LAND SUITABILITY ASSESSMENT OF RICE CULTIVATION USING GIS AND MCE IN THAI NGUYEN, VIETNAM

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ABSTRACT

In Vietnam, rice is the most important staple food, and rice cultivation strategies are given the top priority to ensure the nation's food security and economic development. Efficient planning of rice production requires a comprehensive assessment of suitable land and ecological conditions (Heumann B.W. et al. 2011) [3]. Spatial analyses can enable this critical task by classifying each land unit according to its suitability for rice production. With a case study in Thai Nguyen Province, Vietnam, this study employs Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) tools with a particular emphasis on multicriteria analysis. Nine criteria including elevation, slope, temperature, rainfall, irrigation, soil pH, soil composition, depth of soil classes, and soil types, are utilized for the assessment of land suitability. Based on this analysis, land suitability is classified into four categories: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). In our case of Thai Nguyen Province in 2020, the findings indicate that there were 29,175 ha of highly suitable (S1), 6,999 ha of moderately suitable (S2), 8,041 ha of marginally suitable (S3) and 538 ha of not suitable (N) for rice cultivation.

Keywords: *Rice cultivation, GIS, Land suitability assessment, MCE, Thai Nguyen*.

1. INTRODUCTION

In Vietnam, rice is the most important staple food, and rice cultivation strategies are given the top priority to guarantee the nation's food security and economic development. Rice is used as food by about 97.5 million Vietnamese people. According to the VNGSO, 2020 [1], rice production export is above 15 million tons. Hence, the Vietnamese Government gives a high priority to the development of rice cultivation focused on high quality and quantity. In recent years, rice production has been facing many difficulties due to the pressure of urbanization and industrialization, the impacts of disease and climate change, low export prices, and the low economic efficiency of rice producers. To solve these challenges, the Ministry of Agriculture and Rural Development has established two main goals towards ensuring food security and improving the efficiency of rice land use by maintaining and flexibly using rice-growing areas. Therefore, efficient planning of rice-growing areas is a complex challenge that requires attention and strategic solutions in Vietnam.

Our case study is in Thai Nguyen – a mountainous province located in the Northern Mountainous area. The natural land area of the province is 352,664 ha. The rice cultivation area in 2020 is 44,753 ha (TNSD, 2020) [2]. In the next few decades, as the provincial population continues to rise, demand for food would increase in both quantity and quality. At the same time, with the process of industrialization and modernization, the rice-growing area is decreasing due to industrial development, infrastructure, and urbanization. Besides, a part of the rice area has been converted to other land uses, such as cultivation of different crops. While there is a reduction in rice areas, local rice demand increases due to rising the population. Therefore, it is necessary to develop a plan for rice-growing land areas to sustain rice production, as well as to support the agricultural development strategies of the province. Efficient planning of rice production requires a thorough assessment of suitable land and ecological conditions (Heumann B.W. et al. 2011) [3]. Spatial analyses can enable this critical task by classifying each land unit based on its suitability for rice production. Land suitability can be divided into four classes, namely: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) according to the framework for land evaluation FAO 1976 [4]. Spatial assessment of land suitability for rice production could serve as a starting point for evaluating sustainable land management. Environmental factors deemed suitable can reflect the level of

sustainability for the same land use over the period. Moreover, effective economic factors and agricultural development policies are the other important considerations for planning rice-growing land areas in this study. In recent years, Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) tools (specially, multi-criteria analysis) have been used for land suitability assessment and planning suitable sites for agricultural land use, major crops, and local foods (Pramanik M.K. 2016; Akinci H. et al 2013; Bunruamkaew K. and Murayama Y. 2011; Elsheikh R. et al 2013; Zolekaz R.B et al 2015; Zabihi H. et al 2015; and Widiatmaka W. 2016) [5], [6], [7], [8],[9],[10],[11]. Such suitability analysis includes criteria associated with topographic features, soil characteristics, weather parameters, and crop characteristics. The selection of the most appropriate method for land suitability assessment is important for current and future land use planning. Computational technologies combined with GIS and multicriteria have been used to conduct this study to find solutions for land suitability at the regional scale.

