Flood Risk Assessment of Benin-Owena River Basin, Nigeria

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Abstract

This research paper explored the potentials of Geographic Information System (GIS) and Multi-criteria Decision Analysis (MCDA) in identifying flood-prone areas for the purpose of planning for environmental disaster mitigation and preparedness, using Benin-Owena River Basin of Nigeria as a unit of analysis. The data used in this study were obtained from FORMECU, a Federal Government Department in charge of forest management. Federal Ministry of Environment and Benin-Owena River Basin Authority were entered and used to develop a flood risk information system. Some causative factors of flooding in watershed are taken into account such as annual rainfall, basin slope, drainage network, land cover and the type of soil. Boolean and Weighted Linear Combination approaches were employed in GIS while Analytical Hierarchy Process-AHP and Ranking method used to calculate the weight of each factor were adopted for MCDA. Using AHP, the weightage derived for the factors were Rainfall (34%), Drainage network (26%), Basin slope (20%), Soil type (15%) and Land cover (6%). At the end of the study a map of flood vulnerable areas was generated with a view to assisting environmental managers on the menace posed by the disaster.

Keywords: Flood Risk, Geographical Information System (GIS), Multi-criteria Decision Making, River Basin, Nigeria.

1.0 Introduction

Flooding is a major risk to riversides populations and floodplains causing substantial impacts on the environment, including aquatic, fauna and flora, bank erosion and other aspects due to the infrastructure such as dams, piers, and lands as well as by poor development practices including riverside development, excessive cleaning, encroachment upon water ways, dredging which may cause changes in the hydrological balance of the water ways involved (Nolan and Marron, 1995). According to UN-Water (2011), flood is seen to have caused about half of disasters worldwide and 84% disaster deaths. The primary cause of flooding in many parts of the world is directly or indirectly related to rainfall in the catchment areas of the major river systems. However, flooding is not only related to heavy rainfall and extreme climatic events (Action Aid, 2006); it is also related to changes in the built up areas themselves. At extreme cases of flood, many abandon their houses and completely relocate to other areas that are not affected by flood while others live in their houses for few months of the year during the dry season, after which they relocate and come back when another dry season begins.

In Nigeria, several studies of the hydrological changes associated with urbanisation (Akintola, 1994) have described the contributions of topographic conditions, rainfall characteristics, land use changes (especially the expansion pave impermeable areas), uncontrolled waste dumping and construction on the floodplain, have led tolocal flooding (Oriola, 1994). The roles of rainfall amount and intensity have also been well discussed (Olaniran and Babatolu, 1996). The perception of impact adjustment to flooding in Nigeria has been extensively studied (Ologunorisa, 1999). It is very important to have sound and effective flood management and control measures, because floods impose a curse on the society. This can only be feasible if there are proper and effective flood hazard maps of the area for proper decision making (Sedogo, 2002; McCall, 2008; Rambaldi*et al*., 2006). In the absence of accurate and up-to-date information on issues such as flood hazard and vulnerability, decision-makers often fail or make incorrect decisions (Haack, 1982).

Flood hazard mapping is a vital component in flood mitigation measures; control and land use planning, and is also an important prerequisite for the flood insurance schemes in flood-prone areas (Okosun*et al.*, 2009). It creates easily-read, rapidly-accessible charts and maps which facilitate the administrators and planners to identify areas of risk and prioritise their mitigation/ response efforts. GIS applications in flood risk mapping range from storing and managing hydrological data to generating flood inundation and hazard maps to assist

flood risk management. Over the last decade in particular, a great deal of knowledge and experience has been gained in using GIS in flood risk mapping. Recognising the importance of up-to-date base maps for effective planning, there is need to utilise the opportunities facilitated by modern geospatial technology through the integration of satellite images with GIS for the production of such maps with high accuracy. There is an urgent need to include the concepts of disaster geo-information management into emergency preparedness planning, spatial planning and environmental impact assessment. In developing countries like Nigeria, the advantages of flood risk-related spatial information within a GIS context have not been widely explored. There is a need to convert raw data into useful spatial information that allows analytical processes for flood risk analysis and exploration of risk reduction alternatives (Maskrey, 1998; IFRC, 2005). The aim of this study is to identify flood- prone areas for the purpose of planning for disaster mitigation and preparedness, using Benin-Owena River Basin, Nigeria as a unit of analysis. The specific objectives of the study are as follows: 1) to identify the areas that are at risk of flooding, 2) to identify and detail those factors that are relevant to current and future flood risks in the study area, 3) to examine the impact on and vulnerabilities of residents in the study area to the increasing risk of floods, and 4) to outline policies to be applied to such areas to minimise and manage flood risk.

2.0 Material and Methods

2.1. Study Area

The Benin-Owena River Basin is one of the twelve River Basin Authorities created as part of the Nigeria's Third National Development Plan in 1977 (Federal Government of Nigeria(FGN) 1975). Located between longitudes 5o-6o40I E and latitude 50-70 40I N, the basin is well drained with an average surface slope of 0-6%. Geologically, the basin is within two broad parts- the basement complex rocks of the North with little or no prospect for exploitable groundwater and sedimentary rocks of the South with relatively high groundwater potential. The soils are Oxisols in the South and Utisols in the North. The hydrology is a reflection of the geology and is dominated by the extensive River Niger flood plain in the East and other rivers such as the Ubo, Edion, Orle, Okhuamahun and Owena. The average monthly rainfall ranges from 27mm in December to 365mm in July with a mean annual rainfall of 2165mm.

