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Application of gis and analytical hierarchy process for flood vulnerability assessment in Adamawa Catchment, Nigeria

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ABSTRACT

This study applies Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) to assess flood vulnerability in the Adamawa Catchment of Nigeria. Seven criteria (drainage, rainfall distribution, geology, land cover, elevation, slope, and soil) were analysed, and a pairwise comparison matrix was constructed. The analysis resulted in a flood vulnerability map depicting different levels of vulnerability. The reliability of the approach and results were validated with a Consistency Ratio of 0.0944 and found to be within the acceptable value for reasonable consistency. The methodology used therefore disclosed the areas vulnerable to flooding in the Adamawa catchment. The analysis revealed the following levels of vulnerability - low vulnerability (19.9%), moderate vulnerability (31.4%), high vulnerability (31.8%), and very high vulnerability (16.9%) respectively. The main river and tributaries are pinpointed as areas highly vulnerable to floods and therefore, might be significant contributors to flooding events in the catchment.

1. Introduction

In recent years, the frequency and severity of large-scale flood catastrophes have grown internationally, resulting in deaths, property devastation, and massive economic losses. Similarly, hydrological and meteorological calamities such as floods, droughts, and weather storms have been prevalent across the planet. Despite the availability of sophisticated technological skills for coping with floods in industrialized countries, flood catastrophes are becoming increasingly common and devastating. The United Nations International Strategy for Disaster Reduction describes flooding as a threat to sustainable development and poverty-reduction initiatives (UN-ISDR, 2009).

Flooding claims more lives and causes damage to property and infrastructure than any other natural phenomena (Dilley et al., 2005; Nwilo et al. 2012; Olayinka et al. 2012). In a period of 6 years (1989–1994), 80% of declared Federal disasters in the United States (US) were related to flooding and averaged four billion dollars annually in property damage alone (Wadsworth, 1999).

Many scholars have given a variety of definitions for vulnerability in various contexts. According to the UK Department for International Development (DFID), vulnerability is defined as the interrelationship between a system's exposure, susceptibility, and coping capability (White et al., 2005; Roy and Blaschke, 2015). Likewise, several authors have assessed flood vulnerability using different methods. Nwilo et al. (2012) adopted Remote Sensing and Cellular Automaton Evolutionary Slope and River (CAESAR) model to determine inundation levels and assess vulnerability of settlements in Adamawa State. Roy and Blaschke (2015) used an Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) weighted overlay to build a grid-based technique for assessing the vulnerability of floods in Bangladesh's coastal areas.

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Several researchers or organizations employ the AHP or similar techniques in their investigations. For example, Feizizadeh and Blaschke (2011) employed AHP to create weights for a GIS weighted overlay landslide susceptibility mapping. In a comparison of AHP, weighted linear combination (WLC), and ordered weighted average (OWA), Feizizadeh and Blaschke (2013) discovered that AHP was an effective method for evaluating the consistency of the assessment measures and alternatives proposed by decision makers. They found that the AHP technique effectively reduced the judgment problem's complexity to a series of pairwise comparisons that could be synthesized in a ratio matrix.

Flood problems along the Benue River in Adamawa State of Nigeria have affected more communities in recent times. There is increasing vulnerability of populations and infrastructure to flooding and flood related hazards. Although studies have demonstrated the impacts of flooding in the region, little attention has been paid to the physical factors that contribute to vulnerability to flooding particularly in Adamawa catchment. The present paper therefore presents a set of criteria for estimating flood vulnerability. Based on these criteria, we then describe the preparation of thematic layers and construction of the final flood vulnerability map for Adamawa catchment using GIS techniques and AHP.

1.1. Study area

Adamawa catchment in Nigeria is located along River Benue in the Upper Benue drainage basin. The major river in the catchment area is River Benue. River Benue is an international river entering into Nigeria across the border with Cameroon, and runs for a distance of about 900 km from the border to the confluence with the Niger River at Lokoja. The Sub-catchment border is approximately defined by longitudes 11°46'E and 14°14'E, and latitudes 8° 37'N and 9°41'N as shown in Figure 1.