2. MATERIALS AND METHODS

2.1 Study area

Thai Nguyen is a mountainous province in Northern Vietnam. It is located from Latitude 21°20' North to 22°03 North, and from Longitude 105°52' East to 106°14' East. Thai Nguyen covers 352,644 ha, with a population of 1,291 thousand (TNSD,2020) [2].

This study focuses on 44,753 ha areas of rice cultivation in nine districts of Thai Nguyen Province (Thai Nguyen City, Song Cong City, Dai Tu District, Dinh Hoa District, Phu Luong District, Vo Nhai District, Phu Binh District, Pho Yen District, and Dong Hy District).

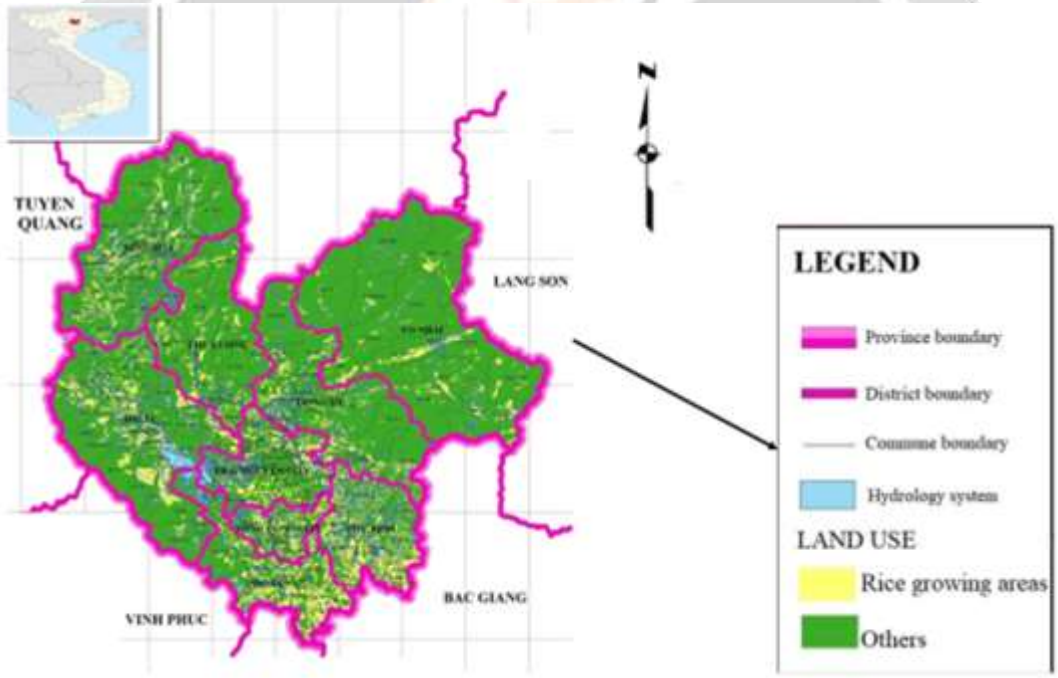

Fig-1: Rice growing areas in Thai Nguyen Province 2020.

2.2 Data Collection

Table 1 lists the secondary datasets collected in this study.

No	Name of data	Description	Source	Note
1	DEM		https://earthexplorer.usgs.gov/	Used to build the slope map and elevation map.
2	Land use of Thai Nguyen Province 2020	Map scale 1/100.000	Thai Nguyen Natural Resource and Environment Department	

3	Data of temperature	10-year data from 2010-2020	Meteorology Hydrological Stations in all cities, and districts of Thai Nguyen Province.	Used to build the temperature map by the interpolation method
4	Data of rainfall	10-year data from 2010-2020	Meteorology Hydrological Stations in all cities, and districts of Thai Nguyen Province.	Used to build the rainfall map by the interpolation method
5	Soil Type Map	Map scale 1/100.000	Thai Nguyen Natural Resource and Environment Department	
6	Irrigation Map	Map scale 1/100.000	Thai Nguyen Natural Resource and Environment Department	
7	pH Map	Map scale 1/100.000	Thai Nguyen Department of Agriculture and Rural Development, 2020.	
8	Depth of soil Map	Map scale 1/100.000	Thai Nguyen Department of Agriculture and Rural Development, 2020.	
9	Soil composition Map	Map scale 1/100.000	Thai Nguyen Department of Agriculture and Rural Development, 2020.	

