LAND POTENTIAL PRODUCTIVITY ASSESSMENT FOR ANNUAL AGRICULTURAL CROPS DEVELOPMENT IN QUANG XUONG DISTRICT BY APPLYING MULTI-CRITERIA EVALUATION AND GIS

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Abstract: *The assessment of land potential productivity for agricultural production and land suitability for selected annual crops was based on FAO guidelines for land evaluation which were adopted and slightly modified for compatibility with Vietnamese conditions. A combination of three main factors consisting of ten variables of all related data were stored, analyzed, mapped and presented in ArcGIS software. Weighted Linear Combination Method developed by Hopkins and GIS techniques were used to analyze and determine the land potential for agricultural use in the study area. The results show that 5.26%, 83.10%, 10.06%, and 1.57% of the investigated areas were assessed as high potential, moderate potential, low potential and very low potential, respectively for growing crops. The findings from this study were also useful to support the land users and land managers to exploit agricultural land effectively.*

Keywords: *Land suitability, GIS, Land potential.*

1. Introduction

In the process of land evaluation, a scientifically standardized technique is used to estimate the characteristics of land resources for certain uses and its results can be used as a guidance for land users and planners to find out a better use [10]. As a land is a limited resource, reliable and accurate land evaluation is indispensable for assisting decision-makers and land users to use the scarce land resources efficiently and develop models to predict the land suitability for different types of agriculture [6].

In terms of physical potential, land suitability evaluation tries to find the best places of the land that suit a given range of utilization types, which may be included agricultural uses or nature preservation alternatives as well. The procedure hereby in use is based on the crop requirements for growth and the environmental conditions [1], [11]. Evaluation of land suitability is analyzing the criteria from different land resources and socio-economic conditions [8].

GIS and MCE (Multi-Criteria Evaluation) are capable of assisting land users in making a right decision in that GIS effectively controls assessment factors and MCE synthesizes them into a suitability index [7]. 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 [9].

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Agriculture is one of the most important economic sectors in Quang Xuong District. It occupied more than 50% of the entire area. However, the cultivated lands have been decreasing over years because of the population growth and the demand for expansion of build-up areas and rural infrastructure development. Thus, appropriate land use planning will be the best way to increase agricultural yield as well as protect cultivated land. Potential productivity assessment is a prerequisite step of evaluating whether or not a specific land is suitable for development of sustainable agriculture.

This study presents the results of spatial analysis to specify potential areas for agricultural production with GIS techniques based on the FAO guideline [2], [3], [4] for land evaluation.

2. Study area

The topography of Quang Xuong district is relatively flat, and runs from the north to the south. The climate condition of Quang Xuong is affected by the tropical and temperate zone. It is hot and humid weather by influence of the south-westernly dry wind in the summer; dry and with little rain, occasional appearance of frost in the winter. The average temperature per day is about 23^0C. The annual average precipitation ranges from 1600mm to 2000mm 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%.

According to soil classification methods of FAO-UNESCO, the study area has 6 major soil groups, with 12 soil units and 18 sub-units. This is a principle for expecting feasible results of various agricultural crops.The average characteristics of the major soil groups is presented in Table 1 and the soil texture of sub-units of soil are presented in Figure 1.

Table 1. *Fertility of soil group in Quang Xuong District*

Soil group	pH_{KCL}	Average OM (%)	Total concentration (meq/100g)		Available concentration (meq/100g)		Exchange cation (meq/100g)	CEC (meq/100g)	BS (%)
			P_2O_5	K_2O	P_2O_5	K_2O			
Arenosols	4.90	0.35	0.035	0.50	16.25	5.40	4.40	6.20	38.0 – 83.0
Salic Fluvisols	5.45	2.70	0.09	1.43	18.50	9.50	10.50	1.50	78.0 – 87.0
Fluvisols	4.90	2.50	0.08	1.05	14.50	7.25	8.40	15.50	26.0 – 86.0
Gleysols	5.05	1.85	0.054	1.72	11.75	4.75	8.50	15.00	45.0 – 84.0
Acrisols	4.30	0.60	0.035	0.51	3.25	6.20	4.00	8.50	35.0 – 57.0
Leptosols	4.56	2.14	0.12	2.30	7.0	21.02	8.60	16.88	28.0 – 50.0

