Application of MCE-AHP technical for modelling paddy zoning: A case study in Vietnam

Tong Thi Hanh[1,*], Mai-Phuong Pham[2], Nguyen Thi Thu Nga[1], Samreen Riaz Ahmed[3], Altaf Hussain Lahori[4], Nataliia Borodina[5,*]

[1] Le Quy Don University, Hanoi 100000, Vietnam
[2] Joint Vietnam - Russia Tropical Science and Technology Research Center, Vietnam
[3] Department of English, Sindh Madressatul Islam University, Karachi 74000, Pakistan
[4] Department of Environmental Sciences, Sindh Madressatul Islam University, Karachi 74000, Pakistan
[5] Institute of Public Administration and Research in Civil Protection, Kyiv 74000, Ukraine

*Corresponding author e-mail address: Nataliia Borodina (N.B.) drmarchenko1968@gmail.com; Tong Thi Hanh (T.T Hanh) hanhkhuenam@gmai.com

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Abstract. The main aim of present study was to determine the most suitable land for paddy via AHP - GIS and Remote Sensing. Ba Thuoc district - Thanh Hoa province was selected as the target area to conduct the experimental set-up. As per opinion of scientists and the guidance of World Food Organization (FAO) on agricultural crops, the criteria selected to estimate the ecological adaptation of crops include soil type, soil texture, soil depth, soil pH, N (%), elevation, slope, distance from rivers, yearly precipitation, low-average and high temperature, average sunny hours, saltwater intrusion. The land suitability map was generated by superimposing the component maps considering the weighting of the criteria. The obtained results showed that in the experimental area nearly 8.26% of the land-use region was very appropriate for rice growing, 26.29% was observed medium appropriate, 43.35% was less appropriate and 22.1% was not fit for paddy cultivation. Overall, the data may be of value for country government, policy makers, managers as well as local authorities to induce local farmers for paddy production on most suitable areas.

Key words: GIS, land suitability, MCE-AHP, model, rice production, land appropriateness, productivity, potential adaptative classification map.

1. Introduction

The rising world population, traditional agricultural practices, conversion of fertile land into construction buildings, technogenic impact and land pollution can be considered for decline in the suitability of land for crop and food production, particularly in developing countries (Wang, 2022; Sydorenko et al., 2022; Ziarati et al., 2020). In addition, a variety of additional concerns, viz., farmland deprivation (erosion, salinity, desert, toxicants), climate change, drought intensification, and development, have challenged agrarian practices and reduced plant yields (Conway et al., 2012; Gerland et al., 2014; Hussain et al., 2022; Ziarati et al., 2022). Over this, reaching the Sustainable Development Goals (SDGs) by 2030, notably the second objective of reaching zero-hunger via 2030 (SDG2), would need sustained and unrelenting determinations on the part of scientists and policymakers to design the ideal framework for land use (OFLU). In this framework, the OFLU offers local planners and users with an overview of land capacity, which is founded on land appraisal and land fitness evaluations (Valin et al., 2021) which they may use to make decisions about land use.

Because of regional change patterns and the fast expansion in the worldwide population since last several eras, land suitability and land appraisal have developed one of the issues that both investigation centres and politicians throughout the globe are concerned in (OECD, 2009). More emphasis has been placed on the management of land resource, land capabilities, agriculture, and long-term stable as a result. According to (El-Sheik et al., 2010; Everest et al., 2021), land appropriateness for any drive may be characterized as the result of a complicated interplay among multiple ecology mechanisms such as environment, soil health, and territory. However, land appropriateness is a mix of the appropriateness of land for a given purpose and the worth and significance of the property to stockholders, which is defined as follows: In this framework, (FAO, 2007) pointed out that the level of socio-economic movement and the effectiveness of public societies have an impact on decisions about land use in each given part of the world. The land estimate process is a useful implement and context for obtaining the most efficient use of available land.