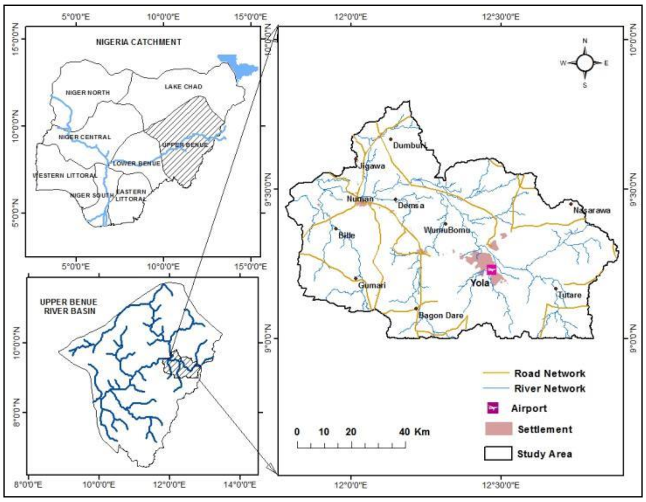

Figure 1. Study area location

2. Methods

Criteria such as drainage density, rainfall distribution, geology, land cover, elevation, slope and soil were reviewed and utilized to investigate flood vulnerability in this study. An empirical approach through the integration of multi-criteria AHP and GIS techniques was adopted for the analysis. AHP is a multi-criteria decision method that uses hierarchical structures to represent problems. Priorities for alternatives are then developed based on the judgment of the user. The following steps were taken based on the works of Saaty (1980) and Lee et al. (2008) to achieve the objectives of the study.

Step 1: Criteria selection
Step 2: Development of the pairwise comparison matrix
Step 3: Computation of the criterion weights
Step 4: Consistency check
Step 5: Generation of thematic layers

Each of the layers were reclassified into four classes and overlaid by computing their various weighted values from AHP techniques using Weighted Sum Analysis in ArcGIS environment to construct the final flood vulnerability map as provided in Eq. (1).

$$\text{Flood Vulnerability Zone Map (FVZM)} = \sum_{i=1}^{n} W_i X_j \quad (1)$$

where, W_i = % weight for each thematic map and X_i = reclassified map

The map produced was categorized into four levels of low, moderate, high and very high vulnerability.

3. Results

A pairwise comparison matrix was constructed as shown in Table 1. The fraction values were further reduced to decimal values and the sum of each column was calculated and then the matrix was normalized as depicted in Table 2. The weights were calculated by averaging the entire elements along the row and the percentage weight was computed. These calculated weights (Table 3) were used in GIS software for weighted sum analysis of the flood factors to produce a flood vulnerability map (Figure 2). Coherence values in Table 3 were obtained by multiplying the total values of pairwise comparison matrix (sum of each column) obtained by criteria weight which gives λmax = Eigen value (7.748). Since, n = total number of factors is 7, to validate the reliability of the approach and results, a Consistency Ratio of 0.0944 was determined from the judgment process. The Consistency Ratio 0.0944 < 0.10, shows that the pairwise matrix is reasonably consistent.

Table 1. The pairwise comparison matrix

Factors	LC	E	R	G	So	DD	Sl
LC	1	1/4	1/7	1/3	1/5	1/9	1/4
E	4	1	1/3	3	3	1/3	1/2
R	7	3	1	3	5	1/2	3
G	3	1/3	1/3	1	3	1/3	1/3
So	5	1/3	1/5	1/3	1	1/5	1/3
DD	9	3	2	3	5	1	5
Sl	4	2	1/3	3	3	1/5	1

LC – Land Cover, E – Elevation, R – Rainfall, G – Geology, So – Soil, DD – Drainage Density, Sl – Slope

Table 2. Normalized pairwise comparison matrix

Factors	LC	E	R	G	So	DD	Sl
LC	0.030	0.025	0.033	0.024	0.010	0.041	0.024
E	0.121	0.101	0.077	0.220	0.149	0.124	0.048
R	0.212	0.303	0.230	0.220	0.248	0.187	0.288
G	0.091	0.034	0.077	0.073	0.149	0.124	0.032
So	0.152	0.034	0.046	0.024	0.050	0.075	0.032
DD	0.273	0.303	0.461	0.220	0.248	0.373	0.480
Sl	0.121	0.202	0.077	0.220	0.149	0.075	0.096
Total	1	1	1	1	1	1	1

LC – Land Cover, E – Elevation, R –

UN-International Strategy for Disaster Reduction (ISDR) Scientific and Technical Committee.

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