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Applying AHP method and GIS to evaluate land suitability for paddy rice crop in Quang Xuong district, Thanh Hoa province

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ABSTRACT

The major purpose of this research is to seek out appropriate cultivated areas for paddy rice crop production in Quang Xuong district. Hence, the assessment of land suitability for this crop is essential for land-users and land managers to understand the capacity and restrictions of the existing land conditions for making suitable policies and plans of land use in the future. In this research, an analytical hierarchy process (AHP) and geographic information system (GIS) were applied to assess land suitability for rice crop. The results found out that 24.82%, 52.33%, 18.40%, and 4.45% of the examined areas were classified as moderate, marginal, current, and permanent unsuitability levels, respectively for rice production. It was identified that the most important constraint factors in the growth of paddy rice were found to be the topography, organic matter, soil texture, soil depth and irrigation condition. The study also indicated that the spatial information resulted could be used to assist land use based directly on its potential to minimize environmental problems, and to increases individual farmers' incomes through proper use.

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1 INTRODUCTION

As many other developing countries, Vietnam is under the pressure of the increasing population and the demand for food. The development of Thanh Hoa province is a typical example of such pressure. The existing land use structures are unsustainable as they lead to the problems of land degradation with respect to the regularly growing population in developing nations. Therefore, it is needed to match land types and land use in the most objective way in order to boost sustainable production and to satisfy the differing needs of society associated with ecological environment protection (FAO, 1993). Because land is limited and successful agriculture requires the sustainable use of soils, so it is necessary to find areas which best suit for crop growing (Selassie *et al*., 2014). In order to solve these problems, it is necessary to update information, to set up a database, and to find the best approaches to determine possible areas for crop production.

Rice was considered as one of the most important food and irreplaceable grain for about two-thirds of the world's population (Ryke, 1987). It is not only the staple food for mankind as the main daily source of nutrition, but is also an indispensable source of employment and profits for rural people (FAO, 2003). In the Asian nations, rice is considered as the first in agricultural production. It also plays a significant role in Vietnamese agriculture, where it is cultivated in every region. Although most Vietnamese regions are ecologically suitable for rice cultivation, its productivity and its output do not match the properties of existing agricultural land, and rice imports, in turn, have increased in recent decades. In order to overcome these issues, the production areas should be evaluated and protected.

In terms of physical potential, evaluation of land suitability is a process of finding a the most appropriate piece of land that meets that requirements, including agricultural use, and nature preservation. Land suitability evaluation is a process of analyzing the criteria from different land resources and socio-economic conditions (Prakash, 2003). According to Vargahan and Hajrasouli (2011), land suitability evaluation is the investigation of a particular area of land in order to satisfy an appropriate type of land use. Many factors are involved in this process, and they may directly or indirectly control the ability of land use. The result of land suitability assessment and generating suitable maps for different kinds of land use will facilitate the land users to reach sustainable agriculture.

Recently, several of GIS-based land quality analysis approaches are developed for land suitability assessment such as mathematical overlay and modeling. Nevertheless, these methodologies do not have enough characterized mechanism for incorporating decision makers' preferences into the GIS procedures. A solution may be the integration of GIS and Multi-Ceriteria Evaluation (MCE) approaches (Mustafa *et al.*, 2011). The combination between MCE and GIS techniques is both traditional and modern approaches to analyzing land evaluation, primarily aiming at evaluating factors and recommending feasible decisions (Sarkar *et al.*, 2014). One of the MCE methods is an analytical hierarchy processes (AHP) that has been integrated into GIS-based suitability process to achieve the required weightings for various criteria. This is a decision-making tool to clarify the overall decision operation by breaking a complex problem into a multi-level hierarchical data structure of objectives, criteria, subcriteria and alternatives (Saaty, 1990). It is practical and effective to dealing with multiple decision problems (Guo and He, 1999) and useful for unifying different conflicting objectives to reach at an agreement decision (Bascetin, 2007). GIS-based AHP has been popularized and widely used in assessing land suitability in the world because of its capacity of integrating a large quantity of inhomogeneous data, even for a huge number of criteria (Kamau *et al.*, 2015).

