MULTICRITERIA ANALYSIS FOR FLOOD VULNERABLE AREAS IN HADEJIA-JAMA’ARE RIVER BASIN, NIGERIA

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ABSTRACT

Flood disaster is considered as a major natural hazard due to its devastating effects on the affected area. Multicriteria Evaluation (MCE) methods are used to analyze the flood vulnerable areas. Geographical Information System (GIS) is integrated with Multicriteria Decision Analysis (MCDA). The aim is to provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors. Some of the causative factors for flooding in watershed are taken into account as annual rainfall, basin slope, drainage network, land cover and the type of soil. In this study two main MCE approaches employed in GIS are used, namely Boolean and Weighted Linear Combination (WLC). In MCE, two methods, pairwise comparison method (Analytical Hierarchy Process-AHP) and Ranking Method are used to calculate the weights of each factor. Using AHP the weightage derived for the factors were, Rainfall 33.9%, Drainage network 25.5%, Slope of the river basin 19.7%, Soil type 15.2% and Land cover 5.7%. A case study of flood vulnerable areas determination in Hadejia Jama’are River Basin, Nigeria is employed to illustrate the different approaches. At the end of the study a Map of flood vulnerable areas in the river basin was generated with a view to assisting decision makers on the menace posed by the disaster.

KEY WORDS: Geographic Information System, Multi Criteria Decision Making, Analytical Hierarchy Process, Pairwise Comparison, Consistency Ratio.

INTRODUCTION

Decision analysis looks at the paradigm in which an individual decision maker (or decision group) contemplates a choice of action in an uncertain environment. The theory of decision analysis is designed to help the individual make a choice among a set of pre-specified alternatives. The decision making process relies on information about the alternatives. The quality of information in any decision situation can run the whole gamut from scientifically-derived hard data to subjective interpretations, from certainty about decision outcomes (deterministic information) to uncertain outcomes represented by probabilities and fuzzy numbers. This diversity in type and quality of information about a decision problem calls for methods and techniques that can assist in information processing. Ultimately, these methods and techniques may lead to better decisions.

Our values, beliefs and perceptions are the force behind almost any decision-making activity. They are responsible for the perceived discrepancy between the present and a desirable state. Values are articulated in a goal, which is often the first step in a formal (supported by decision-making techniques) decision process. This goal may be put forth by an individual (decision-maker) or by a group of people. The actual decision boils down to selecting "a good choice" from a number of available choices. Each choice represents a decision alternative. In the multicriteria decision-making (MCDM) context, the selection is facilitated by evaluating each choice on the set of criteria. The criteria must be measurable - even if the measurement is performed only at the nominal scale (yes/no; present/absent) and their outcomes must be measured for every decision alternative. Criterion outcomes provide the basis for comparison of choices and consequently facilitate the selection of one, satisfactory choice.

Many nations experience fatalities and injuries, property damage, economic and social disruption resulting from natural disasters. Natural disasters, such as earthquakes, hurricanes, flash floods, volcanic eruptions, and landslides have always constituted a major problem in many developing and developed countries. The natural hazards kill thousands of people and destroy billions of dollars worth habitat and property each year. The rapid growth of the world’s population has escalated both the frequency and severity of the natural disasters. Flood disaster has a very
special place in natural hazards. Floods are the costliest natural hazard in the world and account for 31 per cent of economic losses resulting from natural catastrophes. Especially, river flooding has been a major natural hazard worldwide in recent events, e.g., Cleveland in 2006, Bolivia in January 2007, Namibia in February 2007, Australia in March 2007, million of people were affected in socio-economic life, thousands of people died and it caused the physical loss of over 20 billion USA Dollars.( United Nations and European Commission Report 2007.Determining the flood vulnerable areas is important for decision makers for planning and management activities.

Multi-criteria evaluation (MCE) methods have been applied in several studies since 80 per cent of data used by decision makers is related geographically (Małczewski, 1999), Geographical Information System (GIS) may provide more and better information about decision making situations. GIS allows the decision maker to identify a list meeting a predefined set of criteria with the overlay process (Heywood et al., 1993) and the multi criteria decision analysis within GIS may be used to develop and evaluate alternative plans that may facilitate compromise among interested parties (Małczewski, 1996).