An agenda that considers both physical site qualities (e.g. soil, weather, landscape), and socioeconomic elements (people, infrastructures and markets) in order to construct the ideal land use, as well as ideas for different alternative land use options. As a result, land assessment assists savers, farmers, policy makers, and planners in predicting the performance of a piece of land for a certain land use. With another way of saying it, land evaluation provides reliable indicators of land capacity and limitation variables for use in a proposed land usage model. Many models have been created to evaluate land evaluation, including the automated land evaluation system, the land appraisal and spot assessment system, and the land evaluation decision support system. For land appraisal assessment, a variety of models have been utilized recently in a geographic information system (GIS), including uncertain logic with a logical grading process, a biased lined mixture with an analytical hierarchy process (De la Rosa et al., 1992; Hoobler et al., 2003; De la Rosa et al., 2004).

Paddy is the main crop in Southeast Asian countries, especially in Vietnam; paddy is a very popular crop and has been with farmers for thousands of years. This plant is the main food source there (Nguyen, 2019). Currently, the world's population is increasing significantly, leading to an increase in the demand for food. To increase production and ensure food security, crops in general and paddy need to be planted in the most suitable places. Only then, will new plants grow best and bring the highest economic efficiency (HLPE, 2017).

Critical Hierarchy Process is mixed-criteria method combined with GIS and expert opinions to give appropriate weights to the criteria. Mulugeta (2010) applied GIS and Multi-Criteria

Analysis (MCA) method to evaluate based on 5 factors including grade, soil wetness, soil texture, soil thickness, soil nature and current land use types for wheat and maize. In Asia, with the advantage of a large and long-standing agricultural region, there have been many studies on land adaptation, typically Liu et al. (2007) using GIS in suitable land analysis for the management and use of land resources in urban areas. Khoi and Murayama (2010) used MCE and GIS based on biophysical factors and Landsat images to delineate suitable areas for arable land in the reserve - barrier zone of Tam Dao National green, Vietnam. GIS and remote sensing technology are applied by Nguyen in paddy production management in the Mekong Delta (Nguyen, 2014). In addition, there are many studies on applying GIS and AHP in supporting the analysis of large, complex and multi-purpose data volumes in the studies of (Cengiz & Akbulak, 2009; Akıncı et al., 2013; Bagheri et al., 2013). In our previous study, Tong et al. (2021) used a model for rice land suitability based on combined multi-criteria decision making in Quang Tri Province of Vietnam. Recently, Shaloo et al. (2022) performed a crop-suitability analysis by using the analytic hierarchy process and GIS technique for cereal production in Northern part of India. Hence, the main aim of present study was to assess the most suitable land for paddy mapping through AHP - GIS and Remote Sensing techniques.

2. Materials and methods

2.1. Study area description

The famous district namely Ba Thuoc is located in the North-West of Thanh Hoa province with an average altitude between 600-700m, slope around 25^0, total area is 77522 ha (Fig. 1). Ba Thuoc has a tropical climate with 04 seasons. The average summer temperature ranges from 26-33°C, while the winter temperature between 18-24°C. The annual rainfall is 1400-1800 mm. Overall, the climate is quite favourable for rice production.

2.2. Soil sampling

In the present study, approximately 32 soil profiles were created to meet the research objectives. It was decided where each soil profile will be located after conducting a field tour (i.e., land use, soil colour). Following the description of each soil profile, soil samples were collected for physiochemical testing. The soil suitability for rice production for each profile was determined based on the decisions of the focus groups (experts, farmers, and members of the study team). Essentially, the weighting factor technique assigns priority to each soil quality based on how important it is. The findings of the weighted soil characteristics were uploaded to ArcGIS and interpolated via the inverse distance weighted (IDW) technique, after which they were appraised in accordance with the researched paddy requirement. Overall, IDW differs from the stochastic technique (such as simple kriging) in that it does not impose tight numerical hypothesis on the dataset, whereas the stochastic method does. It is expected that each facts point has a limited impact on the resulting surface, and it is typically functional with an extremely adaptable spatial dataset as an interpolator using a touching average; as a result, the inverse distance weighted technique has produced the least amount of error between the popular interpolation approaches.

