, penetration, and seepage [29]; [30] therefore, it indirectly impacts flooding. LULC was considered as a significant factor in the structure. The study area LULC map was generated from satellite imagery (Landsat 8 OLI, 30m resolution) from the USGS website, and further processed into a thematic map through a supervised classification method in the ArcGIS environment. The generated thematic map was further divided into five (5) classes, namely: vegetation/ Agricultural land, bare soil, rock, built-up areas, and water bodies. These classes were subsequently ranked and reclassified into five groups in their respective ability to increase or decrease the risk of flooding.

The degree of elevation differential (slope) influences the speed of water flow and, therefore, is equally significant in causing flood [31]; [32]. Therefore, slope was considered as another flood causative factor in the present study. Low gradient slopes are susceptible to flooding in relation to high gradients. The slope thematic map was generated through the use of DEM and slope creation tools in the GIS software. Slope groups with lower values were assigned a higher rank due to almost flat topography, while the classes having higher values were assigned a lower rank due to relatively high gradient slope and the ability to swiftly evacuate run-off and reduce the possibility of flood.

Elevation is the fundamental representation of the topographic heights. In several studies on flood risk assessment, elevation models were utilized as an important factor [25]. consequently, elevation was selected as one of the significant factors in the analysis. Elevation data was obtained from USGS and processed in ArcGIS 10.5. The SRTM elevation data were utilized in estimating the basin's slope using ArcGIS 10.5 software. The elevation map was subsequently reclassified using the DEM reclassification tools in the GIS software. The elevation groups having lower values were assigned a higher rank due to susceptibility to flooding, while the groups having higher values were categorized as lower rank due to less vulnerability to flooding.

Drainage is a significant factor influencing flood risk; its densities reflect the soil nature and its geotechnical parameters. This implies that watersheds with high vulnerability to flooding and erosion have a higher drainage density and vice versa. In the designation of stream order, the first step is usually the flood risk analysis. In this study, the stream ordering was done using the proposed method by [33]. In thes study, Drainage density was assessed using the tool 'Density' in ArcGIS 10.5. Higher weights were allocated to poor drainage density zones, while lower weights were allocated to zones with adequate drainage. The drainage density layer was subsequently reclassified into five sub-groups using the "standard classification Schemes" (1–5). Areas with very low drainage density were ranked as 5, while those with very high drainage density were ranked with a value of 1.

Flooding results usually from torrential rainfall when natural waterways do not have the capacity to convey surplus water. In this study, an average annual rainfall for a length of ten (10) years was obtained and interpolated using Inverse Distance Weighting (IDW) in the ArcGIS 10.5 environment, and generated a continuous raster rainfall data within and around the study area boundary. The generated raster layer was further regrouped into five classes using an equal interval. The regrouped rainfall was allocated a value of 1 for the least rainfall to a value of 5 for the highest rainfall zones.

➢ *The Analytic Hierarchy and GIS Process*

The AHP method [34] is a multi-criteria decision analysis process that solves decision-making problems by using alternatives according to some carefully selected criteria. The current study was based on the collection of Remotely Sensed and GIS data for producing the risk map. Six governing parameters were considered in developing the flood risk map. The AHP technique was used in analyzing thematic maps of these parameters through the application of normalized weights in assessing the flood risk map of the Abuja Municipal Area Council. The application of AHP requires expertise in science, reliable evidence, and evaluation of matrix consistency [35]; [36]; [37]. The AHP method was applied through the consideration of flood risk factors and the allocation of relative scores.

➢ *Pairwise Comparison Matrix*

A structured questionnaire was circulated to experts for assessment of flood risk causal factors. The questionnaire consisted of six flood causative factors (that is, rainfall, drainage density, LULC, slope, soil, and elevation). The specialists were asked to select a parameter (example, rainfall) and compare it with the other parameters pair wisely in accordance with Saaty's 1–9 ratio scale (Table 2). The result from the questionnaire was then incorporated in Excel and statistically analyzed to obtain the principal eigenvectors and eigenvalues. The principal eigenvectors are the comparative weights of the flood causative factors and were subsequently utilized in the linear combination of the thematic maps to generate the required flood risk map.

➢ *Assessing Matrix Consistency*

The principal eigenvalue (λmax) signified the matrix deviation from consistency [38]. A pairwise matrix can only be consistent if the λmax is higher than the number of the parameters investigated (six factors in the present study); or else, a new matrix should be considered [39]. The consistency of normalized weight was analyzed by estimating the consistency ratio [40]. The assigned weights ware considered consistent when the consistency ratio is smaller than 10%; else, the weights should be re-estimated to decrease the inconsistency [41]. According to [34], the estimation of the consistency ratio necessitates calculating the consistency index (CI):

$$CI = (\lambda max-n)/n \quad (1)$$

λmax represents the principal eigenvalue, and n represents the number of thematic layers. The consistency ratio (CR) was estimated using the following equation:

$$CR = CI/RI \quad (2)$$

RI denotes the random index listed in Table 3 for different "n" parameters.

➢ *Developing the Flood Hazard Map*

Through the analysis, weights were assigned to the thematic maps and were classed according to their importance in flood susceptibility, based on experts' opinions through the questionnaire. Total scores were subsequently calculated using a simple weighted sum. Each pixel of the map was estimated using equation (3). Afterward, the AHP and the regrouped GIS data were combined in the ArcGIS software to produce the flood risk map.

$$LC = 1/n \sum\nolimits^{n}_{i=n} \{Di\ Wi\} \quad (3)$$

"LC" represents the linear combination; "D*i*" designates the decision parameter; "W*i*" represents the AHP weight; and "n" represents the number of parameters.