Multi criteria Evaluation (MCE) method was used to analyze and find the flood vulnerable areas in west of black sea of northern Turkey (Yalcin, G. 2002). In this study GIS was integrated with MCE. This study used seven spatial criteria each was presented and stored in layer by using Arc View 8.2 and the criterion values are generated. The criterion maps are converted into grids and the mathematical processes are applied to the criteria with Map Calculator. Ranking Method was used to rank every criterion under consideration in the order of the decision maker’s preference and Pairwise Comparison Method (PCM) which is designed as a user interface to calculate the weights from input preferences with Visual Basic Application (VBA) program embedded in ArcGIS 9.1 are used.

At the end of the application, composite maps were created using Boolean Approach, Ranking Method, and Pairwise Method. There are three different results depending on the method that was been used. The difference between the three methods was analyzed; this study also did sensitivity analysis. The purpose of it is to examine how sensitive the choices are to the changes in criteria weights. This is useful in situations such as where uncertainties exist in the definition of the importance of different factors.

Another study in Singapore presented a GIS-based multi-criteria analysis approach to assess accessibility for housing development. It applied the multi criteria analysis framework to incorporate buyers’ opinions into accessibility assessment with GIS to determine the overall attractiveness of an area for housing development from a demand-side perspective. In the past, accessibility analysis for housing development focused on the supply-side perspective. The approach proposed here allows planners and housing developers to examine accessibility requirements from a demand-side perspective so that demand and supply issues can be better managed (Zhu, X etal 2005).

Lin et al., 1997 presented GIS-based multi criteria evaluation for investment environment to provide investors and local government decision makers with more specific information on investment location. The aim of this study was to explain how to develop an analysis environment to support various investment researches and investors.

Antoni et al. (1997) presented an example application on integration of multi criteria evaluation technique with GIS for sustainable land use in Kenya; maximizing revenues from crop and livestock production, maximizing food output, maximizing district self-reliance in agricultural production, minimizing environmental damages from erosion.

Other studies used multi criteria analysis to find the best location for the purpose of planning such as the best places to build hospitals (Małczewski and OGLECzyak 1990, Małczewski 1991), a solid waste transfer station (Gil and Kellerman 1993), or more generally, any type of public facility (Joerin 1995, Yeh and Hong 1996).

Another study was performed with spatial multi-criteria analysis in order to rank and display marketability of thirty-two pay pond businesses in West Virginia (Aurora, 2003).

The objective of this study is to determine flood vulnerable areas in Hadejia-Jama’are River Basin, Nigeria using Spatial Multicriteria Evaluation technique, Pairwise Comparison (Analytical Hierarchy Process-AHP) and Ranking Method.

**METHODOLOGY**

Basically two phases are applied in this study to analyze the flood vulnerability structure: to determine effective factors causing flood and to apply several approaches to Multicriteria Evaluation (MCE) in a GIS environment to evaluate in finding the flood vulnerable areas. To evaluate the flood vulnerable areas, two approaches were used: Boolean overlay Approach, and Weighted Linear Combination (WLC) Approach. While Boolean Overlay is used for Boolean Approach, in WLC approach two methods are used: Ranking and pairwise Comparison Method.

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This study provides useful way to examine alternatives and evaluate criteria to reduce uncertainty for the decision solution. Spatial Multicriteria Decision Making Methods (MCDM) aims to achieve solutions for spatial decision problems, derived from multiple criteria. These criteria, also called attribute must be identified carefully to arrive at the objectives and final goal. The performance of an objective is measured with the help of these attributes.

**Data Base Development**

A GIS application is used for managing, producing, analyzing and combining spatial data. The data needed in this study are produced from collected or existing data by using different kinds of spatial functions and analysis. The data required for this study was acquired from United Nations Food and Agricultural Organization-FAO Country Profile and Mapping System, Federal Ministry of Agriculture, Nigeria, and Hadejia-Jama’are River Basin Development Authority, Nigeria.

**Selection and Evaluation of Criteria**

The selection of criteria that has spatial reference is an important step in multicriteria decision analysis (Malezewski, J., 1996). The criteria used in this study were selected due to their relevance in the study area, these are listed below:
- Rainfall (Precipitation).
- Drainage network of the river basin.
- Slope of the basin.
- Soil type.
- Land Cover.

**Conversion to GIS Environment**

There are several stages to prepare this data for GIS environment. Arc View 3 V3.2 with ArcGIS V9.1 was used as professional GIS packages, for the purpose of manipulating and processing data within a GIS environment. Matlab was also used in the calculations of the matrix for Pairwise comparison technique (Analytic Hierarchy Process).