According to Mendoza (2000), there are many significant advantages of applying the integration of MEC and GIS to land suitability analysis and allocation. The GIS environment does not enable sanctioning the partially express analysis of site quality and the assignment of varied measures of quality to specific sites, but also offers space allocations at specific natural locations. The study by Bello-Dambatta *et al.* (2009) on contaminated land management showed that the AHP is capable of handling the related complication of contaminated land management and it has high values compared to most other decision analysis tools.

In this research, GIS technique and AHP approach were used to evaluate land suitability of the study area for rice crop. This result is not only used as a fundamental soil-database but also plays an important role in the use of suitable soil resources and sustainable land management.

2 STUDY AREA

Quang Xuong is one of a coastal district of Thanh Hoa Province and is located in the humid tropical zone. Its geographical location is at $19^{0}34'$ - $19^{0}47'$N latitude and $105^{0}46'$ - $105^{0}53'$E longitude (Figure 1). The topography of Quang Xuong district is saddleback and relative flat, which runs from the north to the south. The average height above sea level is from 3 to 5 meters. Similar to the climate of the entire province, this district is characterized by strong monsoon influence, a considerable amount of sunny days, and with a high rate of rainfall and humidity. The weather of the district is divided into four distinct seasons: spring, summer, autumn and winter. It is hot and humid weather by influence of the south-westerly dry wind in the summer; dry and little rain, occasional appearance of frost in the winter. The total temperature is about $8{,}400^{0}$C per year. The annual average precipitation ranges from 1,600 mm to 2,000 mm and is irregularly distributed. The humidity is rather high. The average account is over 80% in most of the months and is rarely under 60%.