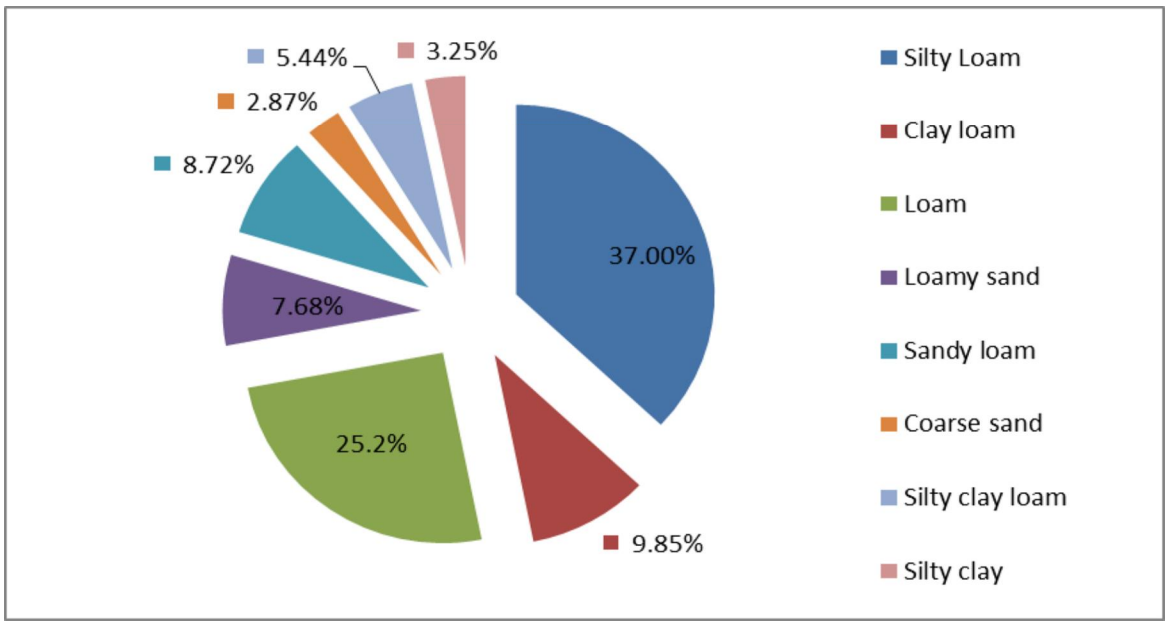

Figure 1. *The soil texture for sub-units of soil in the Quang Xuong District*

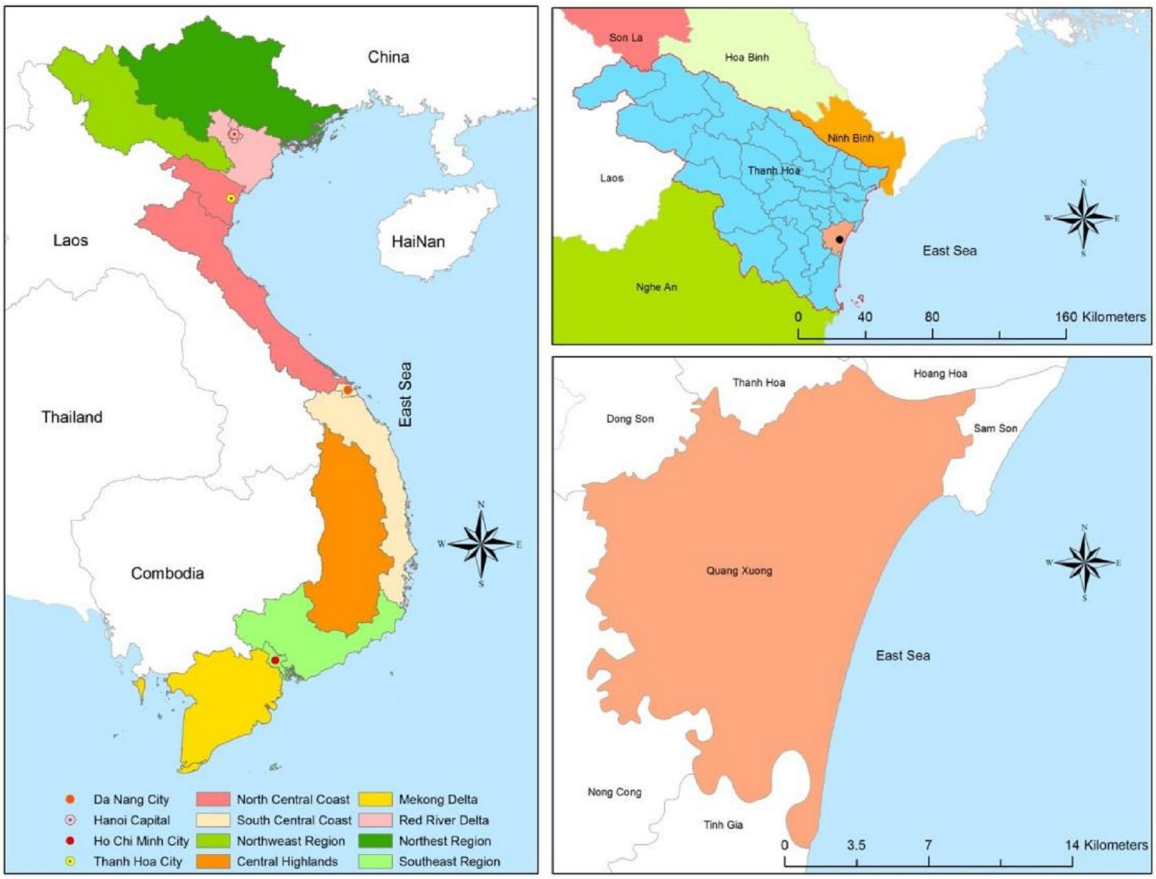

Figure 2. *Location and boundary of the study area*

Source: Department of Natural Resources and Environment Management of Thanh Hoa Province

3. Methodology

At present, the study area does not have a standard model of land capability evaluation for agricultural use. Thus, we examine and generate a potential productivity map for agricultural production in the district based on the available data and the requirement for farming production. The Linear Combination Method developed by Hopkins [5] with the help of GIS was used to express land potential for agricultural production.

3.1. Selection of factors, variables and database development

Three main components and ten variables have been chosen for assessment of land capability (Table 2), namely: (1) chemical property factor including organic matter (OM); cation exchange capacity (CEC); pH; sum of exchangeable basic cation (EC); and base saturation (BS), (2) physical property involving soil texture; irrigated condition; soil depth; and drainage capacity, (3) relative topography including depressed; low flat; flat; upper flat; and high topography. These factors and variables are differently dependent on land capability productivity. The database was developed by using ArcGIS software.

Table 2. *Main factors and their variables for land potential assessment*

Main factor	Variables	Units
Chemical property	OM	-
	CEC	meq/100g soil
	Soil pH	-
	Exchangeable cation	meq/100g soil
	Base saturation	%
Physical property	Soil texture	-
	Irrigated condition	-
	Soil depth	Cm
	Drainage capacity	-
Relative topography	Relative Topography	-

3.2. Land potential productivity model

The potential levels for agricultural production were dependent on the score distribution of each site. The final score of the land capability was calculated by the formula (1) and converted to a level of capability as described in table 3.

$$Score = \frac{\sum_i^n \mathrm{W}iXxyi}{\sum_i^n \mathrm{W}i} \quad (1)$$

Where: n is the number of factors, W_i is the weight of factor i, X_{xyi} is the score of category for each variable of each factor i.