Table-1: The specific collected data

2.3. Soil Classification

The FAO Framework for Land Evaluation (FAO, 1976) [4] was the main framework for soil classification. The suitability of rice growing areas was divided into 4 levels: highly suitable (S1), Moderately suitable (S2), Marginally Suitable (S3), and Not suitable (N).

According to Vietnam National Standard TCVN 8409-2010 (MARD, 2010) [14], the criteria that affect most rice growth and development were: Topography (slope, elevation), Climate (temperature, rainfall), Irrigation, and Soil characteristics (soil type, pH, the depth of soil class, soil mechanical composition).

The specific suitable criteria for rice cultivation in Thai Nguyen Province as Table 2 below:

	SUITABILITY CLASSIFICATION			
CRITERIA	S1	S2	S3	N
Soil Type	Pc, Pf, Py	Pbc,Pg, B, Fl	D, Rk	Others
Temperature	TEM 4	TEM 3, TEM 5, TEM 6	TEM 2	TEM 1, TEM 7
Rainfall	R4	R3	R2	R1
Slope	SL1, SL2	SL3, SL4	SL5	SL6
Elevation	E2	E3	E1	E4, E5
Irrigation	I1	I2	I3	W,N
pH	P3	P2	P4, P1	W,N
Depth of soil	D1	D2	D3	W,N
Mechanical composition	C3	C2	C1, C4	C5, C6

Table-2: Suitability criteria for rice-growing areas

2.4. GIS analysis

Suitability assessment criteria are used as the raster data layers for soil types, rainfall, slope, elevation, temperature, irrigation, pH, soil mechanical composition, and depth of soil classes. Suitable weights determine the importance of each criterion, and the final classification divides land units into suitability classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

Suitability scoring is a way of computing values across the source layers so that there is a common standard. All source layer values are placed on the same scale with the same units. The same scale is used for all individual suitability layers and the final overall suitability layer. In this study, a score of 9 was used for highly suitable areas, 7 for moderately suitable areas, 5 for marginally suitable areas, and 3 as a restricted value for unsuitable areas.

Weighted overlays are raster calculator tools that identify the best or the most preferable locations for rice production. The criteria included in the weighted overlay analysis are not equally important. The weights of key criteria were calculated using the AHP application in Matrix pairwise comparison (Satty 1989,1997) [12], [13].
The formula for calculating the final index is:

$$S = \sum_{i=1} (W_i \times X_i) \quad (1)$$

Where: S: suitable index; Wi: weight of criterion I; and Xi: score of criterion i.
With the reclassification and weighted overlay method, we conduct spatial analysis and generate a suitability map for rice production. [15],[16]. The data were reclassified according to the suitable index hierarchy (Table 3).

SUITABLE INDEX	SUITABLE CLASS
7-9	S1
6-7	S2
5-6	S3
<5	N

Table-3: Suitable index hierarchy.

The maps generated in the study used GIS technology through ArcGIS 10.2 Software built at 1/100000 scale.