**Creation of Data Layer and Attributes**

All the spatial data created in different layer are converted into compatible GIS format, and then the attributes tables created for each particular layer by using ARCGIS

**Multi Criteria Analysis**

Multi criteria analysis is applied in producing and combining spatial data describing the causing factors. In the first part, the vulnerable areas are produced by numerically overlaying a map layer describing the study area. This overlay is carried out as a Boolean overlay. All criteria are combined by logical operators such as intersection (AND) and union (OR).

In the second part ranking method is used. In Ranking Method, every criterion under consideration is ranked in the order of the decision maker’s preference. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance for causing flooding. The inverse ranking was applied to these factors. 1 is the least important and 8 is the most important factor.

In the third part Pairwise Comparison Method is used in determining the weights for the criteria. This method involves the comparison of the criteria and allows the comparison of two criteria at a time. This method can convert subjective assessments of relative importance into a linear set of weights. It was developed by Saaty (1980) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) The criterion pairwise comparison matrix takes the pairwise comparisons as an input and produces the relative weights as output, and the AHP provides a mathematical method of translating this matrix into a vector of relative weights for the criteria.

**Sensitivity Analysis**

The main purpose in sensitivity analysis is to examine how sensitive the choices are to the changes in criteria weights. This is useful in situations such as where uncertainties exist in the definition of the importance of different factors.
Study Area

The Hadejia-Jama'are River Basin lies in the northeastern corner of Nigeria (lat 12° 26’ N and long 10° 04’), within Kano, Jigawa, Bauchi, Yobe and Borno States (Figure 1). At Gashua the area is drained by the Hadejia and Jama'are rivers, the principal rivers of the basin, is 61,120 km². These rivers merge to form the Yobe which flows on to reach Lake Chad at Yau draining a total area of 84,138 km². The basin is known for source of irrigation farming, dams, fishing, transportation, etc but persistent incidence of flood has mitigated the effective utilization of this basin by the populace of this region which has resulted in under utilization of these resources. Nigeria the biggest country in Africa continent is faced with this menace and requires immediate attention by policy makers and the affected communities.

![Figure 1. The Hadejia-Jama'are River Basin.](image)

DATA ANALYSIS, RESULTS AND DISCUSSION

Pairwise Comparison Method

Using the above method the weight of the below criteria can be calculated:

- C1= Rainfall (Precipitation).
- C2= Drainage network of the river basin.
- C3= Slope of the basin
- C4= Soil type.
- C5= Land cover

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Table 1. Square pairwise comparison matrix of the criteria above.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Priority vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0.339</td>
</tr>
<tr>
<td>C2</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0.255</td>
</tr>
<tr>
<td>C3</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>0.197</td>
</tr>
<tr>
<td>C4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>4</td>
<td>0.152</td>
</tr>
<tr>
<td>C5</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>1</td>
<td>0.0574</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2.75</td>
<td>4.25</td>
<td>5.75</td>
<td>7.25</td>
<td>17</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Normalized Matrixes.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Row total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.363</td>
<td>0.471</td>
<td>0.348</td>
<td>0.276</td>
<td>0.235</td>
<td>1.694/5= 0.339</td>
</tr>
<tr>
<td>C2</td>
<td>0.182</td>
<td>0.235</td>
<td>0.348</td>
<td>0.276</td>
<td>0.235</td>
<td>1.276/5= 0.255</td>
</tr>
<tr>
<td>C3</td>
<td>0.182</td>
<td>0.118</td>
<td>0.174</td>
<td>0.276</td>
<td>0.235</td>
<td>0.985/5= 0.197</td>
</tr>
<tr>
<td>C4</td>
<td>0.182</td>
<td>0.118</td>
<td>0.087</td>
<td>0.138</td>
<td>0.235</td>
<td>0.760/5= 0.152</td>
</tr>
<tr>
<td>C5</td>
<td>0.091</td>
<td>0.059</td>
<td>0.043</td>
<td>0.034</td>
<td>0.060</td>
<td>0.287/5= 0.0574</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Note the column average must sum up to 1 approximately.

The row average provides an approximation of the eigenvector of the square reciprocal matrix. The eigenvector is an estimate of the relative weights of the criteria been compared.

Because individual judgment 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, a ratio over 0.1 indicates that the matrix should be revised. Revising the matrix entails, finding inconsistent judgments regarding to the importance of criteria, revising these judgments by comparing again the pairs of criteria judged inconsistently.