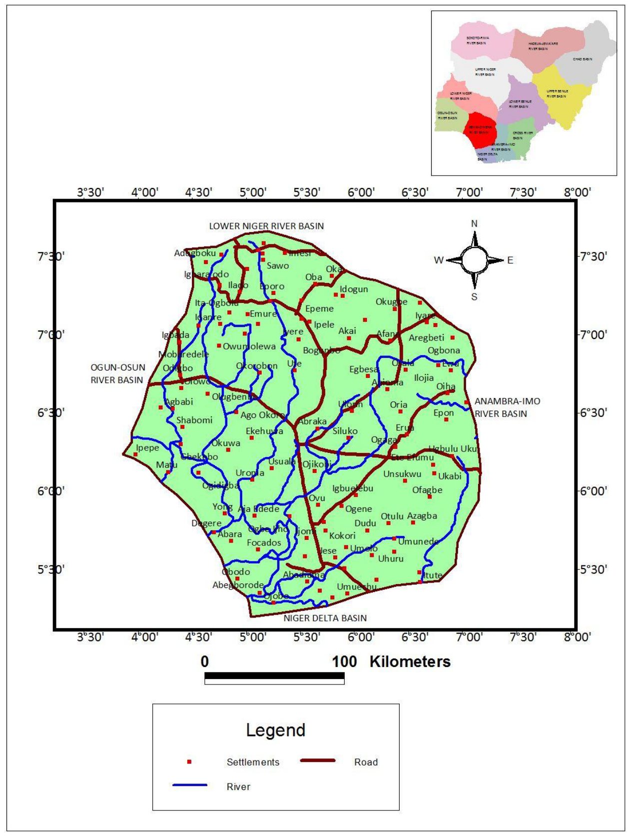


Figure 1: Map of the Study Area (Benin-Owena River Basin in Nigeria)

2.2. Data Source, Processing and Selection

The data needed for this study were obtained from FORMECU, a Federal Government Department in charge of forest management, Federal Ministry of Environment and Benin-Owena River Basin Development Authority. All the spatial data created in different layers are converted into compatible GIS format and the attributes tables created for each layer using ArcGIS 10.0. The criteria used in this study were selected due to their relevance and form the input into the flood risk analysis (Malczewski, 1996). These includes; rainfall pattern (Figure.2), drainage network (figure 3), slope of the basin (figure 4).soil type (figure 5) and land use/land cover (figure 6).