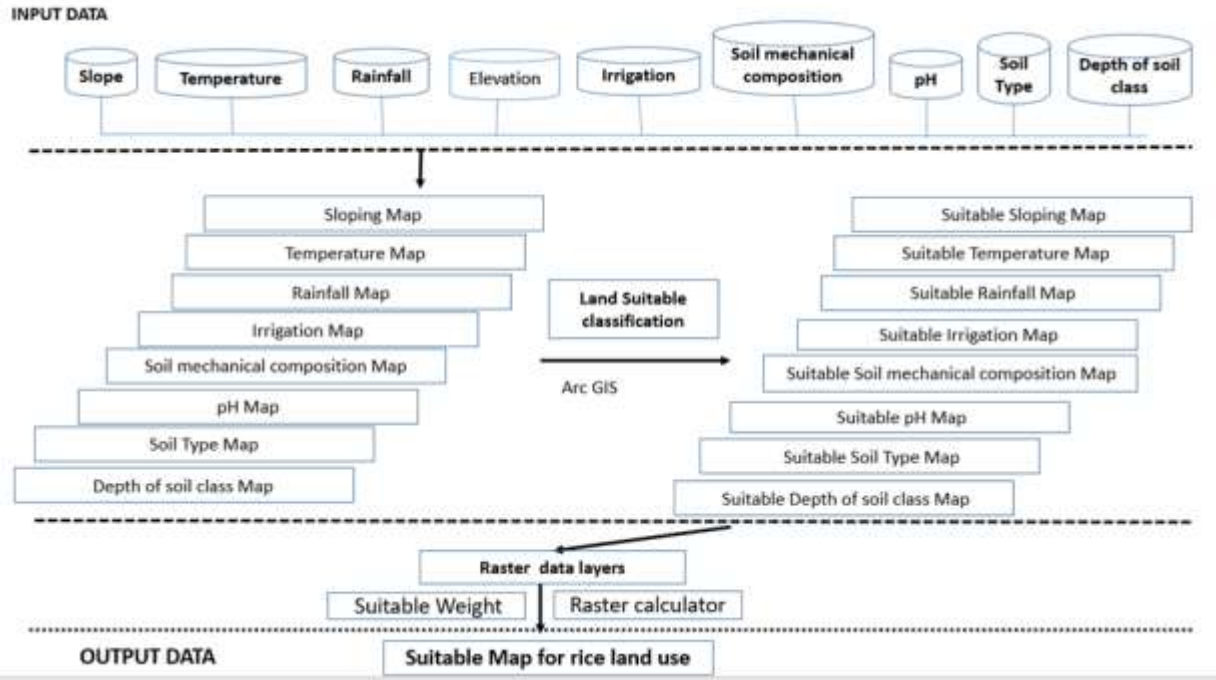

Fig-2: Process in followed constructing suitability of map for rice cultivation in Thai Nguyen Province.

3. RESULTS

3.1. The weight of criteria for land suitability assessment of rice growing areas in Thai Nguyen Province.

Experts' opinion from the survey showed that irrigation is the most important criterion affecting rice cultivation (0.351), followed by rainfall (0.220) and temperature (0.143). The depth of the soil class is the fourth (0.094), and the soil composition is the fifth (0.060). Soil pH (0.046), soil type (0.034), elevation (0.027), and slope (0.025) occupy the 6th-9th places, respectively. It is critical to check the reliability of the weights in an analytic hierarchical process. We verified the accuracy of the expert opinion panel by calculating the values parameters of the composite comparison matrix and determining the consistency ratio (CR). The CR value (0.08) meets the

requirement: hence the weight of each criterion is valid for calculating the suitability index of rice suitability in Thai Nguyen Province.

3.2. Suitability Assessment of Areas Planted to Rice in Thai Nguyen Province

To solve the problem of adaptive assessment of rice growing areas in Thai Nguyen Province, we used the classification function in the spatial analysis of GIS based on a raster data model. We overlay data on the map with the method of weighted overlay of raster data layers. Therefore, the weights of the elements were generated, and the data for the elements' raster data layer in each level of suitability are encoded (Table 4). The suitability index S for each land unit for rice production was computed as a weighted sum of nine criteria including soil type, temperature, rainfall, slope, elevation, irrigation, pH, soil composition, the depth of soil classes corresponding to X1-X9 in the following the equation:

$$S= 0.069* X1 + 0.285* X2 + 0.440 * X3 + 0.049* X4 + 0.054 * X5 + 0.703* X6 +0.091 * X7 + 0.120* X8 +0.189 * X9 \quad (2)$$

We followed an index hierarchy to reclassify land units based on the value of their suitability index (S). A value of 8-9 indicated high suitability (S1), while a value of 6-7 indicated moderate suitability (S2). Land units with a value of 4-5 were classified as marginally suitable (S3), while those with a value of less than 4 were considered not suitable (N).

We followed an index hierarchy to reclassify land units based on the value of their suitability index (S). A value of 8-9 indicated high suitability (S1), while a value of 6-7 indicated moderate suitability (S2). Land units with a value of 4-5 were classified as marginally suitable (S3), while those with a value of less than 4 were considered not suitable (N).