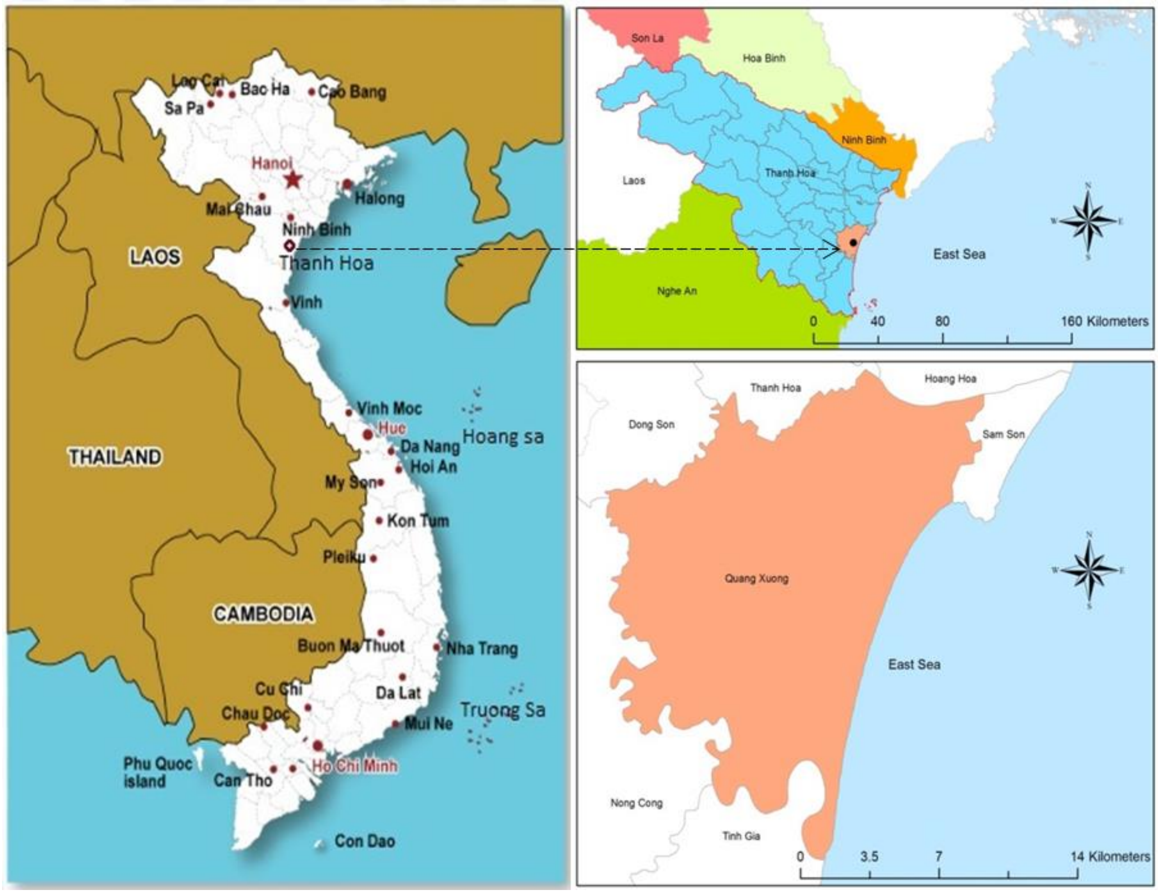

Fig. 1: Location and boundary of the study area

(Source: Department of Natural Resources and Environment Management of Thanh Hoa province)

3 MATERIALS AND METHODOLOGY

3.1 Data resources used for this study

The fundamental survey documents, land classification recently used in the area, soil map data examined by researches of Thanh Hoa province in recent years and thematic maps such as administrative map, land use map, existing land planning map were inheritably selected for further analysis.

In this study, FAO instructions of land assessment (FAO, 1976; 1985; 1993) is applied in order to arrange the institution for collecting, calculating and evaluating data. Land suitability structure of FAO has been modified for Vietnamese conditions (Dao Chau Thu and Nguyen Khang, 1998) as below, which is used for this research:

(1) Land suitability orders that indicate kinds of suitability: S (suitable) and N (non-suitable).

(2) Land suitability classes that reflect the levels or degrees of suitability within orders: S_1 (highly suitable), S_2 (moderately suitable), S_3 (marginally suitable), N_1 (currently not suitable), and N_2 (permanently not suitable).

The data of geology, geography, vegetation cover, socio-economy, and information about yearly agricultural crops of the district were collected from Department of Natural Resources and Environment, Department of Agriculture and Rural Development, Division Statistics of the province and the district, university libraries, and available literatures. Collected information included yearly reports, the strategies for agricultural development of the state and the district, projects and researches of agriculture in the past as well as at the present. In addition, the climate condition such as rainfall, temperature, humidity, hours of sunlight and amount of evaporation are also taken into consideration. Nevertheless, these factors are consistent in the whole area of the research, they are not shown in the land mapping unit. However, they were still examined for the selection of annual agricultural crops in the study area. Finally, the interviewing and discussion methods were applied in order to obtain more information about agricultural production, cultivated methods, the preserving and processing of agricultural products. These approaches were also used to select the parameters for suitability evaluation and examine each evaluation factor for paddy rice crop. Interview and discussions have been organized among groups of 8 experts of agricultural land use and management (3 experts of land use planning, 3 experts of soil science, and 2 agronomy specialists) to examine the weight of main criteria and sub-criteria for land suitability evaluation by applying AHP method.

3.2 Application of MCE using AHP method

AHP can be used as a method to create selections supported multi-criteria in quantitative relation scales from paired comparison (Saaty, 1990a). According to Saaty (1977, 1990b), the AHP is based on following three major consecutive directors:

(1)Definition of the overall goal (suitability assessment)

(2)Comparative judgment of criteria and sub-criteria

(3)Synthesis of the priorities

The first step of AHP technique is to structure the general goal into a number of criteria and sub-criteria in a hierarchy. The first level of the hierarchy is the main goal of the research problem. The next level comprises the main relevant criteria for this goal. The following levels consist of sub-criteria, and the evaluated alternatives are at the bottom level of the hierarchy. These steps are employed to evaluate land suitability, and the relevant criteria and sub-criteria with the goal were defined and organized in the hierarchical structure demonstrated in Figure 2. The combination of both qualitative and quantitative criteria is facilitated by this hierarchy.