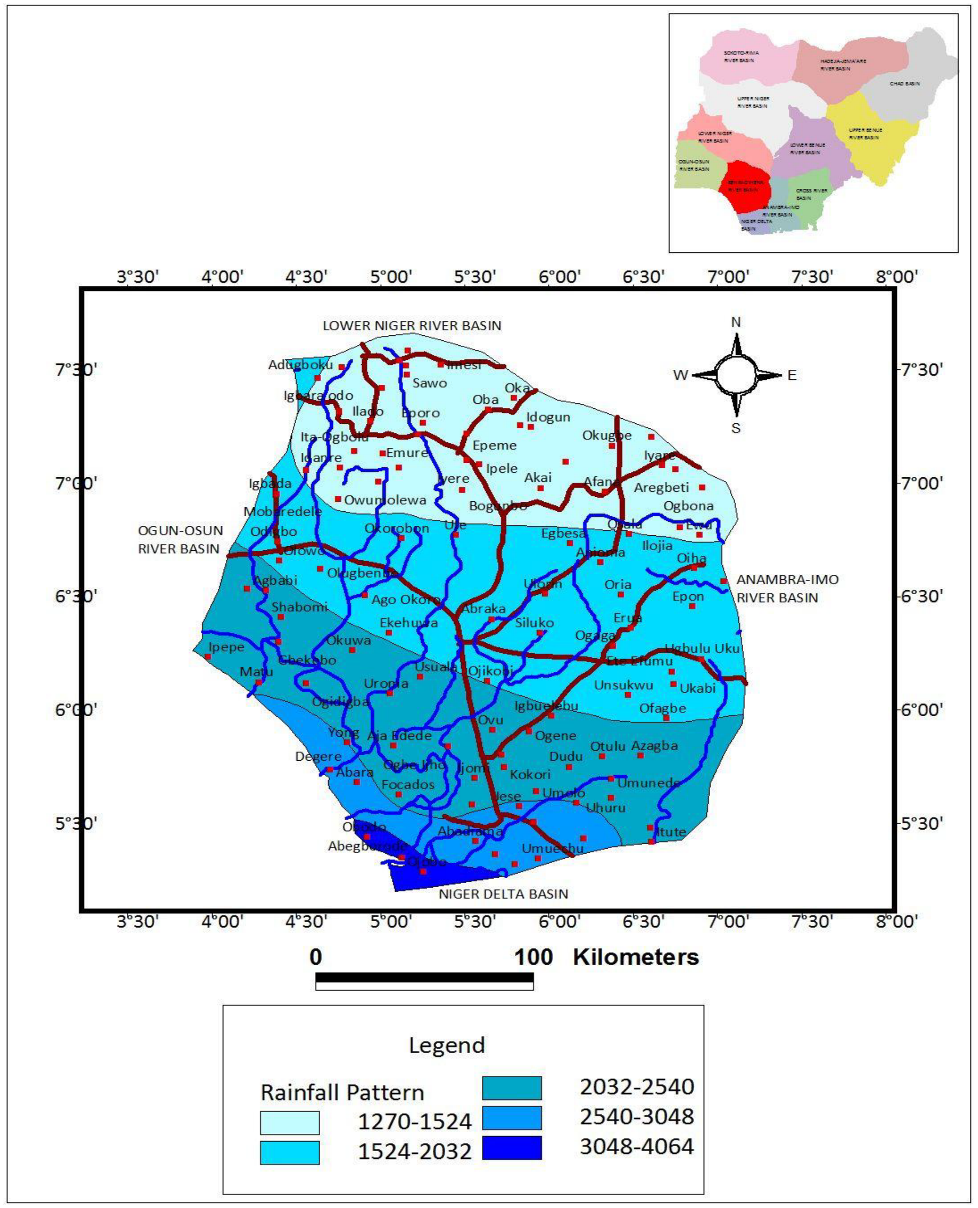


Figure.2: Rainfall Pattern Within the Benin-Owena River Basin

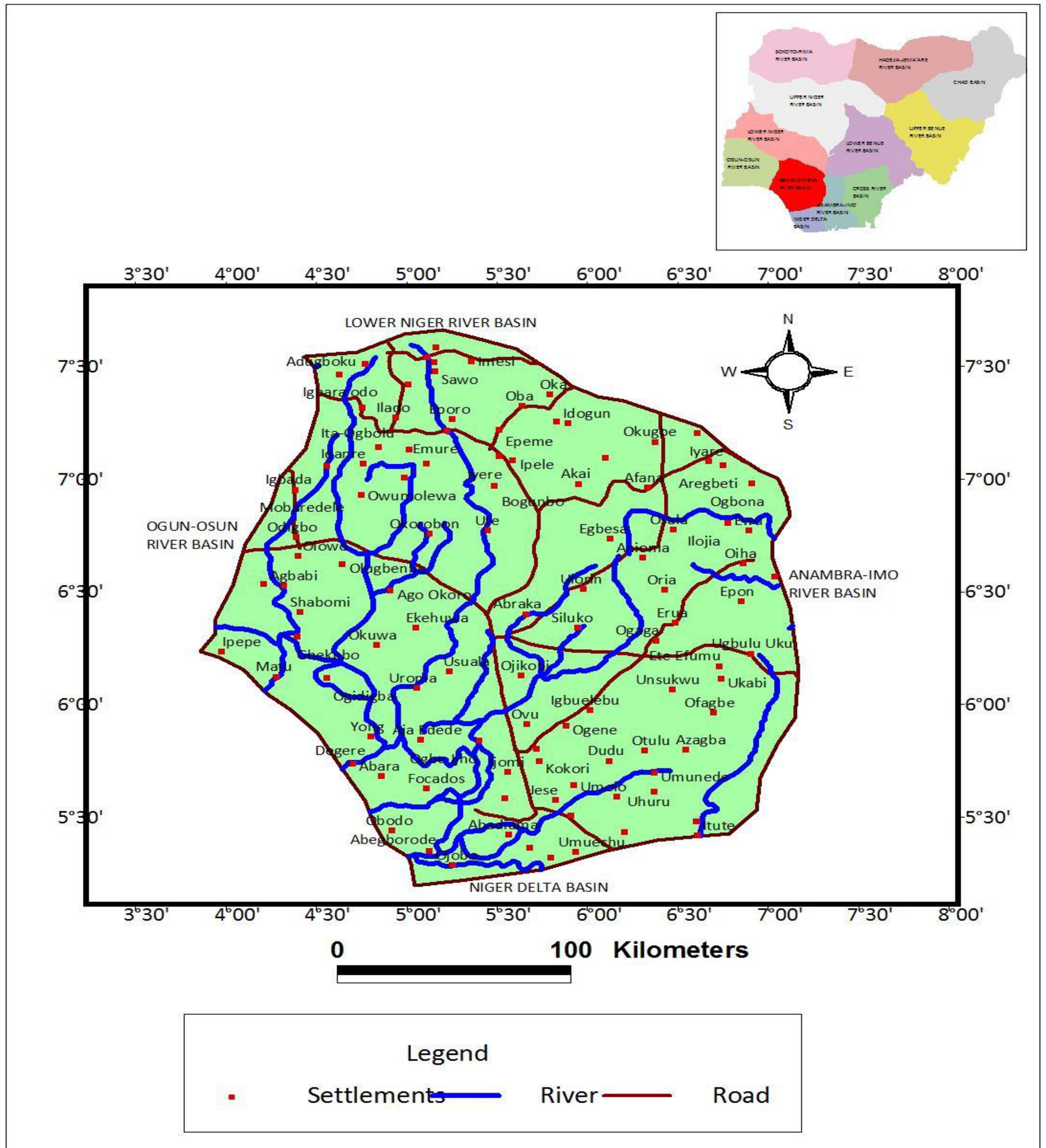


Figure 3: Drainage Network within Benin-Owena River Basin

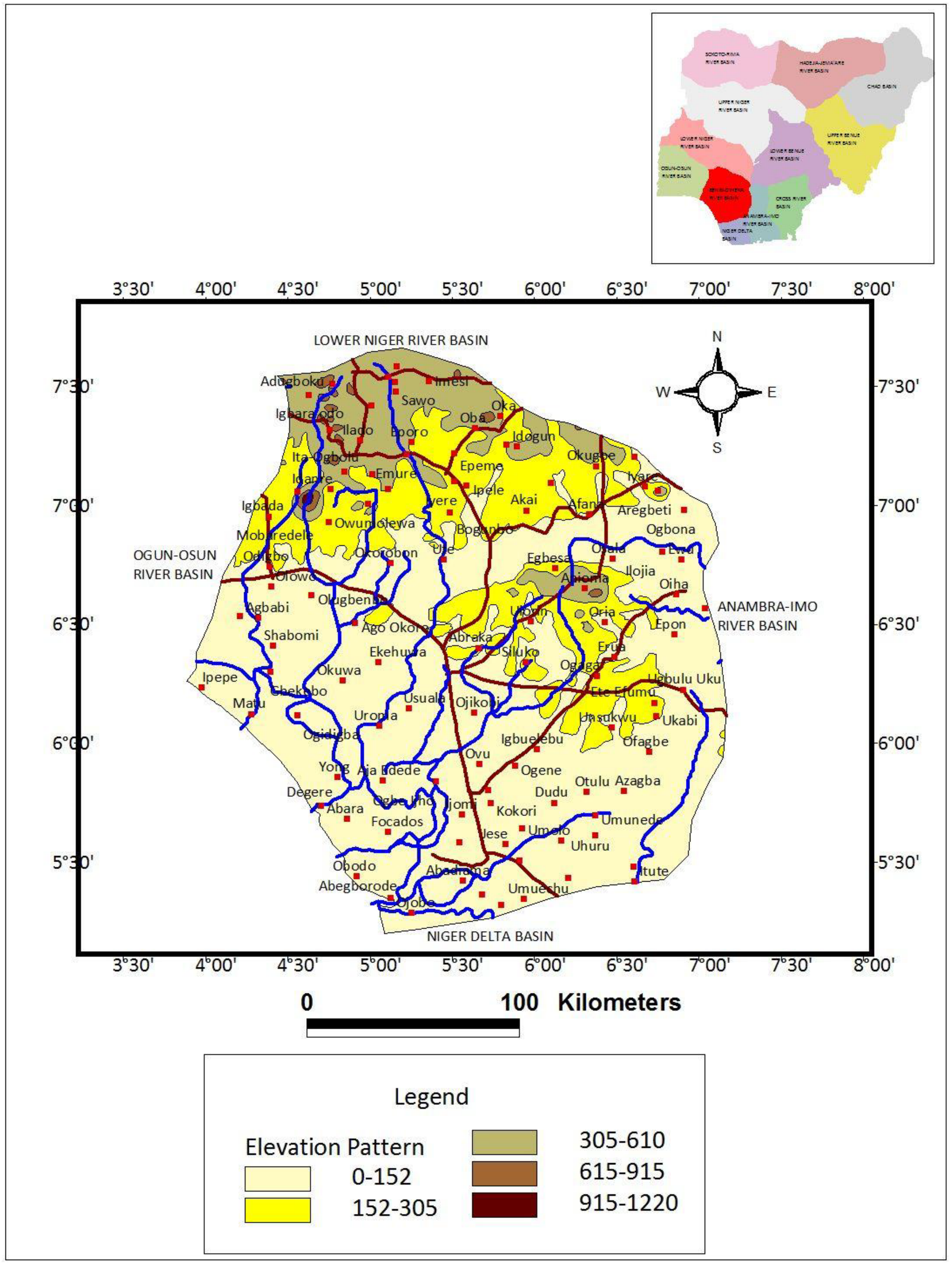


Figure 4: The Slope Pattern of Benin-Owena River basin.