SYMBOL	CRITERIA	SUITABILITY INDEX			
		S1 (9)	S2 (7)	S3 (5)	N (3)
X1	Soil type	0.310	0.241	0.172	0.069
X2	Temperature	1.284	0.999	0.713	0.285
X3	Rainfall	1.979	1.539	1.099	0.440
X4	Slope	0.221	0.1724	0.123	0.049
X5	Elevation	0.243	0.189	0.135	0.054
X6	Irrigation	3.162	2.460	1.757	0.703
X7	pH	0.411	0.320	0.229	0.091
X8	Depth of soil	0.848	0.660	0.471	0.189
X9	Mechanical composition Soil	0.540	0.420	0.300	0.120

Table-4. Suitability indices used in assessing the suitability of rice cultivation areas in Thai Nguyen Province, 2020.

The total area for rice in Thai Nguyen Province in 2020 wass 44,753 ha. Hence, the level of suitability for rice cultivation was determined based on the criteria assessment.

DISTRICT	S1 (ha)	S2 (ha)	S3 (ha)	N(ha)	TOTAL (ha)
Dai Tu	3,365	155	519	35	4,074
Dinh Hoa	1,502	542	421	23	2,488
Dong Hy	4,854	475	517	194	6,040
Phu Binh	3,397	580	1,573	18	5,568
Phu Luong	2,238	960	1,248	12	4458
Song Cong	2,182	682	679	2	3,545
Thai Nguyen	2,881	149	1,249	19	4,298
Pho yen	5,285	263	1,452	5	7,005
Vo Nhai	3,472	3,193	382	230	7,277
Total	29,175	6,999	8,041	538	44,753

S1: highly suitable; S2: moderately Suitable; S3: marginally suitable; N: Not suitable

Table-5: Suitable areas for rice cultivation using four levels of suitability classifications in Thai Nguyen Province, 2020.

The results in Table 5 show that rice growing areas in Thai Nguyen Province 2020 had 29,175 ha highly suitable (S1), 6,999 ha moderately suitable (S2), 8,041 ha marginally suitable (S3), and 538 ha not suitable (N).