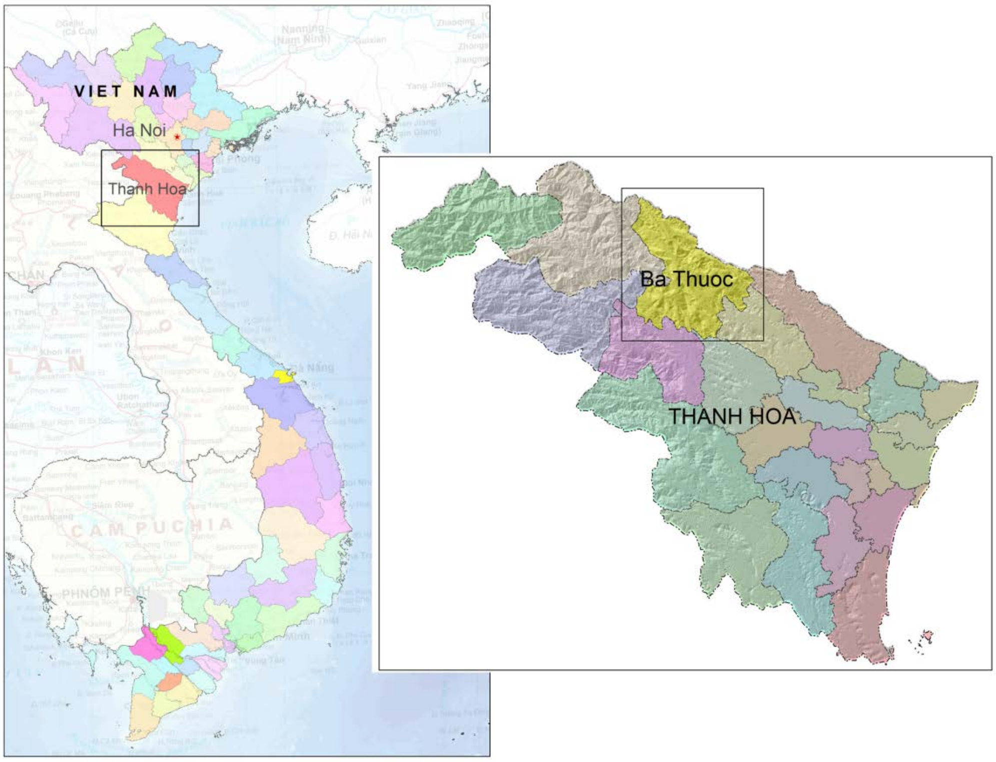

Figure 1. Map of study area

2.3. Topography data

The topography of the earth's surface can be representing by using one of the best digital elevation model (DEM) technique. The DEM for the research region was created using SRTM remotely sensed imagery (Shuttle Radar Topography Mission), which has a global spatial determination of 1 arc-second (about 30 m) and was collected through the Earth Explorer website (https://earthexplorer.usgs.gov). The DEM was then divided into slope groups, and the results were reviewed in accordance with the criteria for paddy production.

2.4. Climatic data

The monthly temperature was obtained by World Clim v.1.4 Data at 30-seconds resolution (https://www.worldclim.org/data/). Using the baseline climatic data, the dataset was clipped for the research region, which was accessible on a worldwide basis at the time (Hijmans et al., 2005; Fick & Hijmans, 2017). This data was obtained from the World Relative Humidity (WRH) database, which provides monthly relative humidity (RH). The average, lowest, and highest relative humidity (RH) were intended at 5 arc minutes globally using "WorldClim," founded on partial data of smallest and extreme temperature and calculated with the dew point method using the tabular relationship for Linacre's method using the dew point method using the tabular relationship for Linacre's method (Jones & Wint, 2015). Finally, in accordance with Table 10, the current climate was assessed in terms of paddy needs.

