Land Suitability Evaluator: a computerized framework for multi-criteria based land evaluation guiding sustainable land use planning

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ABSTRACT

Making decisions on agricultural land use timely, objectively, accurately has still been one of challenges to many countries. This paper introduces supporting software for land suitability evaluation that resolves these challenges. A software package was developed and applied in Vietnam, and can be used internationally. Five steps adapted from the GIS multi-criteria analysis land suitability assessment procedure: (1) defining criteria and data, (2) calculating the standardized data, (3) weighting selected criteria, (4) classifying the partial performance indices, (5) evaluating land suitability were programed. Besides the support tools as conversion, building data two special tools that were developed are the sensitive analysis and validation. The tools support well for determining the criteria importance and enhancing the results' objectivity and accuracy. The software was applied successfully to assess the suitability of land for rubber plantations in Quang Tri and brought promising results. There are two main limitations which are fixation of seven criteria groups and no an integrated module for calculating soil erosion.

1. INTRODUCTION

In order to evaluate land suitability, some software packages for land suitability evaluation (LSE) are being applied. Up to now there are some developed software packages for agricultural land suitability evaluation as the land evaluation computer system based upon the FAO framework (LECS), the automated land evaluation system (ALES), the MicroLEIS DSS, the Intelligent System for Land Evaluation (ISLE), the integrated expert system with multimedia (LIMEX), Land evaluation using an Intelligent Geographical Information System (LEIGIS), the land evaluation model based on FAO's framework (Elsheikh et al., 2013).

These packages follow either of two strategies to provide the evaluation units that constitute the spatial bases for making decision. Packages adopting the first strategy build on the vector data structure. Examples of such software packages are MicroLEIS DSS (De la Rosa et al., 2004, 2009) and ALES (Rossiter, 1990). The MicroLEIS DSS for land suitability evaluation and assessment integrates databases, statistics, expert systems, neural networks, Web applications, GIS, and information technology. The system deals with interfering knowledge using a decision tree (If …then). The ALES provides a structured data entering environment in which the user can build his/her land evaluation model. It has been used to evaluate land units following the land suitability classification method recommended by the FAO (De la Rosa et al., 2004; D'haeze et al., 2004; Dinh, 2007).

Alternatively, analysis tools available within various GIS software packages and based on raster data structure have been used to evaluate land evaluation. This data structure facilitates mathematical operations between data layers and thus promotes the use of multiple criteria, standardized scores, weighting factors and various combination procedures. This approach integrates operations, interfering rules, and GIS. As such, Baja et al. (2002) developed a GIS-based continuous method to assess the agricultural land use potential on slope lands by combining two land evaluation principles: allowing trade-offs among the evaluation criteria, and a limiting conditions approach to calculate an overall (composite) score for each alternative (objective). The authors further developed spatial modeling procedures for land suitability evaluation using compromise programming and fuzzy set approaches in a raster GIS environment (Baja et al., 2007; Liu et al., 2013; Nguyen et al., 2015). Nguyen et al. (2015) designed a GIS-based multi-criteria land suitability analysis (GIS-MCA), integrating three key aspects: agro-ecological aptitude, environmental impact and socio-economic feasibility. At that time, the procedure was not programmed in a packaged software. By consequence, its application required to generation of a spatial database using various spatial analysis tools to take full advantages of the comprehensive approach, followed by the manual integration of the spatial database with the interfering rules or knowledge-based systems. This restricted its use by decision makers that do not have much experience with GIS, and increases the risk for errors introduced during its implementation.

This paper describes the implementation of the GIS-MCA (Nguyen et al., 2015) in a freely available software package (LSE), highlights its key features from a user point of view, and illustrates its application using a case study in Viet Nam.

2. LSE SYSTEM PROGRAMING LANGUAGE, STRUCTURE , AND INTERFACE

2.1. The programming language and operators

LSE is independent software with a user-friendly interface built in Visual Basic. The program is based on the opening code GIS - DotSpatial. The program performs all operations in a Geotif format. To this end two conversion tools were built converting vector (.SHP input format) and raster (Grid, IMG, and BGD file formats) data in Geotif. The core of software was programed by using the land suitability procedure based on GIS-MCA proposed by (Nguyen et al., 2015), in which criteria data are assigned by 0, 1, 2, 3 corresponding to suitable classes: N, S3, S2, S1; the tab of building standardized data was developed by the S membership, a trapezoidal, the Kandel function, and function of classes; the tab of defining weights was created by the rank reciprocal equation (Malczewski, 1999); the tab of classification of the partial performance indices was made by an additive and multiplicative operator; the last tab of valuating the land suitability was programed by three combination methods: the Liebig's law of minimum, the reduction method, and the combining Liebig's law with the reduction method. The tool for standardizing soil erosion criteria and validation were developed by correlation between soil loss tolerance and soil depth and cross-comparison between the output with the planted crop areal data (Nguyen et al., 2015). The sensitive analysis was programed based on the procedure developed by Elsheikh et al. (2013).