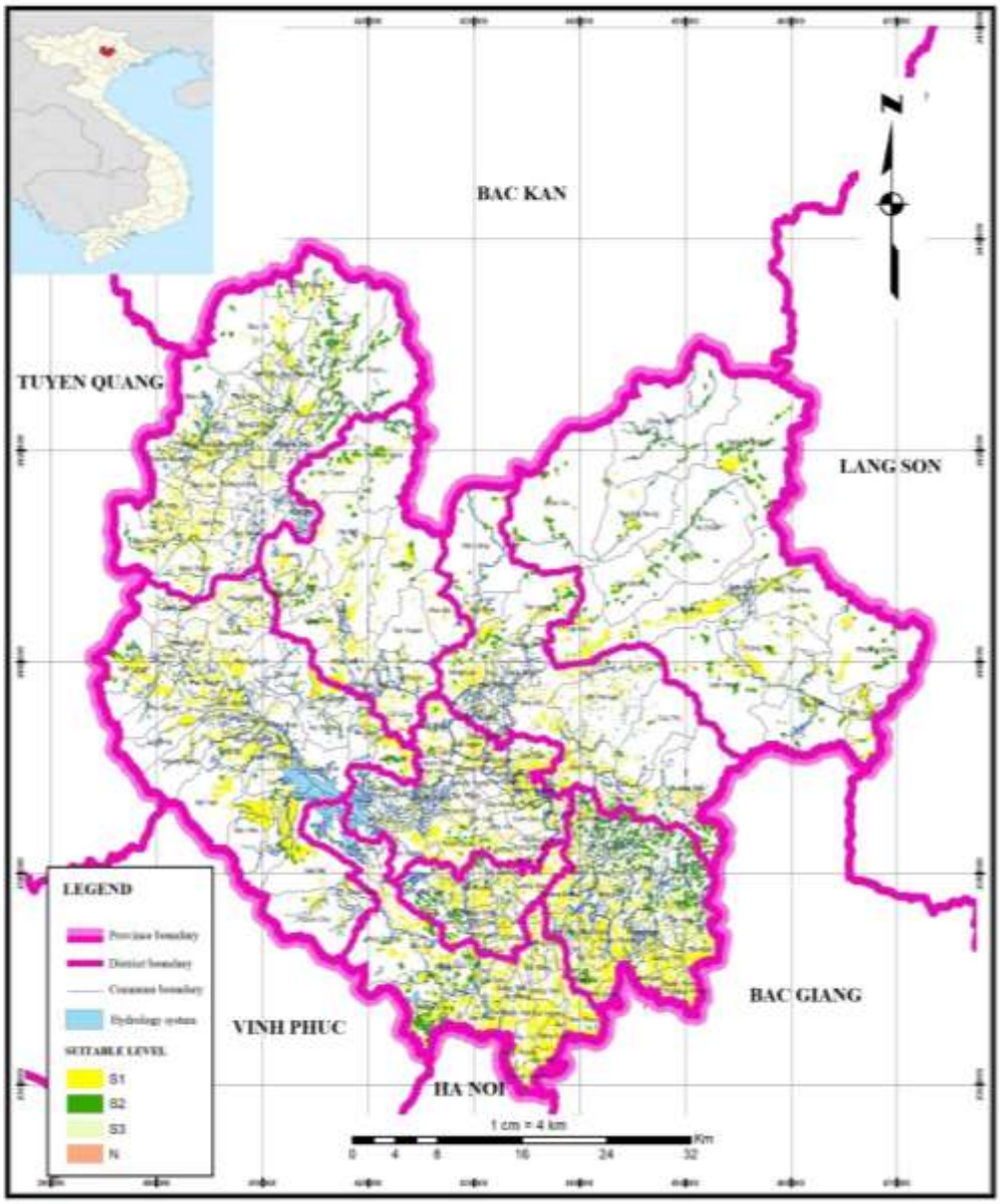

Fig-3: Rice suitability map for nine districts of Thai Nguyen Province in 2020.

4. DISCUSSION

There are two types of land use for rice cultivation in Thai Nguyen: 1) Summer rice-growing areas, and 2) intensive rice-growing areas (planted 2 or more rice seasons per year).

With the tropical climate in Viet Nam, heavy rains are frequent even during summer, which enables a cycle of rice production during summer. Areas for summer rice production (summer rice growing areas) are found in relatively higher terrains and are largely rainfed. In these areas, rice production in other seasons is not feasible due to inadequate rainfall. Besides, the canal systems in the areas are poorly constructed, leading to inadequate water in the field during other seasons.

Intensive rice growing areas are found in flat terrain where irrigation is developed. The canal systems are well-constructed, allowing for sufficient water flow to the fields throughout the year. Consequently, it is feasible to plant more than two rice crops annually in these areas.

In essence, since intensive rice-growing areas had better irrigation than summer rice-growing areas, they typically had higher economic efficiency. For suitability classification of rice cultivation areas, S1 and S2 areas were suitable for intensive rice-growing areas while the S3 areas were for summer rice-growing areas. As such, there were 36,174 ha of suitable areas for intensive rice cultivation and 8,041 ha of suitable areas for summer rice. The detailed classification of rice growing areas in each district was as follows.

The total rice growing area in Dai Tu district was 4,074 ha (2020) of which there were 3,365 ha of highly suitable (S1), 155 ha of moderately suitable (S2), 519 ha of marginally suitable (S3), and 35 ha of not suitable (N). Thus, there was 3,520 ha of suitable areas for intensive rice and 519 ha of suitable for summer rice. Further, the annual rice planted areas in 2020 had 12,117 ha with a yield of 5.7 tons/ha and production of 68,775 tons (TNSD, 2020) [2], which proves that the rice cultivated areas were used effectively. The production was highest in Thai Nguyen Province based on cultivating 3 crops per year and using short-day rice varieties and high technical practices.

The total rice growing area in Dinh Hoa District was 2,488 ha (2020) of which there were 1,502 ha of highly suitable (S1), 542 ha of moderately suitable (S2), and 421 ha of marginally suitable (S3), 23 ha of not suitable (N). Although Dinh Hoa was a highland district of Thai Nguyen Province with the smallest areas of rice cultivation, the annual rice planted area was 8,775 ha with a yield of 5,3 tons and production of 47,321 tons (TNSD, 2020) [2]. Rice-growing areas were effective potentially because farmers focused intensively on rice production. They used short-day rice varieties and intensive cultivation. With high rice quality in Dinh Hoa, the provincial government had planned to build "high-quality rice production areas".

