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THE USE OF FUZZY SET FUNCTIONS FOR ASSESSING LAND SUITABILITY INDEX AS THE BASIS FOR ENVIRONMENTAL MANAGEMENT

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ABSTRACT

A study is conducted to evaluate the potential use of Geographical Information System (GIS) for land suitability assessment. PC-based GIS softwares are used in analysis, processing and mapping spatial data. This paper presents a spatial modeling procedure for the assessment of land suitability by using Fuzzy Set Functions in Geographical Information Systems (GIS) environment. This technique involves the creation of membership maps for every land attribute used as the basis for evaluation criteria adopted from FAO. The study shows that Fuzzy method results in a flexible land-suitability index for identifying and delineating land management units and the suitability of the unit for specific land use. Land suitability map for rice, upland annual crops and coconut derived from Fuzzy methods shows that the suitable area for rice and other annual crops with suitability index 0.5 – 1 is about 57% of the study area. The highly suitable areas for the two land use types are especially found in level to gentle slope. Suitable area for coconut covers about 68% of the study area.

Key words: GIS, Fuzzy set function, Suitability Index, Environmental management

INTRODUCTION

A proper land use decision is of a great importance to achieve optimum productivity of the land and to ensure environmental sustainability. This requires spatially accurate information of land resources and effective management of the information on which such decisions should be based. Land suitability evaluation is one of the effective tools for such purposes [1].

Land evaluation is a tool to predict land performance, both in terms of the expected benefits from and constraints to productive land use, as well as the expected environmental degradation due to these uses and can employ as a preliminary to more detailed investigations [2,3]. Therefore, for land to be suitable (for a given purpose) and for the use to be sustainable, it must address the values that are related to both aspects: degree of suitability and potential degradation (from long-term perspective) resulting from land management practices. Land suitability analysis should consider both aspects of land evaluation, and a GIS may be used to facilitate every stage of the evaluation processes [4]. The paper demonstrates the use of GIS for land evaluation processes. The main purpose is to establish indices of land suitability for cropping land use systems A fuzzy set methodology is employed in the modeling procedures where the classes do not have sharply defined boundaries [5,6].

MATERIALS AND METHOD

The area selected for the study include some watersheds in North-Eastern Laguna covering an area of approximately 90,000 Hectares, located about 60 km, to the east of Manila-the Capital of the Philippines.

In the application of fuzzy set functions, soil attributes maps are used as the basis for generating membership function of every land attributes to represent their suitability rating. Model parameters used for generating the membership function for three selected land use are based on FAO [7]. Once the model parameters have been determined, a membership function for each land attributes is generated. A joint membership function (JMF) of combined land attributes is then determined by using the minimum operation as follows [8]:

Result (JMF) = Min (MFa, MFb, MFc, ...).

where MFa, MFb, MFc are memberships function of land attributes.

Memberships functions used for fuzzy membership classification consists of two basic models: symmetric and asymmetric [9]. The symmetric models consist of two types: one using a single point as the central concept (Type 1), while the other employs a range of ideal points (Type 2). The asymmetric model uses the lower and upper boundaries of a class. This model also consists of two types: asymmetric left (Type 1) and asymmetric right (Type 2). The computation of criterion membership functions is based on the following equation:

Type 1: $MF(xi) = 1/(1 + (|xi - b|/e1)^2)$
Type 2: $MF(xi) = 1$ if $(b + e1) < xi < (c - d2)$
Type 3: $MF(xi) = 1/(1 + (|xi - b - e1|/e2)^2)$ if $xi < (b + e1)$
Type 4: $MF(xi) = 1/(1 + (|xi - c + e2|/e2)^2)$ if $xi > (c - e2)$

The choice of membership function to suit decision criterion depends on the trend of performance of a land attribute in creating a favorable condition...
for selected land use. Model parameters used include ideal point \((b \text{ and } c)\) where the MF is set to be 1, zero points \((a \text{ and } d)\), and \(e\) (width of transition zone which is a distance to cross over point-CP, the point representing situation where a land attribute examined is at the marginal level for a given purpose). Some examples for deriving model parameters are illustrated at Figure 1.

In calculation joint membership function, the land attributes are assumed to have equal weight. The idea is that these land properties represent land variables having an equal importance to each other. There is no tradeoff between the land variables. For example, very steep slope of a land area (or block) cannot be compensated for by the excellent quality of soil profile, or vice versa. Results of the minimum operation are Land Suitability Index (LSIs), expressed as continuous values ranging from 0 (very poor or fully not suitable) to 1.0 (excellent or highly suitable). These land suitability indices could then be reclassified to generate land suitability rating map based on the user-defined criteria.