Calculating Consistency Ratio (CR)

\[
CR = \frac{CI}{RI}
\]

Where \( CI = \lambda_{\text{max}} \cdot \frac{n}{n-1} \)

RI=Random consistency index

N=Number of criteria.

\( \lambda_{\text{max}} \) is priority vector multiplied by each column total.

Table 3. Random Indices for matrices of various sizes.

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
<td>1.51</td>
<td>1.48</td>
<td>1.56</td>
<td>1.57</td>
<td>1.59</td>
<td></td>
</tr>
</tbody>
</table>

CR=0.0506.

The value of CR=0.0506 falls much below the threshold value of 0.1 and it indicates a high level of consistency. Hence we can accept the weights.
**Ranking Method**

In Ranking Method, every criterion under consideration is ranked in the order of the decision maker’s preference. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance for causing flood. There are two common ways of doing this; straight ranking (e.g. most important =1, second important=2) or the inverse ranking (the least important =1, next least important=2 etc.) The inverse ranking was applied to these factors.

**Table 4. Classification values of the criteria**

<table>
<thead>
<tr>
<th>Class</th>
<th>annual rainfall (mm)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>475-724</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>725-974</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>No data</td>
<td>No data</td>
</tr>
</tbody>
</table>

**Table 5. Land Cover**

<table>
<thead>
<tr>
<th>Class</th>
<th>Land cover</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Grass</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Crop</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Shrub</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Nodata</td>
<td>Nodata</td>
</tr>
</tbody>
</table>

**Table 6. Soil Type**

<table>
<thead>
<tr>
<th>Class</th>
<th>Soil Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ferruginous tropical soils</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Regosols and semi arid brown soils on loose sediments</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Semi arid brown and reddish brown soils</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Lithosols Ferruginous tropical soils.</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 7. Ranking Drainage network.**

<table>
<thead>
<tr>
<th>Class</th>
<th>Slope (km)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3-6</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>6-9</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>9-12</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>&gt;12</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table 8. Slope of the river basin.**

<table>
<thead>
<tr>
<th>Class</th>
<th>Buffer(meters)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-500</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>500-1000</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>1000-2000</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>2000-6000</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>6000 &gt;</td>
<td>2</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSIONS

The criterion maps were combined by logical operations such as intersection and union in the Boolean approach. To generate criterion values using Ranking Method for each evaluation unit, the values between 1 and 8 were given, where 8 indicates higher vulnerability and 1 indicates low vulnerability depending on the criteria’s class values.

Using PCM the criterion weights were calculated as 0.339, 0.255, 0.197, 0.152, 0.057, respectively for annual rainfall, drainage network of the river basin, basin slope, type of the soil and land cover. With the input values in pairwise comparison and weights calculated, consistency ratio (CR) was found as 0.0506. This indicated a reasonable level of consistency in the pairwise comparison of the factors. GIS should act as the interface between
technology and the decision maker with integrating MCE methods into the GIS. Different decision makers may apply different criterion and assign different weights for each criterion according to their preferences. The decision maker selects the criteria and compares them in a comparison matrix.

A composite map showing the flood vulnerable areas were created using multicriteria evaluation methods with GIS. In this application, the range numbers are designated as High, Medium, Low on the output map depicting the level of flood vulnerability of the study area, percentage of each zone to flood vulnerability was also calculated as 7.60%, 12.0%, 22.60%, 26.60% and 31.40% respectively, the first shows areas highly susceptible to flood and as it progresses the vulnerability structure decreases.

CONCLUSION AND RECOMMENDATION

Conclusion
The flood vulnerable map can give planners, insurers and emergency services a valuable tool for assessing flood risk. Each of them needs to assess risk for more than one scenario. A project including these vulnerability maps should be used on land planning and management alternatives.

The study also reviewed the role of GIS in 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 present them in a manner familiar to decision makers. By integrating the evaluation techniques with GIS, it was intended that the effective factors would be evaluated more flexibly and thus more accurate decision would be made in a shorter time by the decision makers. By evaluating the criteria, the values of the criteria were classified to explain the opinions and preferences.

Recommendation
Due to the effects of flood there is need to look for ways to mitigate it. Some arrangements must be developed and evaluated to deal with the problems, from the study the following recommendations are made to tackle the problem of flood and for further studies:

Developmental projects on flood prone areas should be critically analyzed based on the effective factor causing flood in order to mitigate the hazard.

Aforestation should be encouraged on areas liable to flood; this is a measure to reduce the risk inherent.

More studies should be undertaken to establish new techniques for evaluating the criteria.

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