The next step in the AHP process is the comparison of the criteria and sub-criteria. To make comparisons, a scale of numbers is created to indicate how important one factor is over another with respect to what they are compared. The basic scale of Table 1 can be used for the relative comparison. The value used when comparing the element on the vertical axis with the element on the horizontal axis changes from 1 to 9. On the contrary, the value of reciprocal varies from 1/2 to 1/9. For instance, when comparing factor A with factor B, if A is three times important than B, then B is as 1/3 times important as A.

Table 1: Basic scale for pairwise comparisons (Satty, 1977)

Number of value	Verbal scale
1	Equally important, likely or preferred
3	Moderately more important, likely or preferred
5	Strongly more important, likely or preferred
7	Very strongly more important, likely or preferred
9	Extremely more important, likely or preferred
2, 4, 6, 8	Intermediate values to reflect compromise

Finally, the last step of the AHP technique is the synthesis of the comparisons to obtain priorities of the alternative with respect to each parameter and the weights of each criterion with respect to the main goal. Afterward, the local priorities are multiplied by the weights of the respective factors. The consequences are summed up for the final priority of each option.

It is crucial to look into the consitency of the pairwise comparison to accept the weight of each level in the structure (Nabarath, 2008). The parametric quantity that is used to confirm this consistency is named the Consistency Ratio (CR). It is a measurement of how much variation is allowed and must be less than 10%. Otherwise, it is needed to improve consistency by revising the process of subjective judgment (Saaty, 1990a). The general AHP structure used in this study is presented in Figure 2.