The total rice growing area in Dong Hy District was 6,040 ha (2020) of which there were 4,854 ha of highly suitable (S1), 475 ha of moderately suitable (S2), 517 ha of marginally suitable (S3), and 194 ha of not suitable (N). The annual rice planted area was 6,517 ha with a yield of 5.6 tons and production of 36,707 tons (TNSD, 2020) [2]. Although the rice growing areas in Dong Hy were large, land use efficiency was limited, leading to low production. The main reason was that farmers were not interested in rice production, and they only maintained a low production level.

Phu Binh was one of the districts in Thai Nguyen that had large rice production from the past to the present. The total rice growing area in Phu Binh district was 5,568 ha (2020) of which there were 3,397 ha of highly suitable (S1), 580 ha of moderately suitable (S2), and 1,573 ha of marginally suitable (S3), and 18 ha of not suitable (N). The annual rice planted area was 12,185 ha with a yield of 5.6 tons and production of 67,103 tons (TNSD, 2020) [2]. Rice growing areas were mostly intensive with 2-3 rice crops/year.

The total rice growing area in Phu Luong District was 4,458 ha (2020) of which there were 2238 ha of highly suitable (S1), 960 ha of moderately suitable (S2), 1,248 ha of marginally suitable (S3), and 12 ha of not suitable (N). Besides this, the annual rice planted area in Phu Luong in 2020 was 5,794 ha with a yield of 5.2 tons and a production of 30,537 tons (TNSD, 2020) [2]. Thus, it was evident that rice-growing areas in Phu Luong had been used inefficiently with the lowest yield in the province.

The total rice growing area in Song Cong City was 3,545 ha (2020), of which there were 2,182 ha of highly suitable (S1), 682 ha of moderately suitable (S2), 679 ha of marginally suitable (S3), and 2 ha of not suitable (N). Annual rice planted areas were 3,582 ha with a yield of 5.2 tons and production of 18,684 tons (TNSD, 2020) [2]. Song Cong District had experienced significant industrial development in recent years, with the establishment of multiple industrial areas. Consequently, there was a shift in the labor force towards off-farm employment in private companies (e.g., Samsung Corporation and Sony Corporation), leading to a shortage of labor for agricultural production. The rice cultivation in this district was maintained at 1 crop/year, and the yield was the lowest in the Thai Nguyen Province.

The total rice growing area in Thai Nguyen City was 4,298 ha (2020) of which there were 2,881 ha of highly suitable (S1), 149 ha of moderately suitable (S2), and 1,249 ha of marginally suitable (S3), and 19 ha of not suitable (N). Annual planted rice was 6,255 ha with a yield of 5,4 tons and production of 33,798 tons in 2020 (TNSD, 2020) [2]. Thus, rice-growing areas in Thai Nguyen City had been used not effectively. Intensive rice growing areas were available for 2-3 crops/year instead of 1-2 crops/year.

The total rice growing area in Pho Yen district was 7,005 ha (2020), of which there were 5,285 ha of highly suitable (S1), 263 ha of moderately suitable (S2), 1,452 ha of marginally suitable (S3), and 5 ha of not suitable (N). Annual planted rice was 9,632 ha with a yield of 5.5 tons and production of 53,745 tons (TNSD, 2020) [2]. The potential of annual planted areas could increase to about 12 thousand ha. However, the current annual rice planted areas only accounted for 3/4 of potential areas.

The total rice area in Vo Nhai District was 7,277 ha (2020) of which there were 3,472 ha of highly suitable (S1), 3,193 ha of moderately suitable (S2), 382 ha of marginally suitable (S3), and 230 ha of not suitable (N). According to the TNSD, 2020 [2], the rice-planted area was 4,900 ha with a yield of 5,4 tons and a production of

26,734 tons. It was too small compared with the potential land areas. The reason was that Vo Nhai is located in the highland area of Thai Nguyen Province, and most of the rice growing areas were used for the cultivation of summer rice which was an inefficient cropping season.

In general, rice growing areas in Thai Nguyen had 36,174 ha of intensive rice growing areas and 8,041 ha of summer rice growing areas, respectively 80.8 % and 18.0% of total rice areas. The small unsuitable area of 538 ha (1.2%) was not efficient for rice cultivation. According to the TNSD, 2020 [2], total rice planted areas were 69,757 ha with a yield of 5.5 tons/ha and production of 383.4 thousand tons. However, considering that the suitable rice production area exceeds 80,389 hectares, with a potential production estimate of over 400 thousand tons, it become evident that the rice-growing areas in the province werenot being optimally utilized. In 2020, Dai Tu District, Phu Binh District, Pho Yen District, and Dinh Hoa District were the four major districts for rice production in Thai Nguyen Province with relatively effective land use, high yields, and high production.