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The flood risk factors in the study area were assessed and weighted based on the essential scale for pairwise comparisons, where intensities of 2, 4, 6, and 8 were utilized to represent intermediate values (Table 2). Values which are close to one (1) have a low risk, while the high-risk areas have values close to nine (9).

IV. RESULTS AND DISCUSSION

A flood risk map presents the likelihood of the incidence of a flooding event in a location based on the hydrological and geomorphological characteristics of the area. Different flood causal factors considered in this study were founded on the hydrological and geomorphological parameters, and these include: elevation, slope, soil type, land use and land cover type, mean annual rainfall, and the drainage density. The choice of the flood contributing factors that have spatial reference is a significant step in AHP decision analysis. Consequently, the contributing factors considered in this study were selected based on their importance to the contribution of flood in the study area.

The highest elevation in the study area is 935m, whereas the lowest is 183m. The elevation map in Figure 3 was reclassified from 1 to 5, indicating the risk levels at different elevations. The lowest elevation group was evaluated as a very high flooding risk group (5), while the highest elevation group was rated as a very low flood risk class (1). It was observed that the lower elevations are dominant in the western portion of the study area, which makes it prone to flooding.

Slope has a considerable impact on stream flow generation due to rainfall. The slope group having lower values was allocated a higher rank owing to flat topography, which results in higher inundation, while the group having higher values were categorized with lower rank due to less likelihood of contributing to flood. In this study, the result of the reclassified slope layer is presented in figure 4. The slope map showed that the greater part of the study area lies on a shallow to a mild slope.

Table 1 Data Type and Sources

S/N	Data Category	Data Type	Data Source
1	Geomorphological	Soil	Digital World Soil Map (FAO)
2	Satellite imagery (Landsat 8 OLI)	Land use/ Land cover	United State Geological Survey (USGS)
3	Digital Elevation Model (DEM)	SRTM Elevation, Slope and Drainage Pattern	United State Geological Survey (USGS)
4	Hydro-meteorological	Average Annual Mean rainfall	Nigerian Meteorological Agency (NiMet)
5	Ancillary data	Other relevant information	USGS, Verbal interviews and Field Surveys

Table 2 Nine-Point Intensity of Importance Scale, Modified from Schoenherr (Schoenherr et al, 2008).

Intensity of importance	Definition	Description
1	Equally important	Two factors contribute equally to the objective.
3	Moderately more important	Experience and judgment slightly favor one over the other.
5	Strongly more important	Experience and judgment strongly favor one over the other.
7	Very strong more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Extremely more important	The evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed.
Reciprocals of above	If an element i has one of the above numbers assigned to it when compared with element j, then j has the reciprocal value when compared with i	-
Ratios (1.1–1.9)	If the activities (elements) are very close	May be difficult to assign the best value, but when compared with other contrasting activities (elements) the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities (elements).

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Table 3 Saaty's Ratio Index for Different n Values (Saaty, 1987).