2.5. Land use/Land cover

The current land use map is built from Sentinel 2 satellite images in 2020 downloaded from Google Earth Engine and analysed on QGIS 3.12 software based on image interpretation keys built and updated in the field (April 2021). All maps are georeferenced to the WGS84 - Zone48 coordinate system. Normalized Difference Vegetation Index (NDVI) is a phytochemical index that correlates with several important biophysical properties and produces various crop indices. Mostly rice harvests take place in May or June. Satellite images (Sentinel-2) were obtained at the end of the growing period and before May 2020. Normalized difference negetation index is developed from two important wavebands: the red and near-infrared (NIR). It has been broadly used for farming mapping and yield tracking. The normalized difference vegetation index is cumulated as follows:

$$NDVI = \frac{RNIR - Rred}{RNIR + Rred} \quad (1)$$

RNIR, Rred are the reflectance spectrum of the surface in the near infrared and red bands.

2.6. Analytic hierarchy process (AHP) and Multi-criteria evaluation (MCE)

The AHP hierarchical analysis method combined with the MCA multi-criteria problem was applied to detect the relative importance (weights) of the criteria. Then, a pairwise comparison matrix is constructed using information gathered from experts and logic. The results are quantified by a pairwise comparison matrix consisting of n rows and n columns (n is the number of indicators) showing the relationship between the criteria. The aij element indicates the significance of row i indicator in comparison with column j with aij > 0 (Table 1). The elements on the main diagonal of the pairwise comparison medium are assigned a fixed value of 1. Since the pairwise comparison matrix is a square symmetric matrix, only the elements of the upper triangular medium need to be determined, then that takes the inverse to get the lower triangular medium. Based on the pairwise comparison matrix, calculate the weight for each criterion.

Summarize the priorities of each alternative to get the most common data on the final priorities of the options.

Table 1. Pairwise comparison matrix.

Criteria	[X1]	[X2]	...	[Xn]
[X1]	1	a_{12}	...	a_{1n}
[X2]	a_{21}	1	...	a_{2n}
...	...	...	...	...
[Xn]	a_{n1}	a_{n2}	...	1

The method of matrix normalization was chosen by the authors to weight the criteria, specifically as follows:

- Calculate the total value of each column of the pairwise comparison matrix: $\sum a_{ij}$ (2)

- Calculate the normalized matrix: Divide each component in the pairwise comparison matrix with the corresponding sum: $a_{ij} / \sum a_{ij}$ (3)

- Examine the set of weights (W): Sum each row of the normalized matrix, and then divide the sum of each row by the sum of all rows to get the corresponding set of weights for the criteria. The AHP provides a mathematical measure to determine the consistency of statements through the consistency ratio (CR) with steps:

- Determine the total weight vector by enlarging the original pairwise contrast matrix by the weight matrix of the criteria:

$$\begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} = \begin{bmatrix} S_1 \\ S_2 \\ \dots \\ S_n \end{bmatrix} \quad (4)$$

- The consistency vector was calculated by separating the total weight vector by the weights of the formerly distinct standards.

$$\begin{bmatrix} S_1 \\ S_2 \\ \dots \\ S_n \end{bmatrix} : \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \\ \dots \\ Y_n \end{bmatrix} \quad (5)$$

- Take the mean of the consistency vector to calculate the maximum eigenvalue (λ_{max}):

$$\lambda_{max} = \frac{\sum_{i=1}^{n} Y}{n} \quad (6)$$

The more consistent the statement, the closer the calculated value of λmax is to n; λmax = n, it means that the pairwise comparison matrix does not have any inconsistencies.

- Calculate the consistency index (CI- Consistency index), the index measuring the degree of consistency deviation, determined by the formula:

$$CI = (\lambda max - n)/ (n-1) \quad (7)$$

- Calculate the consistency ratio CR:

$$CR = \frac{CI}{RI} \quad (8)$$

In which: RI (Random index) is a random index determined from the lookup table proposed by Saaty.