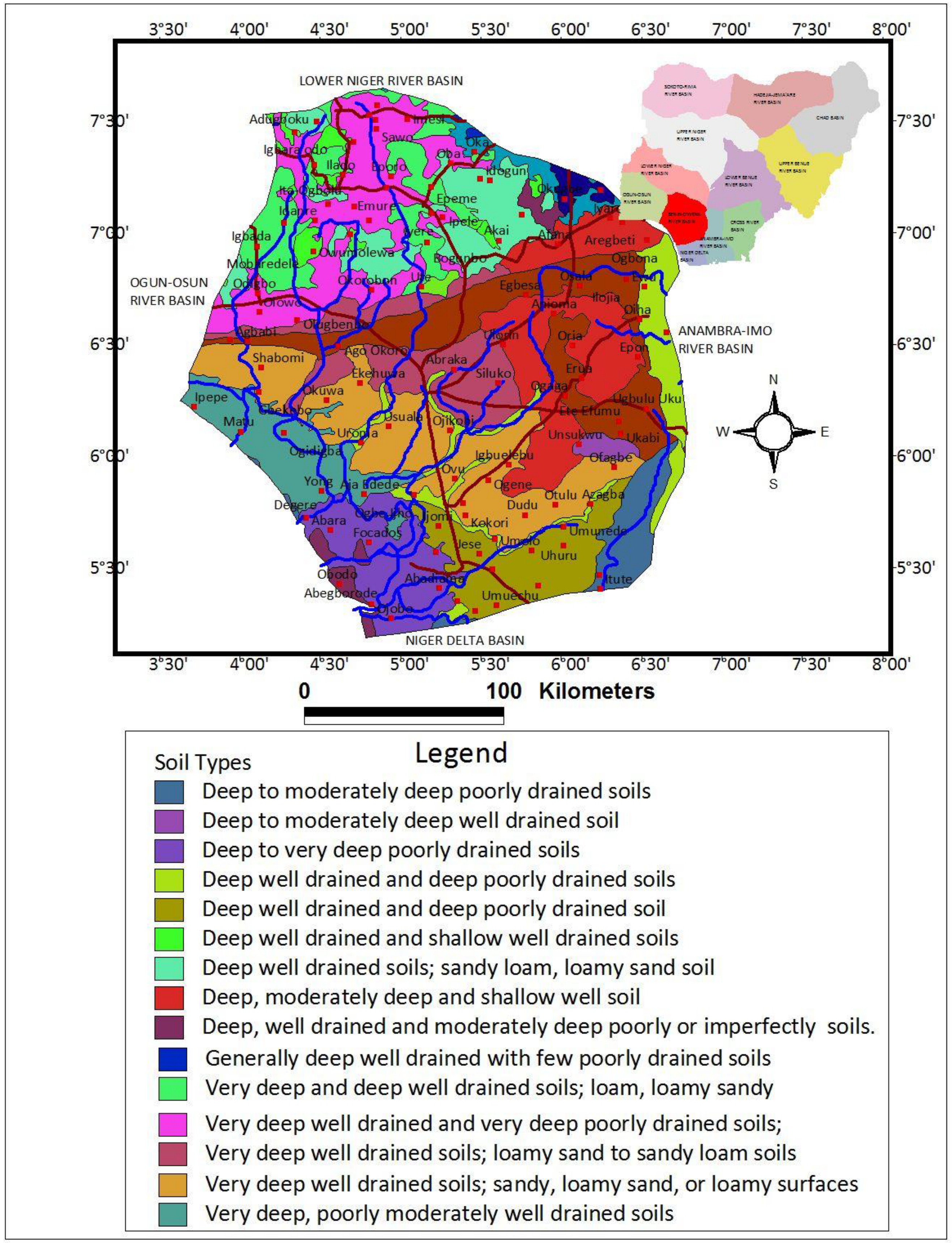


Figure 5: Soil types within Benin-Owena River Basin.