n	3	4	5	6	7	8	9	10
RI	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

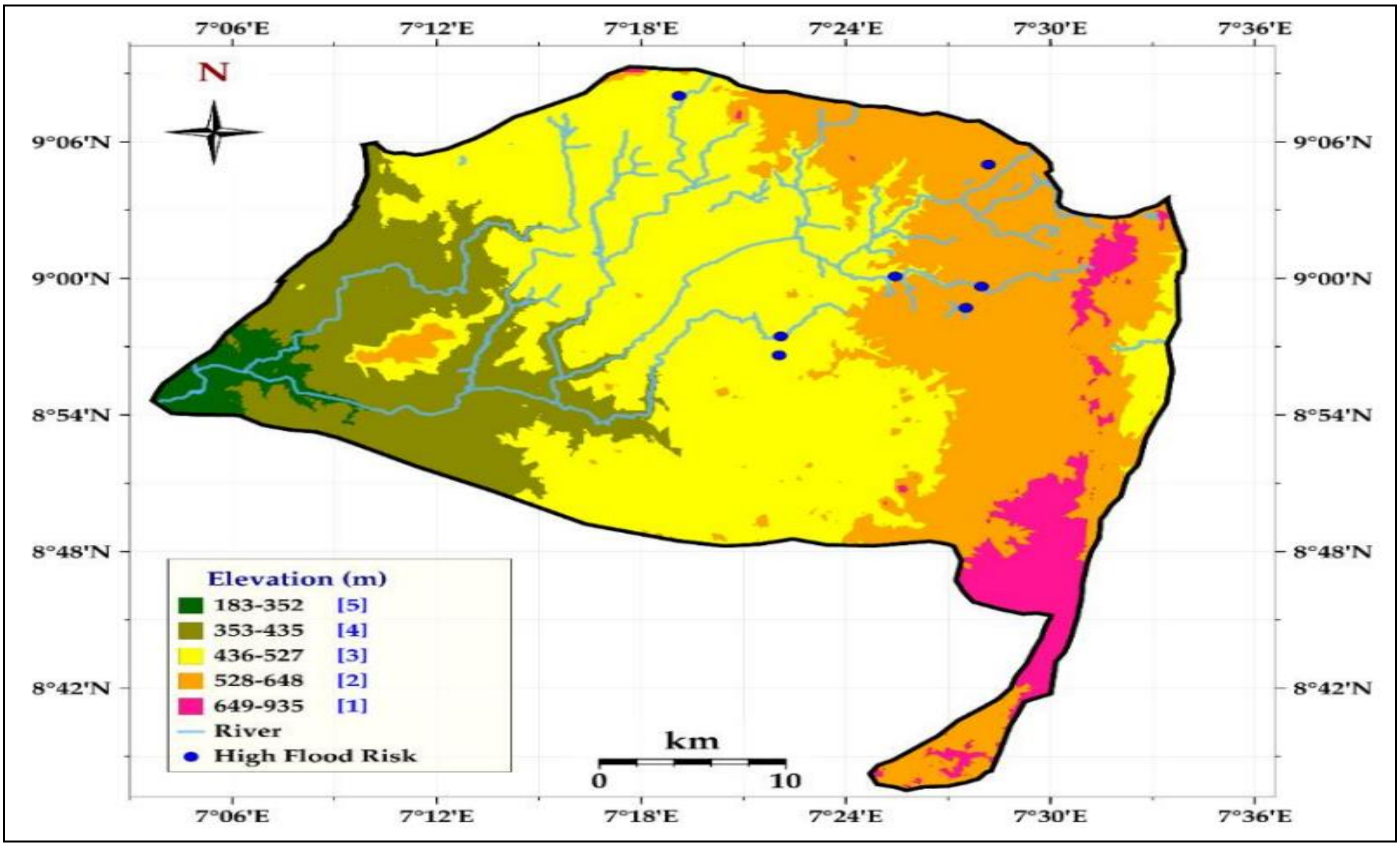

Fig 3 Reclassified Elevation Map.

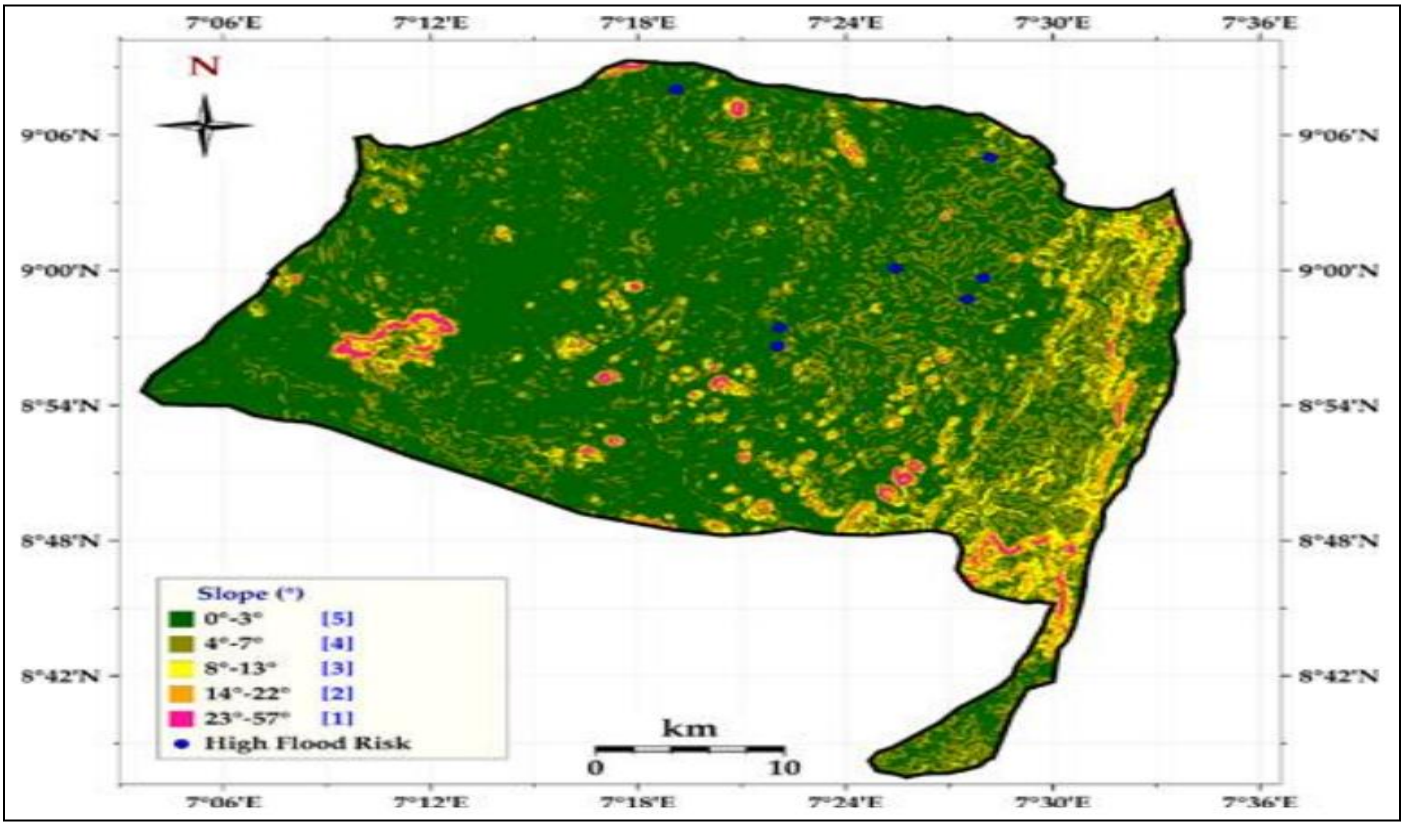

Fig 4 Reclassified Slope Map.

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Figure 5 shows the soil map of the study area and displayed two dominant soil types present in the study area. Loamy soil, which is dominantly located in the North-western part of the study area and is characterized by low permeability hence, is considered to have high flood risk because of its low permeation capacity compared with the most dominant sandy soil type in the study area. The second soil group is the sandy soil, which was broadly classified as the most dominant within the study area. This soil has a high rate of infiltration compared with the loamy soil, consequently having low flooding hazard. The regrouped soil map was produced through the allocation of weights to each soil group in a manner that the soil type with very high capacity to generate a very high flood rate was ranked 5 (loamy soil class), while soils with low capacity to generate flood was ranked 1 (sandy soil class).