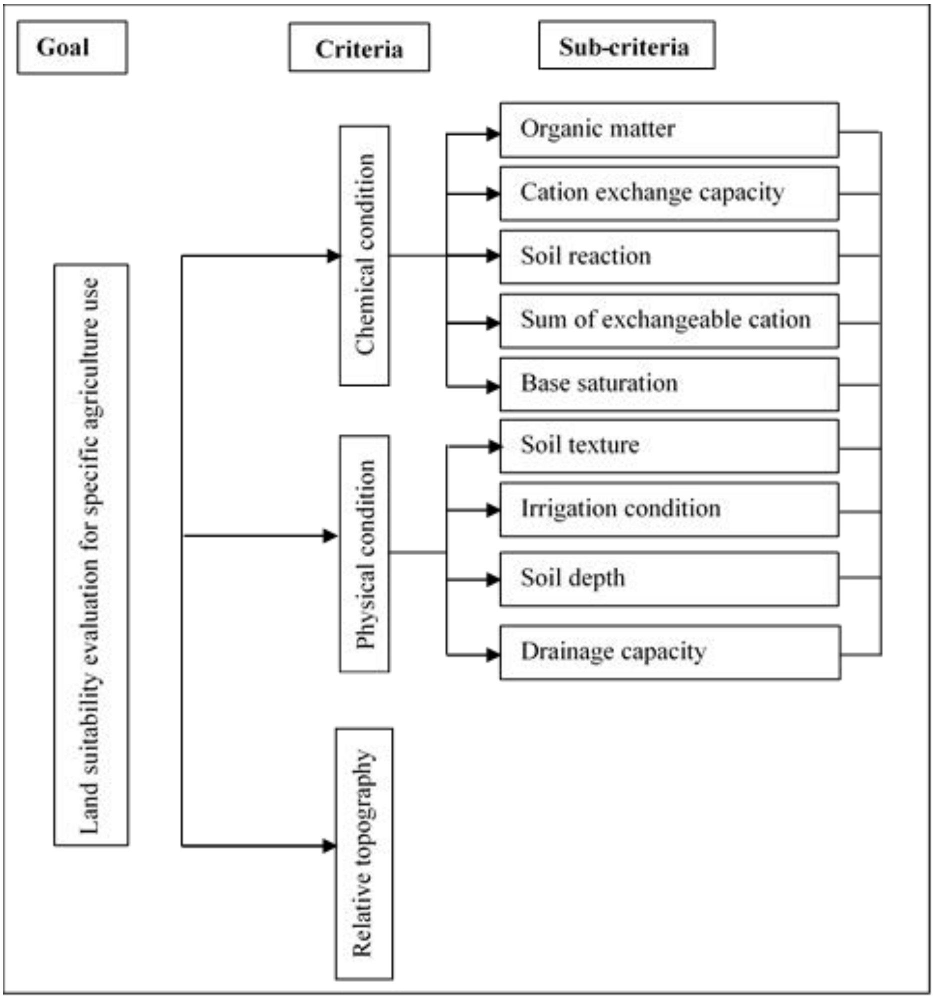

Fig. 2: The goal, main criteria, and sub-criteria in AHP structure

Calculation of consistency ratio (CR)

The formula of CR got from the Consistency Index (CI) (Saaty, 1990a) is as follows:

$$\mathrm{CI} = \frac{(\lambda_{max} - n)}{(n-1)}$$

Where: λ_{max} is maximum eigenvalue; n is the number of factors in each pair-wise comparison matrix; RI is Random Index

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

RI, an average number of comparative matrix in pairs from 1 - 10, is obtained according to a particular number of matrix rows and varies depending upon the order of the matrix, as shown in Table 2 (Alonso and Lamata, 2006). When the matrix is larger, the level is more inconsistent (Permadi, 1992).

Table 2: The average random index based on matrix size

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

According to Zeshui and Cuiping (1999), if CR ≤ 10% then the matrix is already consistent and AHP can be continued, if CR > 10% the matrix needs revising until it is of acceptable consistency.

3.3 Integrated AHP method with GIS for land suitability evaluation

Making decisions on the suitability assessment for rice crop was determined through using the general model of land suitability evaluation as presented in Figure 3.

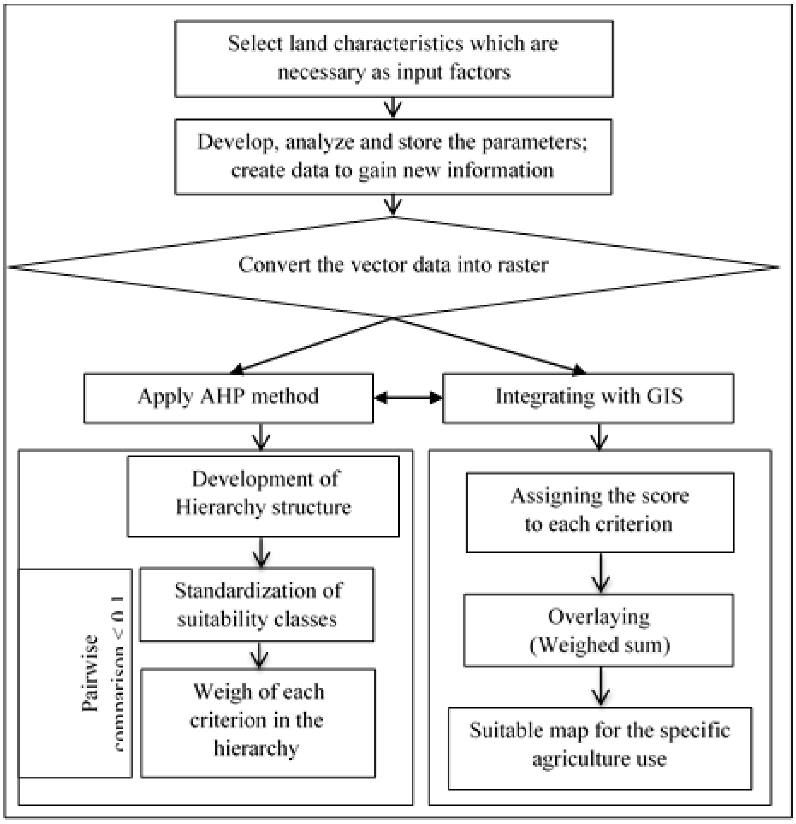

Fig. 3: The general flowchart of Land suitability evaluation for paddy rice crop

The attribute scores of sub-criteria are computed for each land mapping unit. The scores are examined based on experts as well as the local conditions. These scores (X_i) are aggregated with the weights (W_i) to provide suitability value for each land unit matching each selected agricultural crops.

