Integration of GIS and multi-criteria evaluation for cropland allocation in the Tam Dao National Park region, Vietnam

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Abstract: Identifying areas suitable for cropland is essential for preventing deforestation and allocating the land to the appropriate uses that provide greatest benefits for biodiversity conservation. Using the TDNP region as an example, this paper aims to delineate the areas suitable for cropland using a GIS-based multi-criteria evaluation of biophysical factors and Landsat ETM^+ imagery. The result indicates the existing cropland is 46.5% of the study area, while most and moderately suitable areas are estimated to be 52.06% of the study area. The suitability map can be used to identify priority areas for crop farming and other sustainable land uses for the region with the aim of better matching land management with their suitability.

Keywords: land suitability analysis; multi-criteria evaluation; fuzzy set; Vietnam

1. Introduction

Protected areas (PAs) have become an adopted way of conserving biodiversity for a wide range of human values. In Vietnam, PAs are strongly affected by nearby rural communities because the people's livelihoods often heavily depend on forest resources from PAs. To control agricultural expansion into PAs and ensure sustainable uses of land in the buffer zones, there is a great need to locate agricultural activities to suitable locations to avoid ecological consequences. PA managers are often requested to identify suitable areas for cropland in the buffer zone. One way to achieve this identification is to employ a land suitability assessment (LSA) tool. This study aims to delineate the areas suitable for cropland through a GIS-based MCE approach for the Tam Dao National Park (TDNP) region, located in the northern part of Vietnam. We selected the TDNP region as a case study because it is one of the most important protected areas of Vietnam. It contains a rich biodiversity, but several species are known to be threatened by habitat destruction caused by agricultural expansion (Khang at al., 2007).

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2. Method

2.1 Input data

The data of topography, soil, water and distances to road and the park were used for delineating areas suitable for cropland. Landsat ETM^+ satellite images were used to derive the current land use map to analyze spatial matching between the current land uses and suitability patterns. Once the databases were collected, thematic maps were developed for each factor. A digital elevation model (DEM) was constructed using a contour map with a scale of 1:50,000 and an interval of 20 meters. The slope factor was derived from the DEM. Soil organic matter, soil depth, soil pH and soil texture factor maps were extracted from the digitized soil map with a scale of 1:100,000. The distances to water, road and the park boundary were generated from the water, road network and park boundary maps, respectively. The resolution of all raster factor maps was set

at 30 m × 30 m. The Landsat images acquired in 2007 were used to derive the recent land-use map. Six bands (bands 1–5 and 7) were processed to derive the land-use map.

2.2 Multi-criteria evaluation

The GIS-MCE procedure in IDRISI Taiga (Eastman, 2009) was used for the cropland suitability assessment in the TDNP region. Initially, the factors were selected by the TDNP experts. The factors were selected based on their relevance to the suitability of cropland, and the availability of the spatial databases. After discussion with the experts during the field survey period, nine factors (slope, elevation, distance to water, soil organic matter, soil depth, soil pH, soil texture, distance to road, and distance to the TDNP boundary) were identified to be most relevant for the suitability assessment of crop growing areas in the region.

As the factor maps were measured in different original scales, these maps have to be standardized. The standardization transforms the disparate measurement units of the factor maps into comparable suitability values (Eastman, 2009). The fuzzy membership function was applied to standardize the factors. The suitability involves many factors, and each should be weighed according to its relative importance for the growth conditions of crops. The weight of each factor was estimated from a pairwise comparison matrix constructed according to a pairwise comparison method (Saaty, 1990). Finally, all of the factors and their weights were combined as $Grid_{result} = \Sigma (Grid_i \times Weight_i)$ to obtain an overall suitability map for the cropland. $Grid_i$ is the factor i, and $Weight_i$ is the relative weight of factor i.

3. Results

The weights of slope, elevation, distance to water, soil organic matter, soil depth, soil pH, soil texture, distance to road, and distance to the park were estimated to be 0.095, 0.095, 0.143, 0.214, 0.125, 0.076, 0.11, 0.085, and 0.057, respectively. The consistency ratios (CRs) of 0.000 to 0.087 were within the acceptable cut-off level (Saaty, 1990). Then, the standardized factor maps and their weights were combined to produce the suitability map for the cropland in the TDNP region (Figure 1).