LULC is important in categorizing areas prone to flooding. Impervious surfaces, such as inhabited areas and paved areas, increase the generation of runoff. Bare land is more susceptible to soil erosion due to high water flow, whereas areas with dense vegetation usually have low potential to flooding. Agricultural and built-up areas are more prone to flooding compared with bare marshy lands. Hence, built-up areas and paved surfaces were given more weight than other areas. Figure 6 shows the land use map of the study area and is grouped into five (5) classes, namely: water body, bare soil/ land, built-up areas, vegetation and agricultural areas, and rocky areas. The figure showed the regrouped land uses and the ranking of ware based on their influence and contribution to flood risk. Vegetation and agricultural areas were reclassified as 1, bare soil/ land reclassified as 2, rock areas reclassified as 3, built-up areas reclassified as 4, and water bodies reclassified as 5.

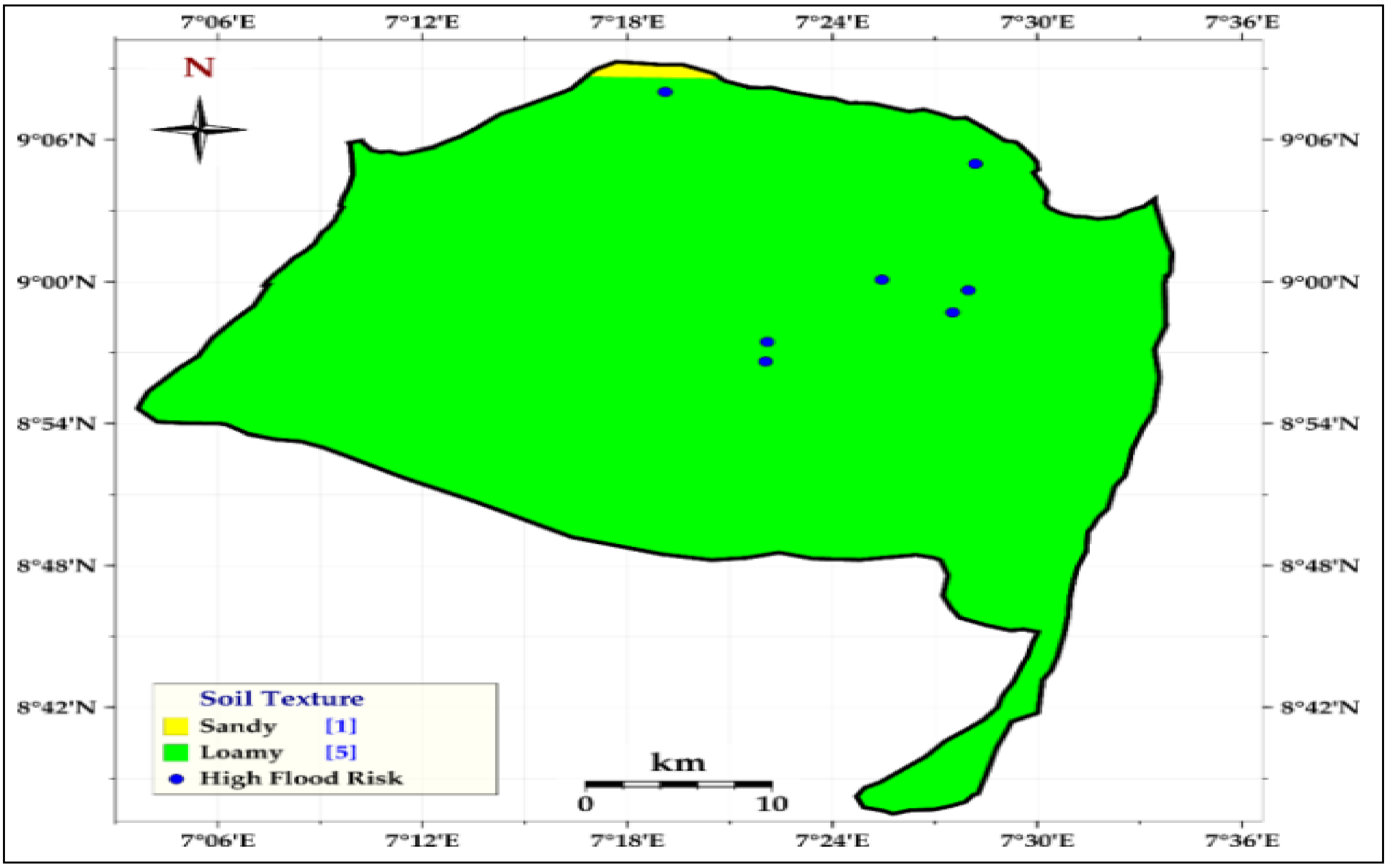

Fig 5 Reclassified Soil Map.

The average annual rainfall ranges from 2265 mm to 2946 mm. The regrouped rainfall was given a value of 1 for the least rainfall to 5 for the highest rainfall. Figure 7 shows the results of the IDW interpolated data layer and the reclassified rainfall data. The figure shows the various mean annual rainfall classes, which are very low (2,265mm – 2,455mm), low (2,456 mm – 2,575 mm), medium (2,576 mm – 2,671 mm), high (2,672 mm – 2,794 mm), and very high (2,795 mm – 2,946 mm). It is worth noting, the northern and central part of the study area receives the highest mean annual rainfall amount (MAR). This high amount of rainfall increases the chances of flash floods in these locations.

A high Drainage Density (DD) in an area indicates susceptibility to high surface runoff generation, hence, a higher probability of flooding, and vice versa. Figure 8 shows the DD map of the study area. The DD map was grouped into five (5) classes; Very low flood hazard (52 m/m2 – 92 m/m2), low flood hazard (40 m/m2 – 51 m/m2), moderate flood hazard (30 m/m2 – 39 m/m2), high flood hazard (20 m/m2 – 29 m/m2), and very high flood hazard (2 m/m2 – 19 m/m2) drainage densities. The DD layer was further regrouped into five (5) sub-groups using the standard classification method (1–5). Sections with very low DD were ranked as 5, and those with very high DD were ranked with a value of 1, as shown in Figure 8.