5. CONCLUSIONS

This study assessed the efficiency of land use in rice cultivation by identifying suitable rice-growing areas. We employed a multicriteria analysis in conjunction with Geographic Information System (GIS) techniques. Nine criteria were utilized for the assessment, including elevation, slope, rainfall, temperature, irrigation, soil pH, depth of soil classes, soil composition, and soil type. Through the analysis, we determined the order of importance for the criteria, with irrigation ranking as the most important, followed respectively by rainfall, temperature, depth of soil classes, soil composition, soil pH, soil type, elevation, and slope. To calculate the weight of each criterion, all the criteria were processed using a weighted overlay approach.

Our land suitability assessment conducted in Thai Nguyen Province for the year 2020 revealed the following distribution of rice growing areas: 29,175 hectares were highly suitable (S1), 6,999 hectares were moderately suitable (S2), 8,041 hectares were marginally suitable (S3), and 538 hectares were deemed unsuitable (N). This indicates that there were 36,174 hectares of suitable land for intensive rice cultivation and 8,041 hectares suitable for summer rice cultivation, accounting for 80.8% and 18.0% of the total rice areas, respectively.

Comparing these findings with the statistics from the Thai Nguyen Statistical Yearbook 2020, it was reported that the total rice planted area was 69,757 hectares, with a yield of 5.5 tons per hectare and a production of 383.4 thousand tons. The assessment results highlight that the potential of rice-growing areas in the province was not optimally utilized. The potential rice growing area was estimated to be more than 80,389 hectares, with the potential production exceeding 400 thousand tons.

Moreover, Dai Tu District, Phu Binh District, Pho Yen District, and Dinh Hoa District are the four important districts for rice production in Thai Nguyen Province with relatively effective land use, high yields, and substantial production levels. The results of our research hold considerable value in guiding decision-making processes related to developing effective land use planning for rice cultivation in Thai Nguyen Province. Understanding the suitability of different areas for rice production is crucial for formulating production scenarios and facilitating regional planning efforts in the province

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Apendix 1:

Criteria	Sub-criteria	Value
Slope	SL1	0-3 degree
	SL2	>3-8 degree
	SL3	>8-15 degree
	SL4	>15-20 degree
	SL5	>20-25 degree
	SL6	>25 degree
Elevation	E1	0-50 masl
	E2	>50-500 masl
	E3	>500-1000 masl
	E4	>1000-1500 masl
	E5	>1500 masl
Rainfall	R1	<1000mm/year
	R2	1000-1200mm/year
	R3	>1200-1400mm/year
	R4	>1400mm/year
Temperature	TEM1	<10^{o}C
	TEM2	>10 ^{o}C- 18 ^{o}C
	TEM3	>18^{o}C- 24 ^{o}C
	TEM 4	>24 ^{o}C- 31 ^{o}C
	TEM 5	> 31 ^{o}C- 36 ^{o}C
	TEM6	>36 ^{o}C-40 ^{o}C
	TEM7	>40 ^{o}C
Irrigation	I1	active watering
	I2	relatively active watering
	I3	none watering or no irrigation system
Soil pH	P1	< 4.5
	P2	4.5-5.5
	P3	>5.5-6.5
	P4	> 6.5
Depth of soil	D1	>100cm

classes	D2	>70-100cm
	D3	>50-70cm
	D4	<50 cm
Soil mechanical composition	C1	Sandy loam
	C2	Loam
	C3	Silt
	C4	Silty clay
Soil type	Pbc	Alluvial soil deposited annually
	Pc	Alluvial soil
	Pg	Gleyic Alluvial soil
	Pf	Red-yellow alluvial soil
	Py	Streaming alluvial soil
	B	Discolored gray soil on ancient alluvium
	Rk	Black soil on the accretion product of basalt
	Fl	Red-yellow soil changes due to paddy rice cultivation
	D	Valley soil

BIOGRAPHIES

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