The land suitability index for each land unit is calculated by using the following formula:

$$\mathbf{S_i = \sum W_i \times X_i}$$

Where: S_i is land suitability index; W_i is the weight of factor (i = 1, 2, 3….n); X_i is the attribute score of each sub-criterion.

The process of land suitability is done in ArcGIS software despite the composite map of land unit. Calculation of the weight and score value of each criterion and sub-criterion were implemented, and the theme layers of each sub-criterion was created. Then all of them were overlaid together to generate the final land suitability classification for paddy rice crop as described in Table 3.

Table 3: The level class of land suitability evaluation

Suitability index	Suitable classification	Description
> 4.0	S_1	Highly suitable
3.5 – 4.0	S_2	Moderately suitable
3.0 - 3.5	S_3	Marginally suitable
2.5 – 3.0	N_1	Currently not suitable
< 2.5	N_2	Permanently not suitable

5 RESULTS AND DISCUSSION

5.1 Determination of weights of main factors and variables

Different ecological parameters required for selecting annual crop species have different contributions the suitability level; hence, different weights should be given to each parameter and sub-parameter. The identification of three main parameters, four sub-criteria, and nine sub-unit criteria indicates that the suitability evaluation is rather complicated. The weight of each criterion was examined to calculate its influence to the final consequence. Thus, it is the fact that the greater the weight is, the larger the value is and the more important decisive criterion is. The process of working out the weight using pairwise comparison method at all level was through interviewing eight specialists of the land use management first. Afterward, the geometric mean method with the formula: $\boldsymbol{a_{ij}} = (\prod_{k=1}^{n} \boldsymbol{aijk})^{\frac{1}{8}}$ was used to aggregate a comparison matrix of experts' judgments. Finally, the eigenvector method was used to calculate the weight of each criterion at all levels. The CR values of all levels are less than 0.10, so the weights are acceptable and reliable. Detailed weights of the chosen criteria at all levels for rice cultivation is presented in Table 4.

Table 4: Weighting matrix at all levels in land suitability evaluation for paddy rice cultivation

Main criteria	Weight		Sub-criteria	Weight	
Chemical property	0.425	$\lambda_{max} = 3.006$; CI = 0.003; CR = 0.005	Organic matter (OM)	0.394	λ_{max} = 5.008; CI = 0.002; CR = 0.002
			Cation exchange capacity (CEC)	0.170	
			soil reaction (pH)	0.274	
			Sum of exchangeable cation (SEC)	0.093	
			Base saturation (BS)	0.069	
Physical property	0.317		Soil texture	0.369	λ_{max} = 4.019; CI = 0.007 CR = 0.008
			Irrigation condition	0.339	
			Soil depth	0.135	
			Drainage capacity	0.156	
Relative topography	0.258		-	-	

5.2 Determination of the score for each Sub-unit criteria

The score of class for each criterion is based on the rice crop requirements for growth, the experts' judgments as well as local natural conditions. The ranking score implies the suitability level of each class' factor and the ecological factors on environmental suitability were classified into four suitable levels, involving highly suitable (S_1), moderately suitable (S_2), marginally suitable (S_3) and not suitable (N). The values of each suitable level were assigned as 4, 3, 2 and 1, respectively (Table 5).