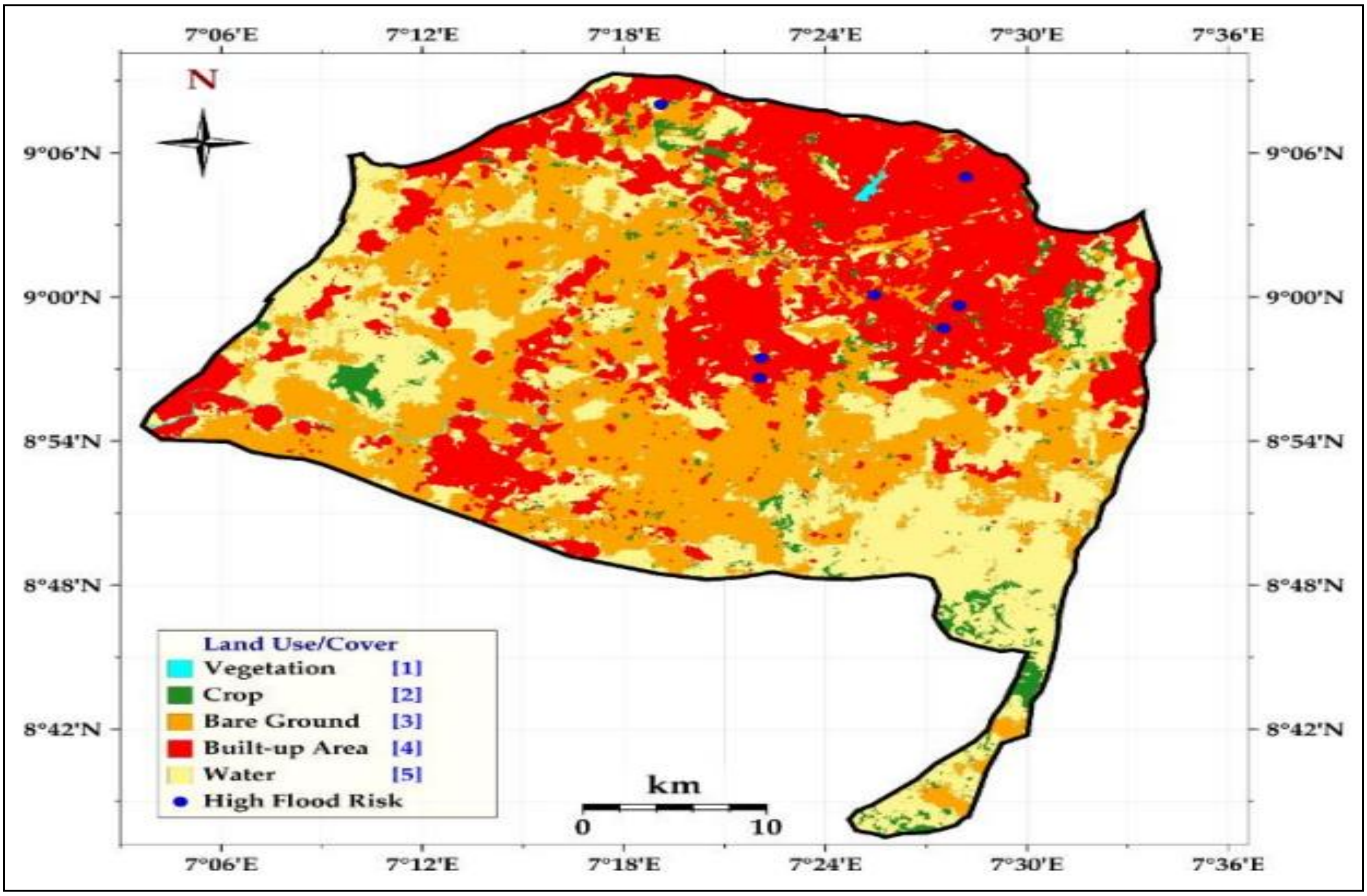

Fig 6 Reclassified Land use/Land Cover Map.