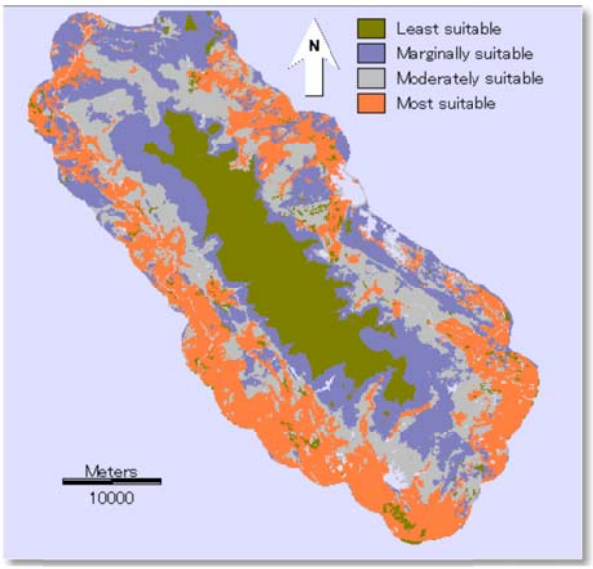

Figure 1: Suitability map for cropland

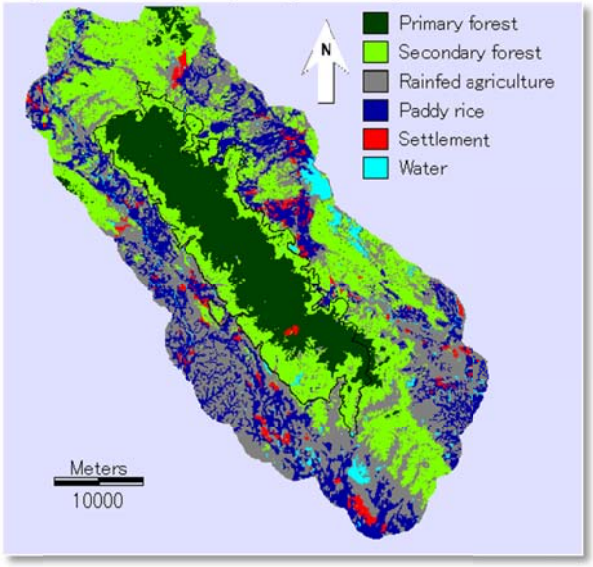

Figure 2: Land use map of 2007

Table 1: Area of the cropland suitability classes

Suitability class	Area (ha)	Proportion (%)
Least suitable	27,069	19.17
Marginally suitable	40,639	28.77
Moderately suitable	33,846	23.96
Most suitable	39,683	28.10
Total	141,237	100.00

Table 1 indicates that 28.10% of the total study area was found to be the most suitable class. The moderately suitable class was found to be 23.96% of the study area. Both the most and moderately suitable classes were 52.06% of the territory, whereas existing cropland is 46.5 % of the area.

To examine whether the land is optimally used in the region, the suitability map (Figure 1) and the land use map of 2007 (Figure 2) was overlaid. As expected, the most suitable and moderately suitable areas were found in the existing rain-fed agriculture and paddy fields. 95.22% of the most suitable class was distributed over the rain-fed agriculture and the paddy rice. 83.01% of the moderately suitable class was found in the rain-fed agriculture and the secondary forest, whereas only 15.94% of the class was located in the paddy rice. For the marginally suitable class, 71.37% of the class was found in the secondary forest. Finally, the majority of primary forest has the least suitable level for cropping.

4. Discussion

The overlaying result indicates that farming activity may extend into primary forest and secondary forest area. To prevent this process, priority areas for farming and other land uses need to be addressed to enhance ecosystem services provision (ESP). The TDNP region ecosystem, if properly managed, yields a variety of ecosystem services (ES). The potential to provide such services depends on the spatial patterns of land uses within the area. The land-use option for the region should consider the ESP as an overall outcome.

Based on the suitability map, the planning scenario of future land use patterns for the region was delineated according to the varying degrees of suitability. The scenario consists of primary forest (35,000 ha), secondary forest (28,636 ha), agro-forestry (32,050 ha), intensive cropland (38,648 ha), rural settlement (3,837 ha) and water (3,066 ha). An increase in primary forest, secondary forest and agro-forestry systems arguably enhance ESP for region. In particular, primary forest provides the greatest value of ecosystem services. To test this, the method for estimating ESP developed by Constanza et al. (1997) was applied. Briefly, the method estimates the ESP in monetary unit for different land uses. As expected, the ESP of land use map of 2007 is estimated to be 235 US$ million, while the planning scenario is estimated to be 266 US$ million.

To ensure the implementation of the recommended scenario, policy instruments are needed for the protection of the primary forest and the restoration of the secondary forest and the development of the agro-forestry systems across the region. A variety of policy tools can be employed. These tools may include regulations, market based mechanism for ESs, voluntary approaches, and education and information. The approaches are not mutually exclusive, but all depend on some extent of education and information provision. The use of the approaches is changing from regulation to economic instruments. The different instruments should be combined to achieve

conservation objectives in the context of protected areas in developing countries.

The restrictive management practices are the earliest approach for the protection of native forest ecosystems. It proved to be efficient in the conservation of biodiversity in many countries. However, they should be not seen as the only means for future biodiversity conservation (Goldman and Tallis, 2009). This approach was applied for the management of the primary forest for the TDNP, but it failed to prevent further deforestation. This failure is caused by weak management and enforcement at the local level. In particular, poor communities nearby protected area depend on forests for their livelihoods; therefore, farmers should be paid to change their practices that are thought to improve conservation values.

The development of markets for ESs can supplement another approach for sustainable uses of the land. This mechanism can share the financial burden of conservation costs for the management of protected areas. It is true that a protected area is designed for the protection of biodiversity, but it also provides a variety of ESs coincidentally. Therefore, the development of markets for ESs can generate money for conservation efforts and development success. By this mechanism, farmers or rural communities are played as ES providers/sellers, while private enterprises, state agencies or individual citizens (stakeholders) play as potential buyers.

The market-based mechanism should apply for the TDNP region because there is the potential for the small landholders to get benefits from the protection of existing forests and the development of agro-forestry systems. By the use of this mechanism, the stakeholders can play as buyers to pay sustainable practices for the region. The local farmers play as ES providers. Specifically, some ESs can be easily identified for the development of the ES market. Genetic resources, carbon sequestration, water supply, soil retention, recreational values are the most important services that can be quantified in protected areas. If mechanisms for ES markets are institutionalized at national levels, financial resources can be strategically channeled to rural communities nearby protected areas.

Government agencies should play as key buyers for the above mentioned ESs in the stage of the development or the restoration of forests and agro-forestry systems. As agro-forestry systems are widely established, other stakeholders should be forced to be buyers for ESs in the region.

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