### RESULT AND DISCUSSION

An example of land suitability index of the study area for annual crops resulted from Fuzzy Approach is given in Figure 1.

The figure shows that land suitability of the study area for upland annual crops is expressed as continuous values ranging from 0 (fully not suitable) to 1.0 (excellent or highly suitable). This continuous expression provides that the fuzzy approach is more flexible than the traditional approach which usually results in classes with strict border (highly suitable, moderately suitable, marginally suitable and not suitable). The flexibility presented especially in term of the decision to what level of suitability index the suitability rating should be set. As the acceptance level of the suitability index is lowered, the proportion of the total area assigned as the desired suitability class increases. This implies that, if, for example, the suitable area obtained for a given land use is limited and not sufficient to satisfy the basic minimum area then the land suitability index can be justified to increase suitable area obtained within the acceptable range. Nevertheless, it does not necessarily mean that contiguous regions of a given minimum size larger than the area sized used for mapping can be located anywhere.

Assuming that the highly suitable area in fuzzy approach corresponds to 0.8 to 1 land suitability index value, the result also shows that the suitable area obtained from Fuzzy Approach is much larger than that obtained from Traditional approach (Table 3). In Traditional approach, the intersection only accepted sites that match all the strict requirements. Many sites would be rejected in this manner, especially if there are many sites having a value of one or more attributes just lower or higher than the class boundary.

By accepting sites that are just outside the ideal strict matching, the coverage area that can be judged as highly suitable can be increased substantially without any change in the original class limits applied to the observations.

The evaluation of the result obtained by fuzzy approach is also undertaken by using cross comparison analysis. An analysis was made by establishing fuzzy membership function (MF) values of land suitability rating obtained from Traditional approach (LST), then comparing these values, based on their corresponding position to MF values of fuzzy approach outputs. Membership values of LST are generated as follows:

\[
\text{MF} = \begin{cases} 
1 & \text{if } x \leq 0.5, \\
0.5 & \text{if } 0.5 < x < 1, \\
0 & \text{if } x \geq 1, 
\end{cases}
\]

where \(x\) is the land suitability index.

There are about 500 points for this validation exercise, distributed randomly over the study area, using stratified random sampling technique. The root mean square error (RMSE) for the corresponding points is then calculated, and the results were presented in Table 4.

Based on spatial comparison analysis, it is found that the variations of land suitability index tend to increase from the area with high suitability classes to medium suitability classes. This is in accordance to land suitability classification study conducted by Burrough et al. [10], who found that the use of Traditional-based categorical system of land suitability analysis had resulted in the rejection of considerable suitable areas. As the result, the land suitability index variations of the lower class increase. The fuzzy approach used thus demonstrates its significance for fine discriminations of land quality in the area of interest. As has also been demonstrated by Burrough et al., [10], fuzzy classification approach allows a user to retrieve data and classify them as normal, but includes the advantage of user-defined criteria (with a certain tolerance level) the class limits in the form of the transition zone. Since the information is not thrown away by strict classification early in the analysis, the user can see which attributes contribute most to the final result.

It has been demonstrated that fuzzy approach used integrates various land attributes to establish land suitability index for the selected crops. The fuzzy approach utilizes membership function-fuzzy set methodology in the assessment procedures, and the results presented in a continuous pattern. Land suitability index is generated by using actually three basic land variables climate, soils and topography. The three land variables are combined by using minimum function assuming that they have equal importance to avoid tradeoffs between them.

Land suitability index produced in this study may serve as a guide to determine what areas can be opened up for agricultural land and what land use management practices is the most appropriate for the areas. It is related to the importance of assessing and identifying the spatial pattern of land suitability of the planned area for selected land use. Nevertheless, the land suitability index resulted from Fuzzy Approach does not indicate the limiting factor acting in the area for the selected crop as it is in land suitability class obtained from conventional approach.
Figure 1. Land suitability index of the study area for upland annual crops obtained from Fuzzy approach
Figure 2. Membership function of selected land properties: drainage (a), soil depth (b), soil pH (c), and slope gradient (d)

Table 3. Coverage area of land suitability rating for selected crops resulted from Boolean approach and fuzzy approach