Table 2. RI random index value (Saaty, 1994, 2008).

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.52	0.89	1.11	1.24	1.34	1.4	1.45	1.49	1.52	1.54	0.52

Table 3. Pairwise comparison matrix in multiple criteria decision making.

Criteria	[X1]	[X2]	[X3]	[X4]	[X5]	[X6]	[X7]	[X8]	[X9]	[X10]	[X11]	[X12]	Weight
[X1] Soil type	1.00	3.00	3.00	6.00	5.00	3.00	4.00	4.00	5.00	5.00	1.00	4.00	0.221
[X2] Soil texture	0.33	1.00	1.00	2.00	1.67	1.00	1.33	1.33	1.67	1.67	0.33	1.33	0.074
[X3] Soil depth (cm)	0.33	1.00	1.00	2.00	1.67	1.00	1.33	1.33	1.67	1.67	0.33	1.33	0.074
[X4] Elevation (m)	0.17	0.50	0.50	1.00	0.83	0.50	0.67	0.67	1.00	1.00	0.17	0.67	0.039
[X5] Slope (^{0})	0.20	0.60	0.60	1.20	1.00	0.60	0.80	0.80	1.00	1.00	0.20	0.80	0.044
[X6] Distance to river and stream (m)	0.33	1.00	1.00	2.00	1.67	1.00	1.33	1.33	1.67	1.67	0.33	1.33	0.074
[X7] Salinization	0.25	0.75	0.75	1.50	1.25	0.75	1.00	1.00	1.00	1.00	0.25	1.00	0.053
[X8] Mean annual temperature (°C)	0.25	0.75	0.75	1.50	1.25	0.75	1.00	1.00	1.00	1.00	0.25	1.00	0.053
[X9] Mean annual maximum temperature (°C)	0.20	0.60	0.60	1.00	1.00	0.60	1.00	1.00	1.00	1.00	0.20	0.80	0.046
[X10] Mean annual minimum temperature (°C)	0.20	0.60	0.60	1.00	1.00	0.60	1.00	1.00	1.00	1.00	0.20	0.80	0.046
[X11] Mean annual precipitation (mm)	1.00	3.00	3.00	6.00	5.00	3.00	4.00	4.00	5.00	5.00	1.00	4.00	0.221
[X12] Monthly average number of daylight hours	0.25	0.75	0.75	1.50	1.25	0.75	1.00	1.00	1.25	1.25	0.25	1.00	0.055
CR = 0,0011 < 10%													

If the CR value is ≤ 10%, then the experts' judgment is consistent, the weight set is accepted. On the contrary, CR > 10%, it is necessary to conduct discussions with experts to re-evaluate the weight of the criteria using pairwise comparison.

Following the evaluation of the ecological requirements of the indicators, the component maps are categorized on Arcgis into four degrees of intensity (S1, S2, S3, N). Component maps are generated in vector format in order to make the calculating procedure relatively accessible. Raster calculator command was used to calculate the efficiency index, which was calculated according to the weighted linear equation of the following criterion [Xi]:

$$S = 0.221[X1] + 0.074[X2] + 0.074[X3] + 0.039[X4] + 0.044[X5] + 0.074[X6] + 0.053[X7] + 0.053[X8] + 0.046[X9] + 0.046[X10] + 0.221[X11] + 0.055[X12]$$

The potential adaptation map for paddy was composed after reclassifying in GIS into 4 levels according to FAO (1976).

Table 4. Categories of land appropriateness index (FAO, 1976).