Table 3. *The level of land potential productivity for annual agricultural crops development*

Score	Potential capacity	Description
≥ 3.5	Highly potential productivity	The land has few limitations for agricultural production, its potential productivity is high.
2.5 - 3.5	Moderately potential productivity	The land has some limitations for agricultural production, its potential productivity is medium.
1.5 - 2.5	Lowly potential productivity	The land has a number of serious limitations for agricultural production, its potential productivity is low.
≤ 1.5	Very low potential productivity	The land has a large of serious limitations for agricultural production, its potential productivity is very low.

4. Results and discussion

4.1. Determination of weights of main factors and variables

In this research, the weights were determined from an average value based on the result of interviewing people who have experience and knowledge in the agricultural field (Table 4). The score of each variable category associated with requirements of potential productivity levels was defined by discussing with local officers. Based on the result of the discussion, the ranking of each variable was clarified from 1 to 4, with 1 being the worst for agricultural use and 4 the best. These are very low potential, low potential, medium potential and high potential corresponding to Arabic numerals of 1, 2, 3 and 4 (Table 5).

Table 4. *Weight of each factor and variable*

Main factor	Weight 1 (%)	Variables	Unit	Weight 2 (%)	Overall Weight (%)
Chemical properties	40	OM	-	30	12
		CEC	meq/100g soil	25	10
		Soil pH	-	25	10
		EC	meq/100g soil	10	4
		BS	%	10	4
Physical properties	35	Soil texture	-	30	10.5
		Irrigated condition	-	30	10.5
		Soil depth	cm	25	8.8
		Drainage capacity	-	15	5.2
Topography	25	Relative Topography	-	-	25

Table 5. *Score of each variable category for land potential productivity assessment*

Variable	Category	Score	Variable	Category	Score
Base saturation	> 50%	4	Soil texture	Silty loam, Loam, Silty clay loam	4
	35% - 50 %	3		Silty clay, Clay loam	3
	< 35 %	1		Loamy sand, Sandy loam	2
				Coarse sand	1
OM (%)	> 2	4	Irrigation	Actively irrigated	4
	2 - 1.5	3		Somewhat irrigated	3
	1.5 - 0.8	2		Poorly irrigated	2
	< 0.8	1		None irrigated	1
CEC (meq/100g soil)	> 15	4	Soil depth	> 70cm	4
	15 – 10	3			
	< 10	1		50cm – 70cm	3
pH	> 6.5 - < 7.0	4		30cm – 50cm	2
	6.5 - 6.0	3		< 30cm	1
	6.0 - 5.5	2	Drainage	Good	4
	< 5.5	1		Moderate	2
			Relative topography	Flat	4
EC (meq/100g soil)	> 8.0	4		Low flat	3
	8.0 - 4.0	3		Upper flat	3
	< 4.0	1		High	2
				Depression	2

4.2. Assessment of chemical factors

Chemical properties of soil include five variables (OM, CEC, pH, EC, BS) as determinants of agricultural land quality such as agricultural productivity. It is commonly regarded as an important predictor of potential productivity of farmlands. The results of chemical factor examination for agricultural potential use are presented in Table 6. Based on the table, 1464.57ha of cultivated land is classified under high potential level, accounting for 10.50% of the research area and only located on the Fluvisols group. 5797.51ha is assessed as moderate potential category, accounting for 42.89%, prevailing in Fluvisols, Gleysol, and Arenosols groups. The low potential level is about 5293.80ha, occupying for 37.97% and is distributed in the Fluvisols, Gleysols, salicFluvisols and Arenosols. The area for very low potential of agricultural use is about 1203.93ha or 8.64% of the entire investigated area and mainly distributed in the Acrisols, Arenosols, and Leptosols groups.