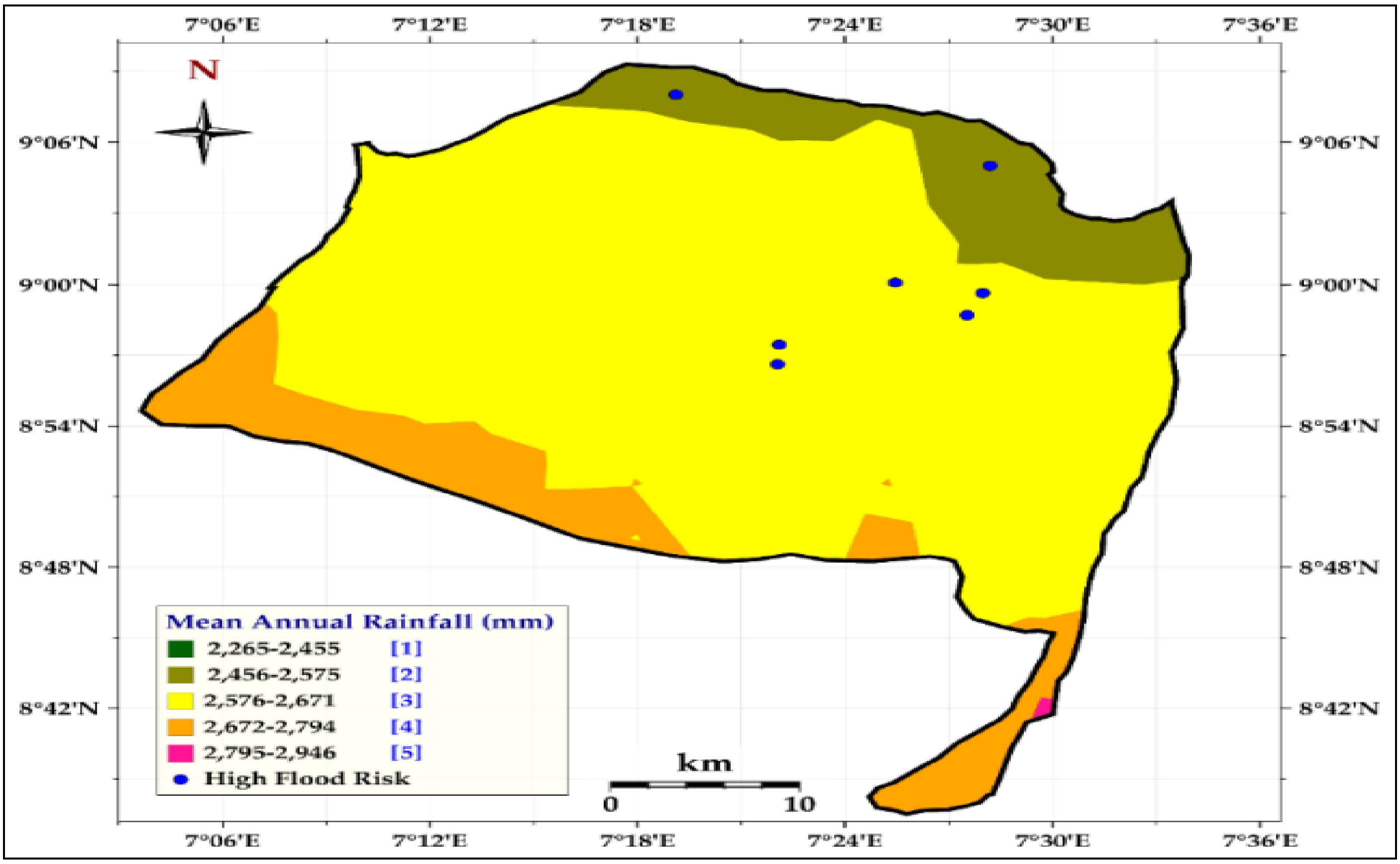

Fig 7 Reclassified Mean Annual Rainfall Map.

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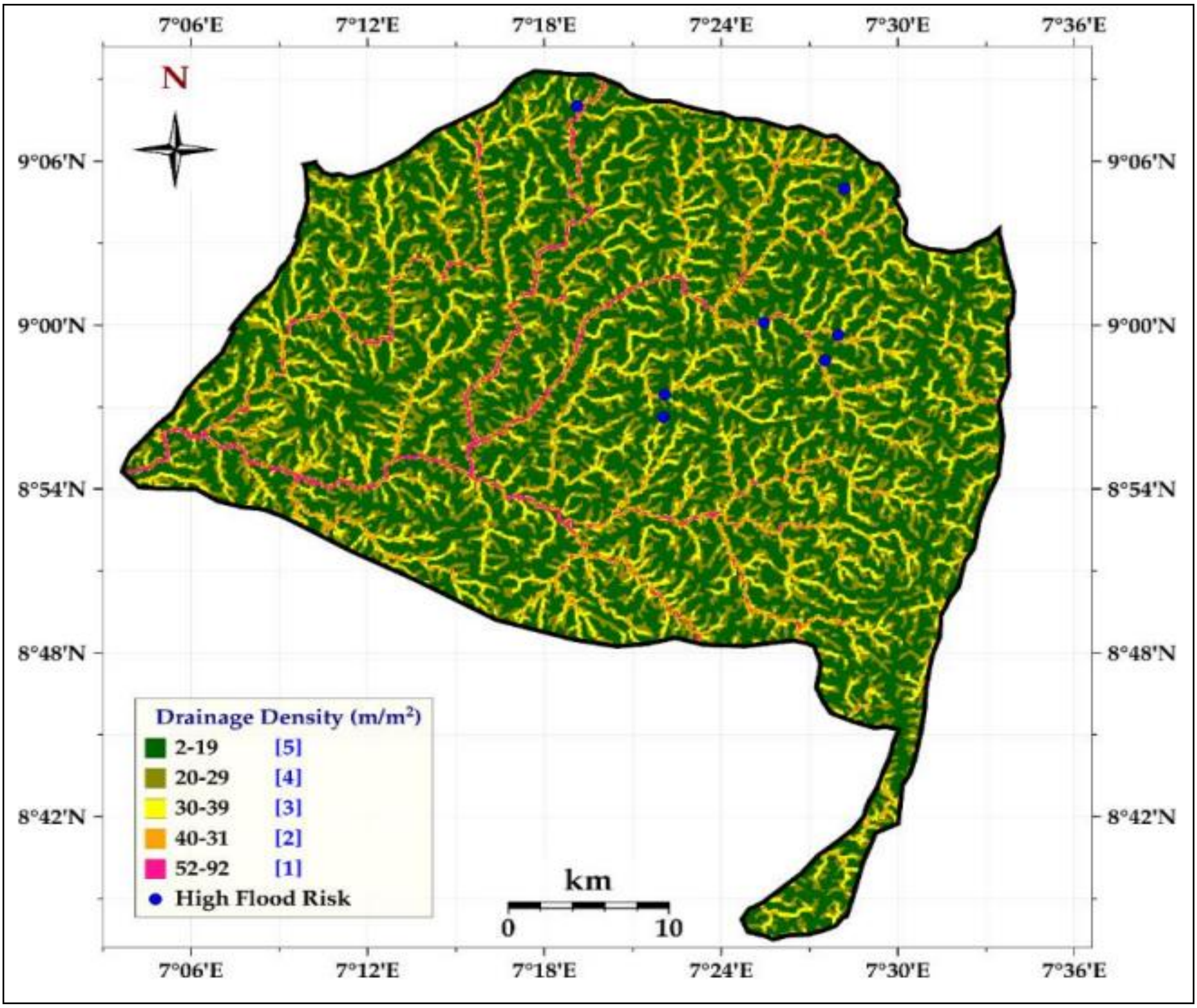

Fig 8 Reclassified Drainage Density Map.