Categories of land suitability	Explanation	Index
Suitable index 1 (highly suitable)	Land unit is very favorable for paddy there are not any limits of environmental supplies	>80
Suitable index 2 (medium suitable)	Land unit is almost favourable for paddy and there are few limits of environmental requirements	60-80
Suitable index 3 (marginally suitable)	Land unit is marginally desirable for paddy and there are severe limitations of environmental supplies	30-60
Unsuitable index N (unsuitable)	Land unit is nearly unfavourable for paddy and there are severe limitations	<30

3. Result and discussion

3.1. Soil map analyses

Ba Thuoc has 7 soil classification units that moderately adapted the paddy ecological requirements, included red-yellow soil on clay rock and reddish-brown soil on the igneous rock, accounts for about 70% of the province's total area, followed by the low-adapted and non-adapted soil groups accounts for 3% and 27%, respectively (Fig. 2a, Table 5). There is no alluvial soil group in the experimental area; the most suitable soil for paddy, considered is one of the limitations to the growth and development of paddy in the present work. The soil texture of the part is quite diverse; there are 4 types of soil: loamy soil, sand, sandy loam, and clay. Most of the area is clay (66% of the area) and sand (25% of the area) which is low adaptation for paddy. The remaining small area was light loamy soil, sand accounting for about 8% of the area, corresponding to high and moderately suitable for paddy (Fig. 2b, Table 5).

Soil thickness is essential that affects crop yields, and it is considered the limiting factor for paddy because the plants do not take enough nutrients from the soil without the depth of the soil layer. The criteria of thick layer for rice adaptation are divided into 4 levels: >100 cm, 70-100 cm, 30-70 cm, and <30 cm. According to the classification results from the soil adaptation map by thick layer, the area of land with high adaptability and moderate adaptability to rice cultivation accounts for over 70% of the total land area, concentrated in the communes in the south of the district. Thus, the density of the soil surface layer in the study area provides a lot of nutrients for plants with a soil layer thickness of >100 cm occupying quite a large area, very suitable for rice cultivation (Fig. 2c, Table 5). A study conducted by Shaloo et al. (2022) who revealed that agrarian production could be enhanced by cultivating the crop such as wheat, rice, sorghum, maize and pearl millet in a highly and moderately appropriate zones.

Table 5. Potential area of soil factors.

	Soil type		Soil texture		Soil depth	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**
High potential (S1)	0	0	1815.28	3	26052.61	34
Moderately potential (S2)	54428.81	70	4563.44	6	28951.14	37
Low potential (S3)	1815.28	3	51431.43	66	2800.94	4
Not potential (N)	21277.93	27	19711.87	25	19717.32	25

3.2. Topography analyses

The study area has a relatively high altitude, characterized by mountainous terrain with values from 0-1700m. Areas with elevation >100m are not fit for growing rice, as a result for most of the area (83%). Areas of moderately acclimatized and less adapted elevations account for only 17% of the area (Fig. 3d, Table 6).

The slope mainly affects the mechanization in farming and affects the water holding capacity, leaching of the soil. The results of the slope mapping show the slope in the variable area quite large movement. The area with a slope < 8^0 accounting for 35% is suitable for growing rice, distributed mainly in the district's central area. The remaining area is poorly adapted and unsuitable for rice cultivation (accounting for 65%) (Fig. 3e, Table 6). Al-Sababhah and Hazaymeh (2019) observed a strong association among topography and green cover diversity in Irbid governorate could be identified.

3.3. Climatic analyses

Climate is also an essential factor in assessing crop adaptation. Indicators of extreme climate such as average maximum and minimum temperature are significant for the ecological threshold of crops so that farmers can arrange planting seasons to suit climate conditions. The criteria of annual average temperature, annual maximum temperature, average annual rainfall, and an average number of sunshine hours per month in the experimental area are favorable conditions for paddy to grow and develop under favorable conditions. However, due to the mountainous terrain, the average annual minimum temperature is relatively low, which is also one of the limitations to the area (Fig. 4, Table 7).