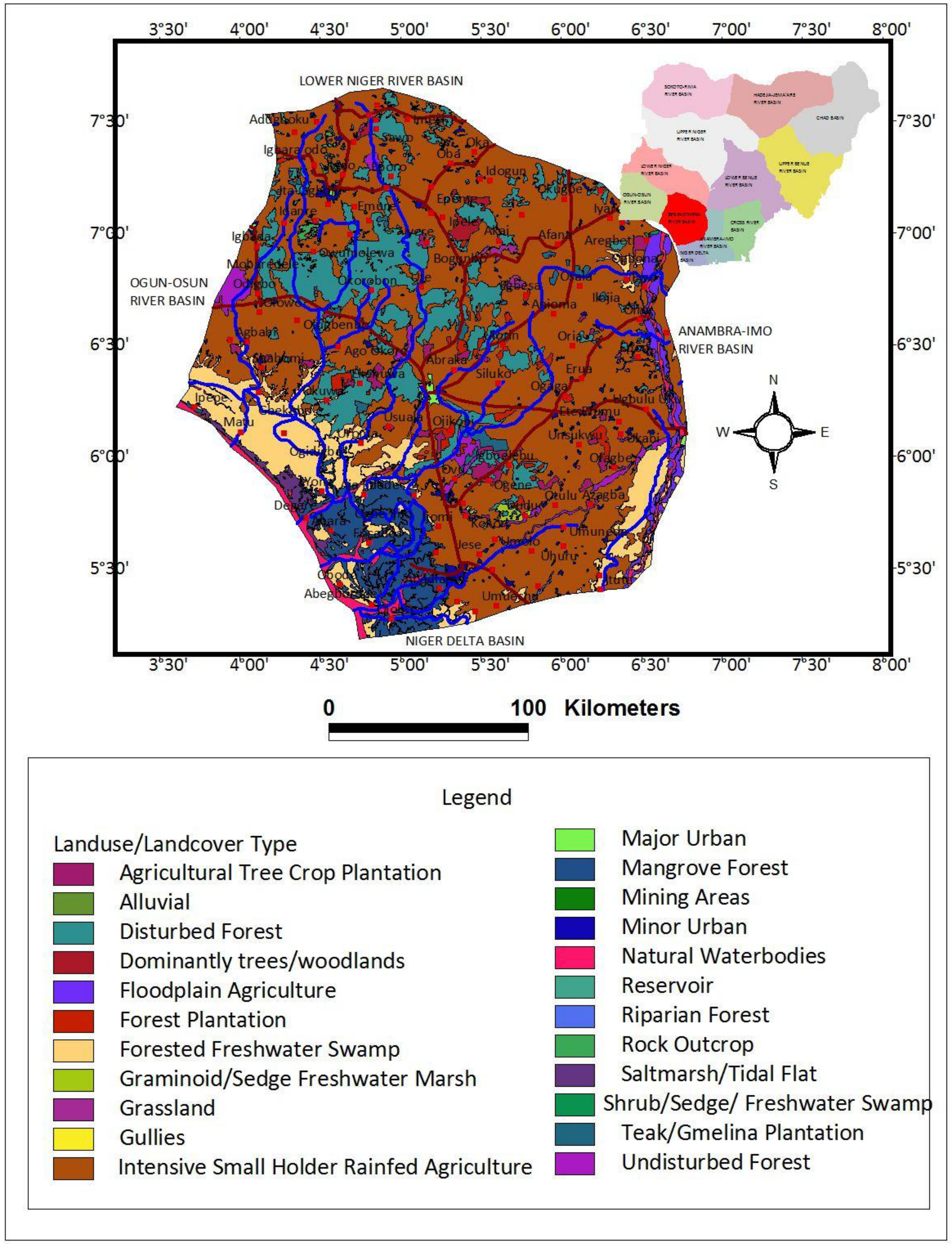


Figure 6: Land use/ Land cover pattern of Benin-Owena River Basin.

2.3 Data Analysis

2.3.1 Multi -Criteria Analysis

Multi -criteria analysis is applied and integrated with the spatial data in describing the factors causing flood. In this study, the flood- prone areas were first mapped by numerically overlaying drainage network, soil type, slope, land cover and rainfall pattern layers. This overlay is carried out as a Boolean overlay. All criteria are combined by logical operators such as intersection (AND) and union (OR). Secondly, Ranking Method was used, where every criterion was ranked in the order of the decision maker's preference. Each factor was weighted according to the estimated significances for causing flooding. The inverse ranking method was adopted for these factors with rank 1 for the least important and 8 for the most important. Thirdly, Pair - wise Comparison method which was developed by Saaty (1980) was adopted to determine the weight of each criterion.

2.3.2. Pair-wise Comparison Method

Pair-wise comparison developed by the American Professor of Mathematics (Saaty, 1980) is another method usually used for weighting several criteria. It stems from the Analytic Hierarchy Process (AHP) a famous decision- making framework. Using the above method the weight of the below criteria can be calculated as presented in table 1, 2 and 3.

C1= Rainfall Pattern
C2= Drainage Network
C3= Slope of the basin
C4= Soil Type
C5= Land cover

Table 1. Pair-wise comparison matrix of the criteria above.

Criteria	C1	C2	C3	C4	C5
C1	1	2	2	2	4
C2	0.5	1	2	2	4
C3	0.5	0.5	1	2	4
C4	0.5	0.5	0.5	1	4
C5	0.25	0.25	0.25	0.25	1
Total	2.75	4.25	5.75	7.25	17

Furthermore, the matrices derived were normalized by dividing each matrix by the sum of its column with their summations equal one (1) as shown in table 2 below

Table 2. Normalized Matrices

Criteria	C1	C2	C3	C4	C5	Priority Vector
C1	0.363	0.471	0.348	0.276	0.235	0.339
C2	0.182	0.235	0.348	0.276	0.235	0.255
C3	0.182	0.118	0.174	0.276	0.235	0.197
C4	0.182	0.118	0.087	0.138	0.235	0.152
C5	0.091	0.059	0.043	0.034	0.060	0.0574
Total	1	1	1	1	1	1

Because individual judgement will never agree perfectly, the degree of consistency achieved in the ratings is measured by a Consistency Ratio (CR) indicating the probability that the matrix ratings were randomly generated. The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix while a ratio over 0.1 indicates that the matrix should be revised. In this study, the adopted expression for calculating consistency ratio is stated below (Sani, 2010) and presented in table 3

CR=CI/RI

Where CI=λ max-n/n-1

R1= Random consistency index

N=Number of criteria

λmax is priority vector multiplied by each column total.

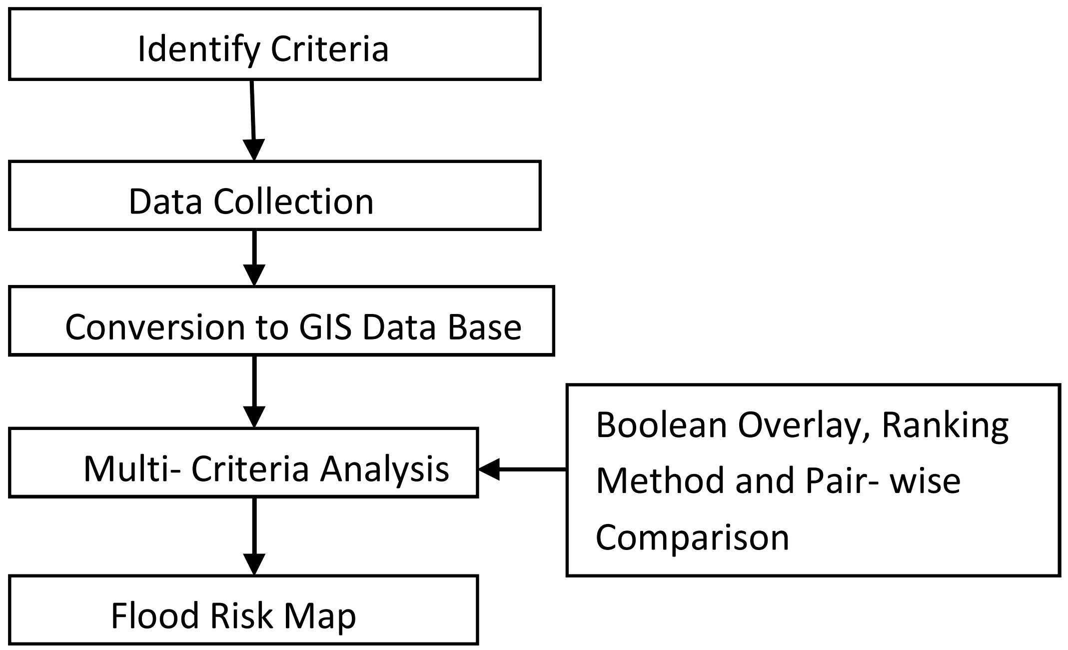
Table 3. Random Indices for Matrices of various sizes (n)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R1	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The value of CR= 0.0506 falls below the threshold value of 0.1 showing a high level of consistency hence we can accept the weights.