➢ *Weights Estimation and Ranking of Flood Causative Factors Using AHP*

In applying the AHP method, a structured questionnaire based on pairwise comparisons was used and established priorities among the effects of the flood causative factors from eight (8) respondents. This research utilized a closed-ended questionnaire style and obtained experts' opinions on the hierarchy of the flood causative factors through ranking pairs of the factors. In this study, the Excel application was used for the pairwise comparisons and estimation of weights (eigenvectors) and Consistency Ratios (CRs). In the pairwise comparison matrix, the comparative value of each parameter was assigned by rating each parameter against every other factor based on the relative scale proposed by [34. Table 4 shows the comparison matrix for the six (6) flood contributing factors. The CR value for the matrix is 1.2% and is less than 10% signifying a satisfactory consistency level [39].

Tables 5 and 6 shows the weight and ranking of each flood causative factor with their respective weights and rankings. From the resulting weights of the flood causative factors, it is observed that slope has the greatest weight, followed by LULC and DD. This implies that slope and LULC have more influence in contributing to flooding in the study area than other factors.

➢ *Flood Risk Map*

Figure 9 shows the flood risk map of the study area and indicates areas predisposed to flooding. The map presents five risk levels, from very low to very high flood risk. The very high and high classes predominantly lie towards the northern part of the Abuja Municipal Area Council and the mid-section of the study area. These areas are basically known to have relatively flat slopes and are built up with inadequate drainage systems. High and very high hazards were obvious in built-up areas of the study area as observed from the flood risk map.

The results obtained show that a greater section of the study area is prone to “high” and or “very high” flood risk. These areas are those within the built-up area and generally lie at low elevations. Equally, most regions towards the southern part of the study area are susceptible to “very low” to

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"moderate" levels of flood risk. Most of these areas are located on higher grounds and high DD areas. The result showed that AMAC is susceptible to "moderate" to "high" flood risk. Due to the fact that despite a larger section of the study area having drainage networks, most are insufficient, and coupled with the fact that the urban paved surfaces inhibit water infiltration, these zones are prone to flood events during heavy downpour. As the multi-parametric/ criteria analysis forms a single map from the combination of thematic maps, hence the final output Figure 9 shows the desired flood risk map of the study area.

Table 4 Comparison Matrix

COMPARISON MATRIX						
CRITERIA	**Soil Type**	**LU/ LC**	**Slope**	**Elevation**	**Drain. Pattern**	**Rainfall**
Soil Type	1	1/6	1/6	2/3	1/5	2/7
LU/ LC	5 5/9	1	3/4	5 1/6	1 3/8	3
Slope	6 2/7	1 1/3	1	6 2/3	1 3/8	3 1/7
Elevation	1 1/2	1/5	1/7	1	1/5	3/8
Drain. Pattern	4 7/8	3/4	3/4	5	1	3
Rainfall	3 1/2	1/3	1/3	2 2/3	1/3	1

Table 5 Normalized Principal Eigenvectors

CRITERIA	**Soil Type**	**LU/ LC**	**Slope**	**Elevation**	**Drain. Pattern**	**Rainfall**
PERCENTAGES	4.06	26.62	30.96	4.86	23.03	10.47

Table 6 Flood Causative Factors, Respective Weights and Rankings

Causative Factors	**Relative Weight (%)**	**Reclassified Values**	**Ranking**	**Risk Level**
Soil Type	4.06	Loamy	5	Very high
		Sandy	1	Very low
Land use/ cover	26.62	Vegetation/ Agric.	1	Very low
		Bare soil/ land	2	Low
		Rock	3	Moderate
		Built-up areas	4	High
		Water body	5	Very high
Slope (Degrees)	30.96	0 - 3	5	Very high
		4 - 7	4	High
		8 - 13	3	Moderate
		14 - 22	2	Low
		23 - 57	1	Very low
Elevation (m)	4.86	183 - 352	5	Very high
		353 - 435	4	High
		436 - 527	3	Moderate
		528 - 648	2	Low
		649 - 935	1	Very low
Drain. Pattern (m/m2)	23.03	2 - 19	5	Very high
		20 - 29	4	High
		30 - 39	3	Moderate
		40 - 51	2	Low
		52 - 92	1	Very low
Rainfall (mm)	10.47	2,265 - 2,455	5	Very high
		2,456 - 2,575	4	High
		2,576 - 2,671	3	Moderate
		2,672 - 2,794	2	Low
		2,795 - 2,946	1	Very low