Table 6. *Potential productivity level of chemical factor for annual cultivation*

Land use purpose	Potential level	Area (ha)	Percent (%)
Annual cultivation	High potential	1464.57	10.50
	Moderate potential	5979.51	42.89
	Low potential	5293.80	37.97
	Very low potential	1203.93	8.64
Sum		**13,941.81**	**100**

4.3. Assessment of physical factor

The potential productivity was the result of overlaying thematic maps of soil texture, soil depth, irrigation condition, and drainage capacity. The details of physical factor assessment for cultivation use are described in Table 7. Based on the results examination, there is no agricultural area under the very low potential situation in the study area, and most of the investigated land is of moderate capability for agricultural development with 11,152.26ha, covering 79.99%. The areas with low potential productivity amounted to a small proportion compared with entire area for agricultural use. They cover about 619.74ha, equivalent to 4.45%. The results also demonstrate that the land with high potential productivity for crops growth is about 2169.81ha, occupying 15.56% of the total examining area. In general, the research area has a good condition of physical properties for agricultural development.

Table 7. *Potential productivity level of physical factor for annual cultivation*

Land use purpose	Potential level	Area (ha)	Percent (%)
Annual cultivation	High potential	2169.81	15.56
	Moderate potential	11,152.26	79.99
	Low potential	619.74	4.45
Sum		**13,941.81**	**100**

4.4. Assessment of relative topographic factor

The study area is a coastal sandy land, so most of the areas are plain except for an area of 219.33ha of the Leptosols group whose slope is more than 25^0 and considered as unsuitable for annual agricultural crops. In Vietnam, the term of relative topography is usually used in land evaluation projects for the plains at districts, communes, villages or small areas. Based on the natural condition of the area, the observation, experts' opinions, and discussion with local farmers, the topography was classified into five classes as flat, low flat, upper flat, depression and high. The potential levels of classification are shown in Table 8. This factor of the enquired area is assessed as follows: high potential for cultivated activities is 1785.06ha or 12.80%; moderate potential is 8699.13ha, covering of 62.40%, 2132.10ha of which belongs to low flat, and 6567.03ha is topography of upper flat. The total assessed area of low potential is 3328.29ha or 23.23%, 2837.88ha of which is under the relative topography of depression, and 400.41ha is under the highly topographic condition.

Table 8. *Potential level of relative topographic factor for annual cultivation*

Land use purpose	Potential level	Relative topography	Area (ha)	Percent (%)
Annual cultivation	High potential	Flat	1785.06	12.80
	Moderate potential	Low flat, upper flat	8699.13	62.40
	Low potential	Depression, high	3238.29	23.23
	Very low potential	Slope > 25^0	219.33	1.57
Sum			**13941.81**	**100**

4.5. Final land potential productivity assessment

The result of the multiplication of all the score points out which site is better for agricultural use based on the scores and weights expressed in the model. The weights for the other factors and the scores for its variables were calculated based on agricultural experts' opinions as well as local conditions.

Three main factors of current environmental conditions in the study area, including chemical soil property, physical soil property, and relative topography were overlaid together in one layer. The information about multiple overlays was input into GIS to find out land potential map for cultivation. Its results were mainly classified as high, moderate, low, and very low potential suitability level for agricultural use. The consequences of the classification indicate that 11585.97ha or 83.10% of the total investigated area is under low to medium potential for agricultural activities, while the smallest area with only 219.33ha, making up 1.57% was determined as very low potential productivity category and only concentrated on the Leptosols group with the soil depth of less than 30cm. The classification of land potential assessment is showed in Table 9 and Figure 3.