2.3.3 Ranking Method

Generally, the easiest way is weighting the criteria by ranks in either ascending or descending order. Ascending means the most important criterion is given 1; the second is ranked 2 etc. When ranking in descending order, 1 is given to the least important criterion etc. Once the ranks are assigned, the numerical weights corresponding to the ranks are derived in different ways either by Rank Sum, Reciprocal or Rank Exponent. For this study, the descending order or inverse ranking was applied to the flood causing factors. Figure 7 below illustrates the general procedure used to produce flood risk map for the study area.



Source: Adapted from Ranya, 2015.

Figure 7: General Procedure Undertaken to Develop Flood Risk Map for the Study Area

3.0. Findings and Discussions

The flooding vulnerability maps (figures 8 & 9) below in this study were generated by creating a digital database of all the selected variables as listed and mapped above. The software used was Arc GIS 10.0 and the criteria maps were combined by logical operations such as intersection and union in the Boolean overlay technique in GIS. Using Pair wise Comparison Matrix, the criterion weights were calculated as 0.339(33.9%), 0.255(25.5%), 0.197(19.7%), 0.152(15.2%) and 0.057(5.7%) respectively for rainfall pattern, drainage network, basin slope, soil type and land cover. The significant findings showed a consistency Ratio value of 0.05 which fell much below the threshold value of 0.1 showing a high level of consistency. Hence, the weights are acceptable. The flood vulnerable maps generated and shown in figure 8&9 were classified based on weighting ranking of flood vulnerability such as;

4 for the highly floodable areas

3 for the moderately floodable areas

2 for the low floodable areas.

The range numbers are designated as High, Moderate and Low on the output map depicting the level of flood vulnerability of the study area (figure 9). The study further revealed that low-lying coastal areas are in grave danger of perennial flooding due to its hydro-climatic as well as topographic configurations and human interference. Figure 8 below shows that the population with high risk of exposure to flooding is more than half of the total population within the basin. Proximity to river channels is an important variable in this study. Distance from rivers and their tributaries were reckoned at 0.5km 1km and 1.5km with areas within 0.5km of river channels were categorised as high risk areas; areas within 1km as moderate and areas located at 1.5km were described as low risk areas. (Figure 10)