Table 5: Standardized score corresponding to criterion attribute values

Criterion	Standardization	Score	Criterion	Standardization	Score
Base saturation	> 50%	4	Soil texture	*SiC, CL, SiCL	4
	35% - 50%	3		*SiL, L	3
				*LS, SL	2
	< 35%	2		*cS	1
Organic matter (OM %)	> 1.5	4	Irrigation	Actively irrigated	4
	0.8 - 1.5	3		somewhat irrigated	3
				Poorly irrigated	2
	< 0.8	2		None irrigated	1
CEC (meq/100g soil)	> 10	4	Soil depth (cm)	> 75	4
	5 - 10	3		50 - 75	3
	< 5	2		20 -50	2
pH(H2O)	5.0 – 6.5	4		< 20	1
	4.5 – 5.0	3	Drainage	Good	3
	4.0 – 4.5	2		Moderate	4
			Relative topography	Flat	4
	< 4.0	1		Low flat	4
Sum of exchangeable cation (SEC -meq/100g soil)	> 4.0	4		Upper flat	3
	2.8 - 4.0	3		High	1
	1.6 - 2.8	2			
	< 1.6	1		Depressed	2

Note: ** CL: clay loam, cS: coarse sand, L: loam, LS: loamy sand, SL: Sandy loam, SiL: Silty loam, SiC: silty clay, SiCL: Silty clay loam*

5.3 Suitability of land area for paddy rice crop

After the values of the weights and scores were figured out, they were transferred and processed in ArcGIS to determine the final suitable level for rice crop corresponding to each land unit. The weights and score values of each criterion were created as thematic maps for the overlaying process, following the formula presented in section 3.3. The suitable level of the different land units for rice crops is classified according to the suitability indexes in Table 3 of section 3.3.

The ultimate evaluation of the physical land suitability for paddy rice crop using AHP method combining with GIS is given in Table 6 and land area suitability in Figure 4.

Table 6: Suitability level area for growing paddy rice in Quang Xuong District

Suitability class	Symbol	Area (ha)	Percent (%)
Highly suitable	S_1	-	-
Moderately suitable	S_2	3,415.59	24.50
Marginally suitable	S_3	7,824.78	56.12
Currently unsuitable	N_1	2,081.70	14.93
Permanently unsuitable	N_2	619.74	4.45
Total area (ha)		13,941.81	

Table 6 reveals the range changes amongst class levels and no land area at S_1 level is found out for rice cultivation in the district regarding to AHP method. The number of hectares available to each suitability class, identified by weight overlay using spatial analyst tools in ArcGIS 10.2, shows that the largest evaluated area falls into the marginally suitable level for growing rice crop. It is about 7,824.78 ha, accounting for 56.12%. The next largest evaluated land for this kind of crop belongs to the moderately suitable class with 3,415.59 ha, making up 24.50% of the investigated area. Regarding this model, 2,701.44 ha, equivalent to 19.38% of the total surface area is evaluated as unsuitable class for paddy rice growth, of which 2,081.70 ha is assessed as currently unsuitable land, accounting for 14.93% and 619.74 ha or 4.45% is evaluated as permanently unsuitable area for paddy rice crop, respectively.