The results of land potential productivity assessment indicate that the highly potential level for agricultural production is only located in the Fluvisols group and with soil depth of more than 70cm and soil texture of silty clay loam. It was 733.77ha, covering 5.26% of the evaluated area. The results also show that the moderate potential level prevails in different types of soil groups such as the Fluvisols, salic Fluvisols, Acrisols, Arenosols, and Gleysols with different types of soil texture and the soil depths fluctuated from 50cm to 70cm. The low potential level for growing crops is mainly located in the Arenosols, Acrisols and a part of the Fluvisol groups with 1402.74ha, equivalent to 10.06%. It has different soil textures such as loam, clay loam and coarse sand with soil depth levels from 30cm to 50cm.

Table 9. *Land potential productivity assessment for annual agricultural crops*

Land use purpose	Potential level	Area (ha)	Percent (%)
Annual cultivation	High potential	733.77	5.26
	Moderate potential	11585.97	83.10
	Low potential	1402.74	10.06
	Very low potential	219.33	1.57
Sum		**13,941.81**	**100**

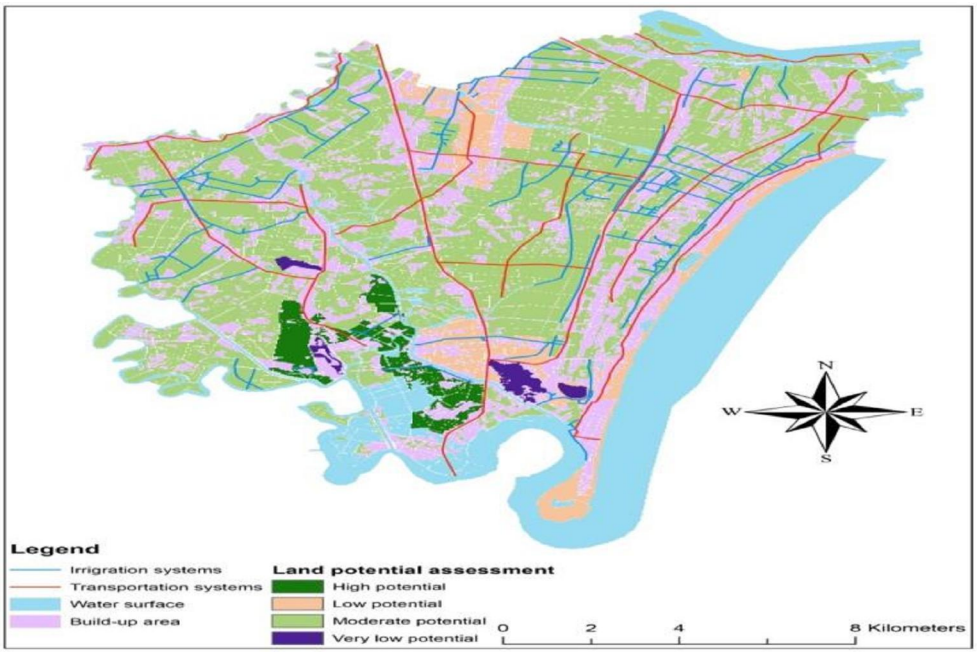

Figure 3. *Assessment of Land potential productivity for annual agricultural crops*

5. Conclusion

The results of defining potential areas for agricultural production using GIS techniques in combining with Weight Linear Combination Method [5] in this study are divided into four levels as highly potential, moderately potential, low potential, and very low potential productivity, respectively, in which, highly potential, moderately potential and low potential are considered as suitable for agricultural production, while very low potential is not suitable for croplands because of extremely severe limitations or hazards, but it can be used for permanent vegetation like forest or natural plant covering.

The findings from this study demonstrate that the process of determining the potential productivity is significantly useful to support the land users and land managers finding out the problems in a certain use of agriculture land and provided more information for appropriate investment for cultivated production. Furthermore, the results of land potential productivity assessment are also significant for local land users to make possible strategies for development of agricultural land in short term as well as in a long term of use. Finally, it is helpful for setting up a land information system for sustainable use of land resources and land management not only in the case study.

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