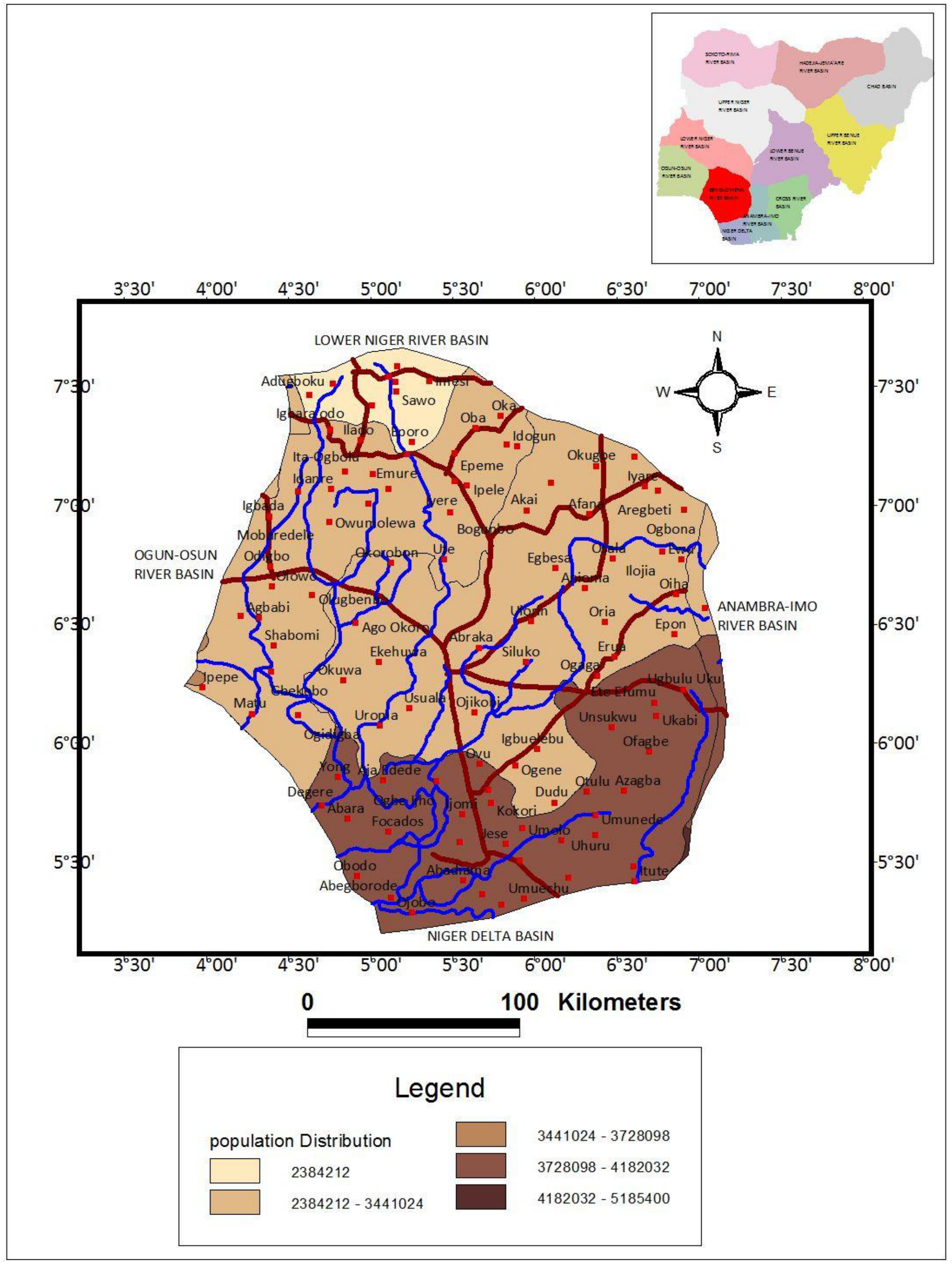


Figure 8: Population Distribution within Benin-Owena River Basin.

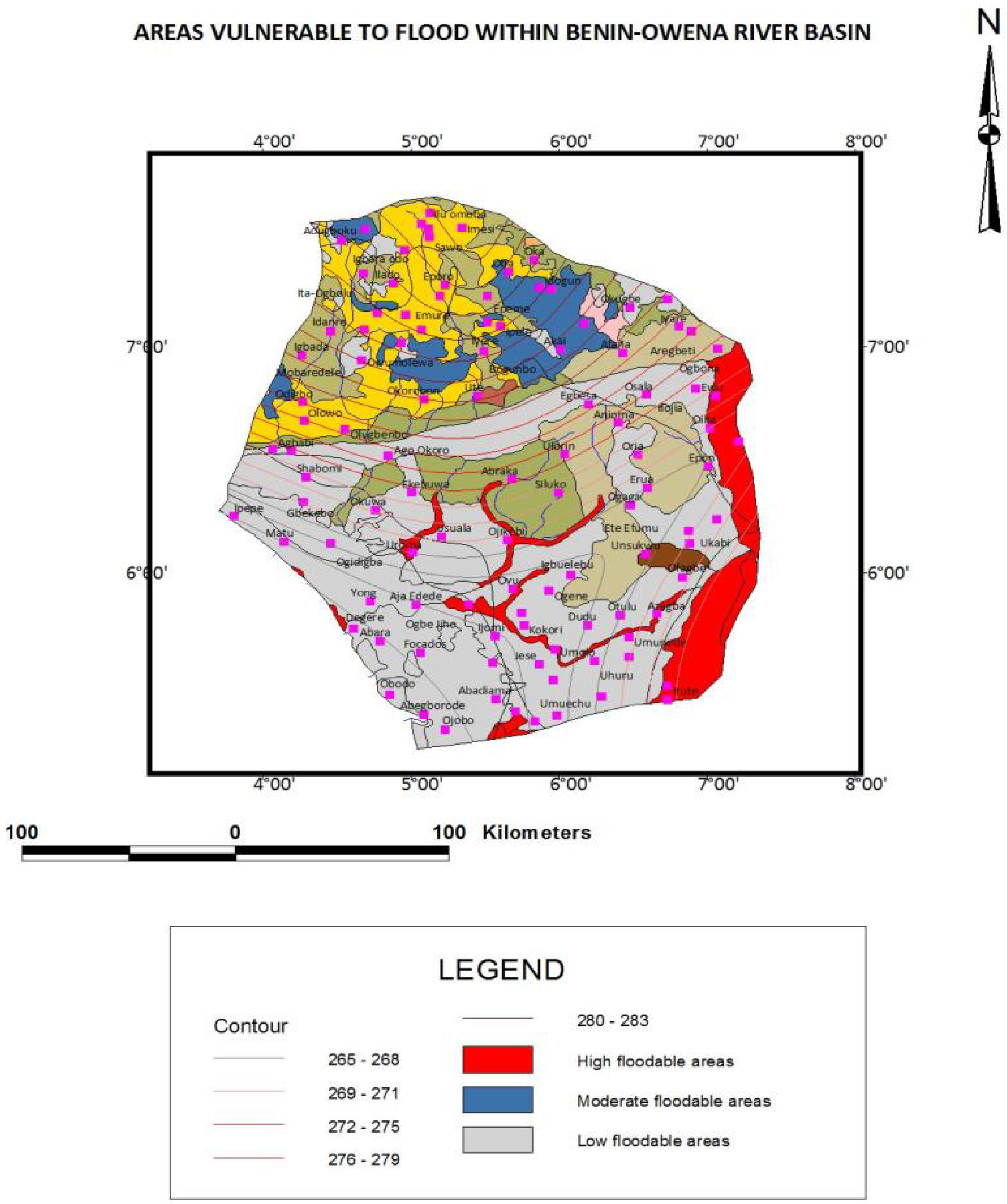


Figure 9 above shows floodable prone areas within the Benin-Owena River Basin located in the South Western part of Nigeria. According to the figure, the basin is well drained with an average surface slope between 265m to 283meters. The basin is dominated by the extensive River Niger flood plain in the east and other rivers such as the Ubo, Edion, Orle, Okhuamahun and Owena. The areas that are delineated with red colour are areas highly prone to flooding. These are areas very close to the extensive River Niger flood plain in the Eastern part of the basin. The other parts of the basin are largely areas categorised as moderate and low floodable areas.