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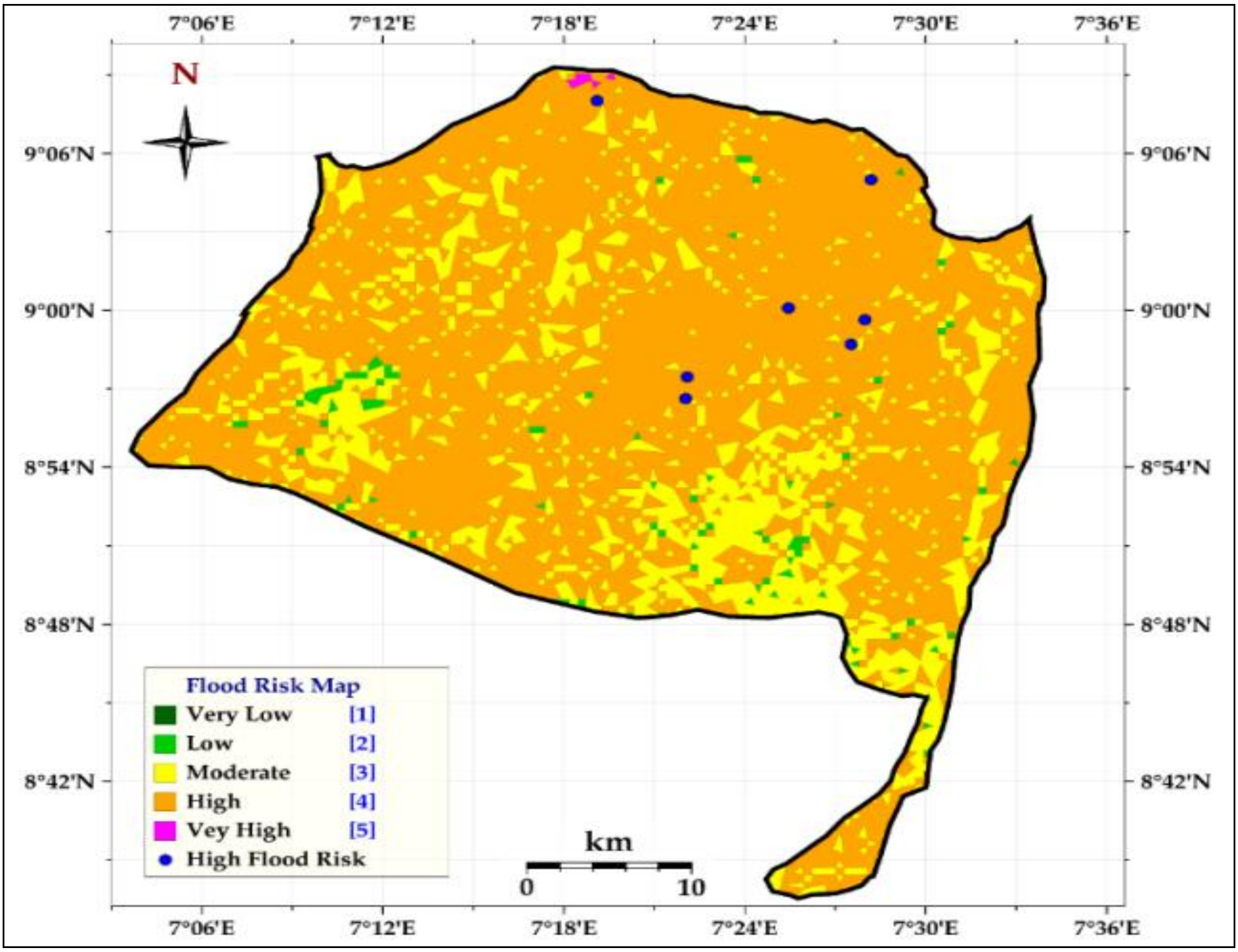

Fig 9 Reclassified Flood Risk Map.

➢ *Flood Risk Map Validation*

The flood risk map validation was based on field assessment carried out at eight (8) assessment areas within the study area, as shown in Figure 9. Historical flood records within the Abuja Municipal Area Council were obtained, and the following areas were discovered to have one or recurring flood events: Kubwa, Mpape, Wuse Market, Galadimawa roundabout, Gaduwa housing estate, Lokogoma, Light gold housing estate, phase 5, and Trade More estate, Airport Road.

The validated flood risk map of the study, as shown in Figure 9, revealed synergy between the flood risk map and the obtained historical flood records of the area. All the areas investigated, as outlined above fall under the classification of “high flood” to “very high” flood risk areas. This shows that the utilized procedure can be applied in other study areas to produce a flood risk map because it is flexible, accessible, highly accurate, and demands fewer data. Figure 9 shows that the high and very high flood risk areas are situated in the northern part of the study area that has historical flood records, whereas low and very low flood risk areas are dominant in the southern part, which were verified to have experienced no flooding event. Consequently, this shows that the utilized procedure can forecast areas that are probable to experience flooding with high and reasonable certainty.

V. CONCLUSIONS

This study concludes that the spatial distribution of flood risk in AMAC can be mapped using the AHP integrated with GIS. The study utilized the hydro-geomorphic risk analysis, which is easy and involves less hydrological data to map flood risk areas. The flood causative factors utilized for the study were obtained through a wide literature review, field survey, and conversations with specialists, local community representatives, and inhabitants of the study area. The study identified six factors essential for flood risk assessment in the study area, which include slope, elevation, drainage density, soil type, land use/cover, and average annual rainfall. Based on the obtained results, the following conclusions can be drawn;

The study reveals that the northern to middle section of AMAC falls under high to very high vulnerability classes mainly due to the level of dense built-up and paved surfaces, occasioned with milder slope topography. In contrast, the southeastern part of the study area falls mostly under the category of moderate to low flood risk classes due to less built-up areas combined with more vegetative surfaces and steeper slopes.

The high to very high-risk classes are concentrated mainly in the northern to middle section of AMAC, and all the flood events recorded within the study area are concentrated within the same zones. Locations such as Kubwa, Mpape, Wuse Market, Galadimawa roundabout, Gaduwa housing estate, Lokogoma, Light gold housing estate phase 5, and Trade More estate, airport road have all witnessed flood events in history; therefore, this demonstrates the consistency and applicability of the utilized methodology. Hence, the study results further validate that integration of AHP and GIS methods provides an efficient tool for decision-making process in flood risk mapping, and it equally permits a lucid and effective use of spatial data. In general, the result of the case study showed that the GIS-AHP-based integration model is effective in flood risk mapping.

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