2.2. The structure and interface

It consists of the following main parts: (1) An interface with data entry fields and action buttons, (2) Spatial database consisting of maps uploaded by users as well as maps generated throughout the modeling phase, (3) The land evaluation model, performing all calculations and generating the resulting maps, (4) Other support tools (Converting, building, validating, analyzing sensitivity of data, viewing). The LSE interface is available in both Vietnamese and English and consists of two main panels.

3. LSE MODEL APPLICATION

LSE allows users to build his/her own land suitability evaluation, following the principles laid out in Nguyen et al. (2015). This implies that - prior to applying the software - the users have (1) selected (an) appropriate land use(s) and the corresponding diagnostic factors and constraints, (2) (access to) expert knowledge to reliably design their requirements, and (3) a spatial database (vector and/or raster maps) characterizing the spatial distribution of the diagnostic factors within the study area. The the main interface has been designed to include five tabs, guiding the users to implement each land use type of his/her interest. They include (1) Criteria data, (2) Building standardized data, (3) Defining weights, (4) Classification of the partial performance indices, (5) Evaluating the land suitability.

3.1. A case of study

The application of LSE is illustrated to find potential rubber expansion areas within the province Quang Tri, Central Vietnam. The Quang Tri's annual rainfall exceeds 2000 mm and is characterized by a unimodal distribution, with excessive rainfall in the rainy season from September to November, and relatively dry months from December to April. There is a temperature gradient from east to west. Quang Tri covers a floodplain, hilly region, and mountainous region, about 79.8% of the land being hilly or mountainous. The soilscape is dominated by Acrisols and Ferralsols and soil erosion is the main threat leading to soil degradation. Rubber is one of the most important industrial crops in Quang Tri and is mainly cultivated in the hilly areas on Ferralsols.

3.2. Database

An overview of the factors and constraints and their characteristics was implemented in LSE is given in Table 1. Three of the 10 criteria in total, are non-limiting ones, while the remaining ones are limiting and constraints.

Table 1. Agro-ecological, environmental and socio-economic factors and criteria for rubber plantations in Quang Tri

Criteria	**Aptitude, impact and feasibility class**				**Type of criteria**
	S_1	**S_2**	**S_3**	**N**	
Agro-ecology					
Climate					
Length dry season (months: P < 0.5 PET)	0-2	2-3	3-4	> 4	Non-L
Mean annual temp. (^oC)	> 22	22-20	20-18	< 18	Non-L
Mean annual max. temp. (^oC)	> 27	27-24	24-22	< 22	Non-L
Topography and wetness					
Slope (%)	0-8	8-16	16-30	> 30	Non-L
Flooding	F_0	-	-	F_x	L
Drainage	good	moderate	imperfect	poor	Non-L
Physical soil fertility					
Texture	C, SC, SCL	SL	LS	S	L
Soil depth (cm)	> 100	100 -70	70-50	< 50	L
Chemical soil fertility					
Ca^{2+} (cmol(+)/kg soil)	≤ 3.5	3.5 - 4.5	> 4.5	-	Non-L
Mg^{2+} (cmol(+)/kg soil)	≤ 0.7	0.7 - 0.9	> 0.9	-	Non-L
CEC (cmol(+)/kg soil)	≥ 6.0	6.0 - 0	-	-	Non-L
N (%)	≥ 0.1	0.1 - 0	-	-	Non-L
O.C (%)	≥ 1.0	1.0 - 0	-	-	Non-L

Environment						
Annual soil erosion (ton/ha/year)	SD < 0.5 m	0-1.0	1.0-2.8	2.8-5.5	> 5.5	-
	SD 0.5 – 0.7 m	0-2.8	2.8-5.5	5.5-10.0	> 10.0	-
	SD 0.7 –1.0 m	0-5.5	5.5-10	10.0-12.5	> 12.5	-
	SD > 1.0 m	0-10.0	10.0-17.5	17.5 – 25.0	> 25.0	-
Accessibility						
Distance to road (m)		< 500	500-1,000	1,000-2,000	2,000-5,000	-

F_0: no floods; F_x: a land is very often flooded for a period of more than 2 months
C: clay; SC: sandy clay; SCL: sandy clay loam; SL: sandy loam; LS: loamy sand; S: sand
SD = soil depth; Non-L: Non-limiting; L: Limiting (Source: Nguyen et al. (2015))

The available land resources database comprised a digital elevation model (DEM) and vector maps of the road network, climatic, land cover, soil, and actual soil erosion losses under rubber plantations at a scale of 1:50,000, the projection of UTM. All thematic maps uploaded in LSE were rasterized to a resolution of 30 m.

3.3. Results and discussion

3.3.1. Sensitivity analysis of input data and weights of non-limiting factors

Results of the sensitivity analysis indicated that the Mg^{2+} content criterion created the most change in the highly suitable class areas, sequentially the length of dry season criterion, the annually mean temperature one made the least change in the areas. Therefore, the Mg^{2+} content is the most sensitive one of considered criteria to the land suitability evaluation results under agro-ecological aptitude; the second is the length of dry season, sequentially the mean annual maximum temperature. Similarly, the sensitivity of remaining criteria was defined. Finally, the importance of the non-limiting criteria and their weights calculated in Table 2 based on the Weight tab of LSE. The results are different from the weights which were determined before by Nguyen et al. (2015). They indicated the slope criteria was the most important and the mean annual maximum temperature was the least. This come from the inference and expert knowledge, while the results of the sensitive analysis which were relied on the LSE software are objective outputs coming from scenarios with different supposed weight values.