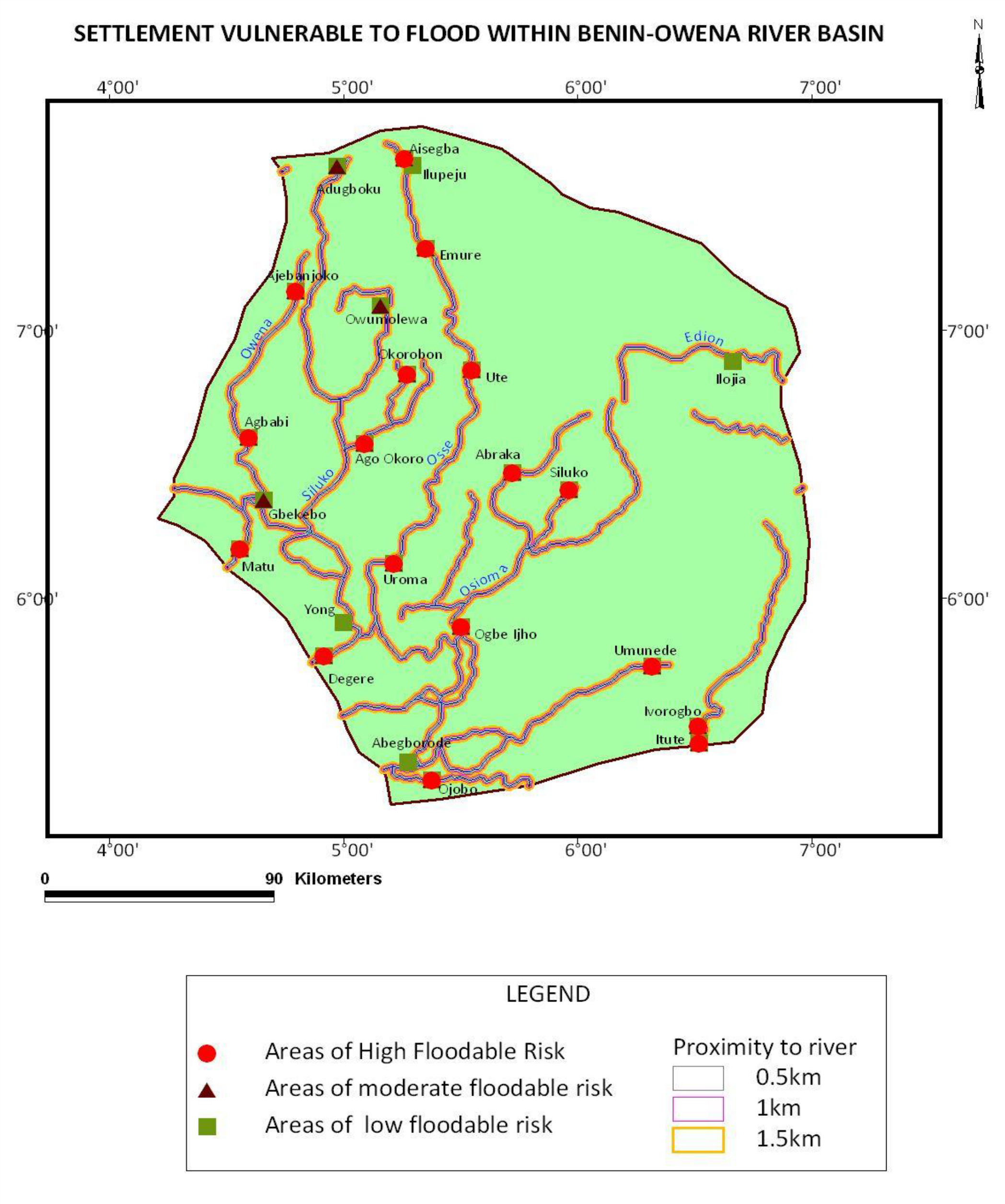


Figure 10: Proximity of Settlements within the River Basin to Drainage Channels.

3.1. The Role of Flood Risk Assessment and Management in Environmental Sustainability

Understanding the distinction between the three elements that create risk; hazard, exposure and vulnerability - gives the necessary information for factoring in most flood related aspects in the overall management of flood risks and at the same time contribute substantially to the development and wellbeing of the people. The models available for flood risk mitigation include the traditional structural measures (dyke, dams, reservoirs, relief channels, embankments) and integrated non-structural (land use planning, flood warning systems, evacuation, preparedness and insurance) options at the individual, institutional and government level (Correla*et al.*, 1998). The first component is the hazard and the structural model that targets mostly the flood hazard. The traditional structural flood risk reduction measures have been primarily on river training, construction of embankment and retention by reservoirs, aimed at reducing the flood hazard, i.e. the probability of flooding. Secondly, other models considered flood risk in a different angle by integrating exposure and vulnerability aspects of the flood risk. Since, it is recognized that structural flood control alone does not solve the flood risk and hazard problems, because flood control measures have been usually planned in isolation from other development. Therefore, they are reactive rather than proactive, by focusing on structural measures, and sought solutions from mono-disciplines (Shresha, 2012).

Gilbert White was the first to argue that flood control measures should be integrated with non-structural methods, like land use planning to produce a more comprehensive flood management (Smith, 2013). Hence, the paradigm shifts from post-disaster response and relief centric approach to pre-disaster proactive preparedness and mitigation centric approach focusing on disasters as direct concern and a common understanding of the concept of vulnerability as important for developing a central notion.

However, an environmental sustainability and efficiency require a shift from the traditional structural flood defense to a more comprehensive Flood Risk Assessment and Management approach that include prevention, protection, preparedness, response and recovery. The most efficient and sustainable reduction of flood risks could be achieved by reducing the potential damage (vulnerability) in flood-prone areas through adapted land use and spatial planning. The third perspective argued that flood hazards tend to be better understood by the local people involves, because their proximity to the waterways acts as constant reminders of the risks to which they are exposed to. Hence, their willingness to participate in the flood management planning is essential (Correla*et al.*, 1998).

Whether responses to flood hazard take a structural, non-structural or mixed measure, there remains a need for a mechanism for public involvement in decision making for flood risk sustainability. This is because measures to mitigate flood hazard may include what can be done to reduce vulnerability and this can be done through increasing the resilience and coping capacity of communities affected by the flood. Sustainable flood risk management approach integrates water resource management, land-use management, and hazard management and changes the flood mitigation and control paradigm from defensive to pro-active, from ad-hoc to integrated flood management and focuses on managing and living with floods, balancing floods for sustainable development, and approaching the decision-making process differently by learning to manage risk and live with the floods. This is because urban flood is inevitable in as much as urban development continued plus the increasing flood hazard globally (SOURCE).

4.0. Conclusion and Recommendation

This study has attempted an assessment of flood risk in Benin-Owena River Basin. It also demonstrated the potential of GIS in environmental decision-making and then outlined the evaluation approach for many criteria in decision process. The design of multi- criteria environment attempted to use a variety of evaluation techniques to data from GIS and presented them in a manner familiar to decision makers. It is therefore, imperative that policies aimed at mitigating the effect of flooding on the environment be strictly implemented in order to forestal its menace.

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