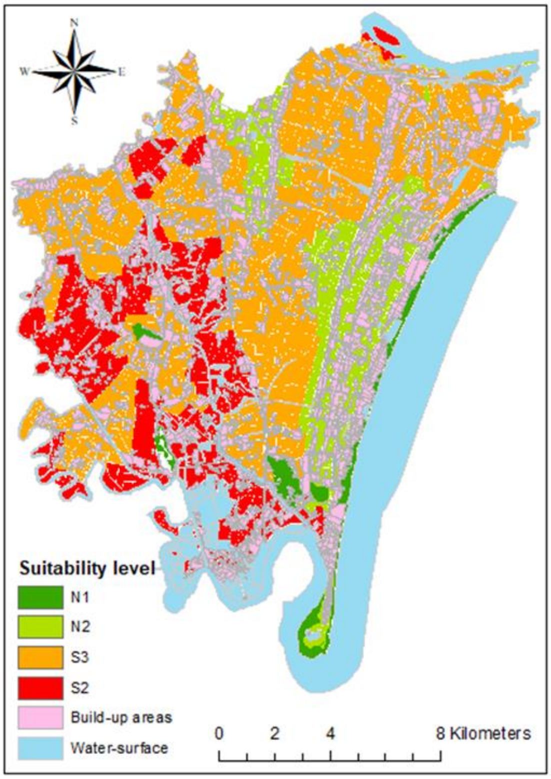

Fig. 4: Suitability map for paddy rice crop

The different results of land suitability evaluation for rice crop can be explained that the suitability level depended on matching of the collected data of land properties with the crop requirement as mentioned in Table 4. This means that different suitability classes were determined for different land characteristics. The results also indicate that the final suitability class depended not only on the score of land properties, but also counted on the weight of each parameter used in the land evaluation procedure. In this method, the suitability ratings and weights are aggregated over hierarchy levels. Eventually, final suitability map for rice growth was generated by overlaying all of the thematic maps together. Regarding this method, in the weight calculation step of pairwise comparison matrix at the main criteria, the chemical property of soil was assessed as the most important parameter with the weight values of 0.425, in which organic matter, and soil pH reaction were assessed as the most important factors with the weight values 0.394 and 0.274, respectively. The next important parameter was the physical property with the weight value of 0.317, in which the most important factors belonged to the soil texture and irrigation system with the weight values 0.369 and 0.339, respectively. The last important factor was the relative topography with the weight value of 0.258. The weight values of sub-criteria of AHP structure were presented in Table 4. The final results of land suitability evaluation found out that the most serious limitations for cultivating and developing of rice crop were relative topography, soil chemical and physical properties such as low percentage of organic matter content, high acid in soil, shortage of irrigated condition, shallow soil depth or some soil textures not suitable for rice growth. These limitations could affect the results of land suitability evaluation from moderate level (S_2) to unsuitable level (N) by themselves or with together. These lands of moderate suitability (S_2) were suitable for rice cultivation over long period of time. These areas were highly productive, but they had several slight hazards and limitations in comparison with high level, which require moderate conservation and was in need of slight management inputs to maintain and prevent the degradation of the resource. At the marginal suitability (S_3), these lands could be used for rice cultivation, but severe limitations which will restrict the length of cropping phase. The limitations of these areas were due to their topography, low content of organic matter, soil texture or the shortage of water supply from irrigation system. Therefore, it was necessary to apply major conservation treatments and careful management practices to reduce the degradation of the resource. At the unsuitable level (N), the dominant limitations were very difficult to transform or correct such as topography, soil texture, soil depth, and irrigation condition. Some limitations influenced land suitability rating, but it could be improved in the future.

6 CONCLUSIONS

In this study, AHP method and GIS technique have been implemented for the land evaluation process. This approach was adopted by Vietnam after the FAO framework with modifications to suit the local environment. Furthermore, the AHP method is considered as the complex method, and found to be as a useful approach to defining the weights. It can endow with visualization of the results of the normalization procedure. On the contrary, the final suitability level is depended on the score of land properties and the weight value of each parameter in which experts should be consulted to understand the weight value of each parameter. This study found out that different criteria play differently important roles and weigh values in the land assessment. The suitability ratings and weights are aggregated over hierarchical levels and the final suitability class depended not only on the score of land properties, but also counted on the weight of each parameter used in the land evaluation procedure. The results show that the suitability levels for agricultural use were mostly depended on soil qualities, and there were four suitability levels for rice production in Quang Xuong district from N_2 to S_2, and most of the agricultural area was fall into suitable levels (S_3, S_2) in which, the marginal and moderate levels were 52.33% and 24.82%, respectively. The total unsuitable levels (N_2, N_1) were about 19.38% of the investigated area for growing rice, in which, the currently unsuitable and permanent unsuitable classes were 14.93% and 4.45%, respectively. The spatial information resulted from this study could be used to assist effective land use based directly on its potential to minimize environmental problems, and to increase individual farmers' incomes through proper use. The results of land suitability levels could not only help land users and land planners to make right decisions, but also recommend appropriate techniques, investment inputs in order to improve land quality and achieve effective results from cultivation practices.

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