<table>
<thead>
<tr>
<th>SUITABILITY RATING</th>
<th>Rice</th>
<th>Coconut</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traditional approach</strong></td>
<td>Hectares</td>
<td>Percent</td>
</tr>
<tr>
<td>Highly suitable</td>
<td>7751</td>
<td>8.5</td>
</tr>
<tr>
<td>Moderately suitable</td>
<td>23734</td>
<td>26.1</td>
</tr>
<tr>
<td>Marginally suitable</td>
<td>19378</td>
<td>21.3</td>
</tr>
<tr>
<td>Sub total</td>
<td>50863</td>
<td>55.9</td>
</tr>
<tr>
<td>Currently not suitable</td>
<td>16567</td>
<td>18.2</td>
</tr>
<tr>
<td>Permanently not suitable</td>
<td>21846</td>
<td>24.0</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td>38413</td>
<td>42.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Suitability index from Fuzzy approach</strong></th>
<th>Rice</th>
<th>Coconut</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 - 1.0</td>
<td>18590</td>
<td>20.5</td>
</tr>
<tr>
<td>0.8 - 0.9</td>
<td>16516</td>
<td>18.2</td>
</tr>
<tr>
<td>0.7 - 0.8</td>
<td>6053</td>
<td>6.7</td>
</tr>
<tr>
<td>0.6 - 0.7</td>
<td>5273</td>
<td>5.8</td>
</tr>
<tr>
<td>0.5 - 0.6</td>
<td>5227</td>
<td>5.8</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td>51658</td>
<td>56.8</td>
</tr>
</tbody>
</table>

Therefore, the combination of land suitability index and land suitability class may be used as a good basis for identifying and defining land management units, and serves as a spatially-based decision-making parameter in land use planning.
Table 4. Root mean square error (RMSE) values for land suitability index obtained from Fuzzy approach against land suitability from Boolean Approach

<table>
<thead>
<tr>
<th>BOOLEAN SUITABILITY CLASSES</th>
<th>NUMBER OF POINTS</th>
<th>AVERAGE LAND SUITABILITY INDEX</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>0.937</td>
<td>0.097</td>
</tr>
<tr>
<td>2</td>
<td>147</td>
<td>0.873</td>
<td>0.177</td>
</tr>
<tr>
<td>3</td>
<td>101</td>
<td>0.698</td>
<td>0.227</td>
</tr>
<tr>
<td>4</td>
<td>93</td>
<td>0.312</td>
<td>0.149</td>
</tr>
<tr>
<td>5</td>
<td>115</td>
<td>0.003</td>
<td>0.097</td>
</tr>
<tr>
<td>Overall</td>
<td>496</td>
<td>0.536</td>
<td>0.164</td>
</tr>
<tr>
<td>Annual Crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>56</td>
<td>0.911</td>
<td>0.228</td>
</tr>
<tr>
<td>3</td>
<td>209</td>
<td>0.724</td>
<td>0.259</td>
</tr>
<tr>
<td>4</td>
<td>115</td>
<td>0.354</td>
<td>0.243</td>
</tr>
<tr>
<td>5</td>
<td>117</td>
<td>0.003</td>
<td>0.098</td>
</tr>
<tr>
<td>Overall</td>
<td>497</td>
<td>0.488</td>
<td>0.224</td>
</tr>
<tr>
<td>Coconut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>0.948</td>
<td>0.104</td>
</tr>
<tr>
<td>2</td>
<td>79</td>
<td>0.909</td>
<td>0.212</td>
</tr>
<tr>
<td>3</td>
<td>221</td>
<td>0.756</td>
<td>0.280</td>
</tr>
<tr>
<td>4</td>
<td>114</td>
<td>0.304</td>
<td>0.137</td>
</tr>
<tr>
<td>5</td>
<td>48</td>
<td>0.021</td>
<td>0.107</td>
</tr>
<tr>
<td>Overall</td>
<td>502</td>
<td>0.622</td>
<td>0.219</td>
</tr>
</tbody>
</table>

CONCLUSION

1. The use of fuzzy approach in land suitability assessment provides more flexibility to identify the suitable area for certain crop, depending on the suitability index value preferred by the user defined as suitable. The method developed shows the significance of the fuzzy approach for refining available land suitability evaluation systems. Land suitability map for rice, upland annual crops and coconut derived from Fuzzy method shows that suitable area for rice with suitability index 0.5 - 1 is about 57 percent of the study area. Suitable area for upland annual crops covers about 56 percent. The suitable areas for the two land use types are especially found in level to gently slope. Suitable area for coconut covers about 68 percent of the study area. The dominant limiting factors are slope steepness, erosion hazard and soil pH.

2. The study confirms the capability of remote sensing and GIS to integrate spatial and attribute data and offers a quick and reliable method of natural resources appraisal. The spatial relationship between different geographically referenced data can be established by using GIS. In the study, RS has been used to derive land use map and GIS has been used for digitization of base map, digitization and delineation of land resource boundary and also for generation of soil erosion and land suitability map. The result presented shows the potentialities and constraints of the area with regard to its land resources and will be a useful tool for any planning in the study area.

REFERENCES