Table 2. The importance and weights of the non-limiting criteria

Criteria	Importance	Weights
Length dry season	2	0.165
Mean an. temp.	9	0.037
Mean an. max. temp.	3	0.110
Slope	7	0.047
Drainage	6	0.055
Ca^{2+}	4	0.083
Mg^{2+}	1	0.330
CEC	5	0.066
N	5	0.066
O.C	8	0.041

3.3.2. Land suitability for rubber plantations

Figure 1 shows the location results of the reduction method as an example, assessing the land suitability for rubber plantations in Quang Tri. The areas that are very suitable for rubber trees cover 9,847.7 ha; land which is moderately and marginally suitable for rubber plantations extents over 14,251.2 ha and 19,558.4 ha, respectively. Applying the Libig method, which integrates the partial performance indices, 9,847.7 ha of land comes out as very suitable. This is the same surface as the outcome of the reduction method.

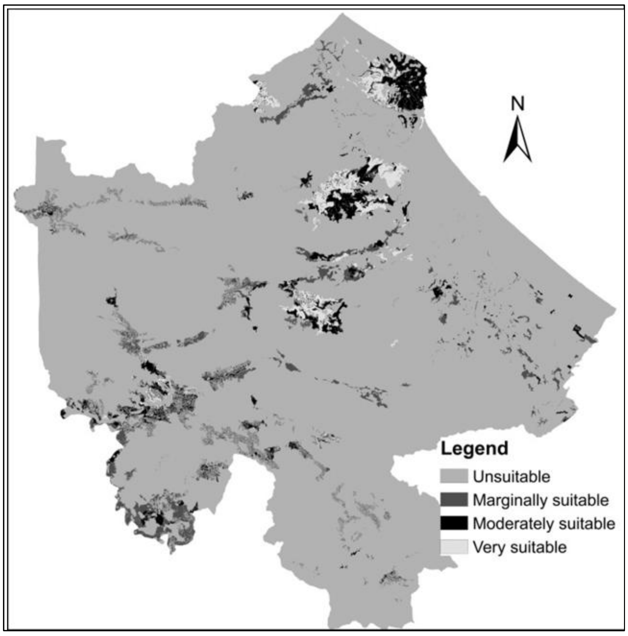

Figure 1: A land suitability map for planting rubber trees using the reduction method

Areas being moderately or marginally suitable are larger than what results from the reduction method. Combining the Libig with the reduction methods, the very suitable locations for rubber trees cover again the same surface as the ones obtained after applying the reduction and Libig method separately. Areas classified as moderately or marginally suitable for rubber cultivation are smaller as compared to the outcome of the Libig method, but larger than the results of the reduction method. The differences which emerged in applying the three approaches are explained as below. In case of integrating the partial performance indices for suitability class S2 (moderately suitable) using the three methods, it means if the suitability class at one pixel is the same S2 for the indices, the output of integration is still S2 (no level reduction) with the Libig approach, to decrease two levels with the Reduction one (N), and to reduce one level with the Combination approach (S3).

3.3.3. Preliminary validation by cross-comparison with actual rubber production zones

The overlap of the existing rubber plantations with the areas the reduction method identified as very suitable for rubber cultivation provides 44.4% of coherence. The same exercise for moderately and marginally suitable land results in a coincidence of respectively 27.5% and 5.5%, respectively. With respect to the Libig method, the values are 44.4%, 29.6% and 4.9%. The combination method results in 44.4%, 28.2% and 5.6%, respectively. Some locations identified as unsuitable for rubber plantations have been planted. The soil depth in these areas is below 100 cm and/or the distance to road is over 500 m, and/or a serious environmental impact was identified. This shows that next to the reduction method (Nguyen et al., 2015), the Libig method and the combination between both, provides promising results on assessing land suitability. The overlap areas between the cultivated rubber plantations and the suitable lands for rubber cultivation (very suitable and moderately suitable) obtained by the LSE’s reduction method (71.9%) are approximate the ones published by Nguyen et al. (2015) (72.6%). It means the suitability land evaluation outputs of the LSE assure accuracy.

4. CONCLUSION

The LSE software is useful for evaluating land suitability at a regional scale. It saves time while assessing the land suitability more objectively and assuring accurately. The rationale consists of five steps: (1) criteria data, (2) building standardized data, (3) weighting, (4) classification of the partial performance indices, (5) evaluating land suitability. It also includes the supporting tools e.g. converting raster and vector data in a Geotif format, calculating slope data, reclassifying raster data, standardizing erosion criteria, validating the results, viewing maps, specially the sensitive analysis. The software is coded both in Vietnamese and in English with user friendly interface, allows managing different evaluations following a list. Three methods allow integrating the partial performance indices including (1) reduction, (2) Libig, and (3) a combination between Libig and reduction. The software was applied successfully to evaluate land suitability for rubber plantations in Quang Tri.

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