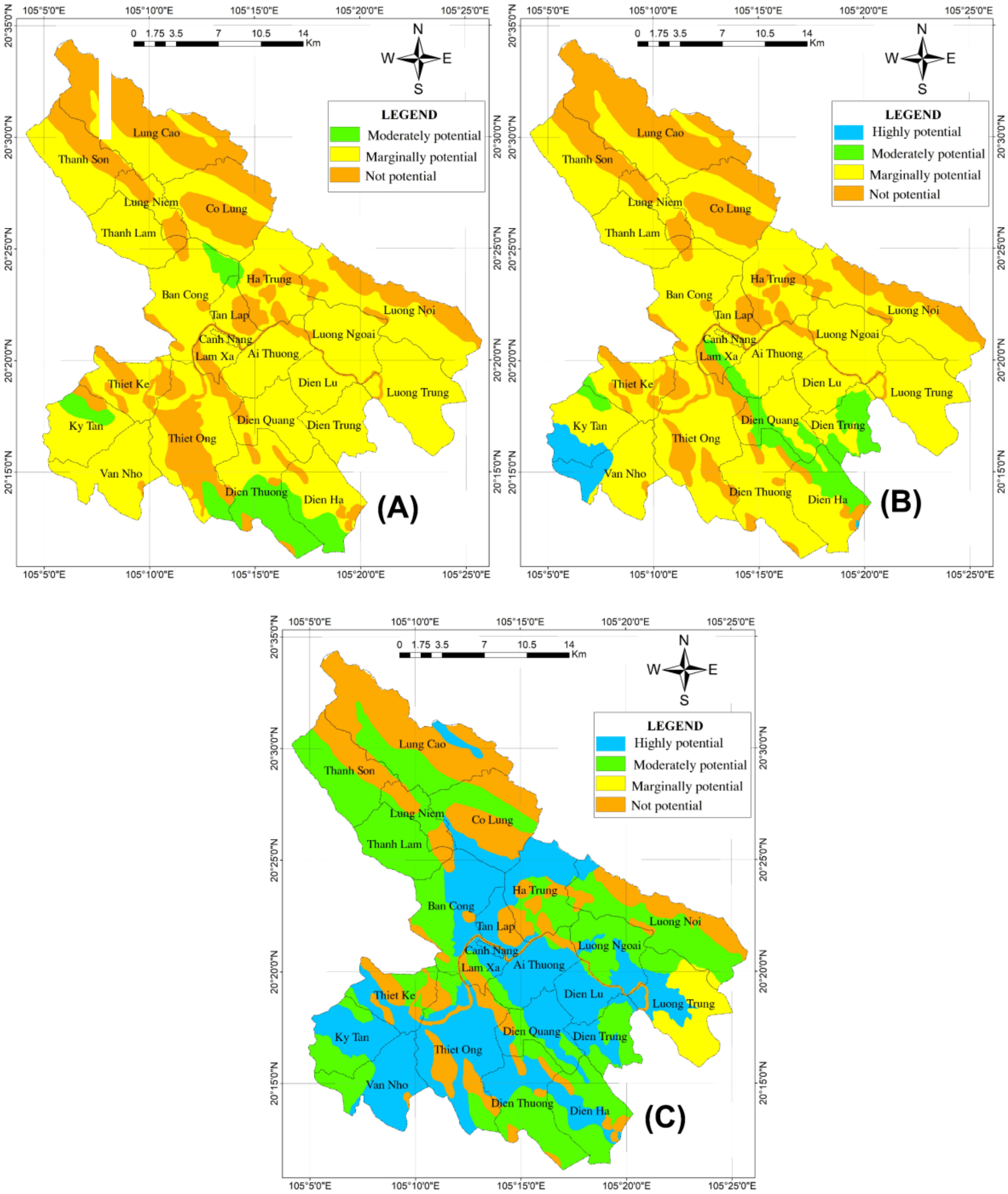

Figure 2. Evaluation of land potential for paddy based on soil criteria (A) Soil type, (B) Soil texture, (C) Soil depth.

Table 6. Potential areas of topography factors.

	Elevation		**Slope**	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**
High potential (S1)	0	0	10506.67	14
Moderately potential (S2)	2464.61	3	16544.30	21
Low potential (S3)	10491.61	14	18719.25	24
Not potential (N)	64565.80	83	31751.80	41

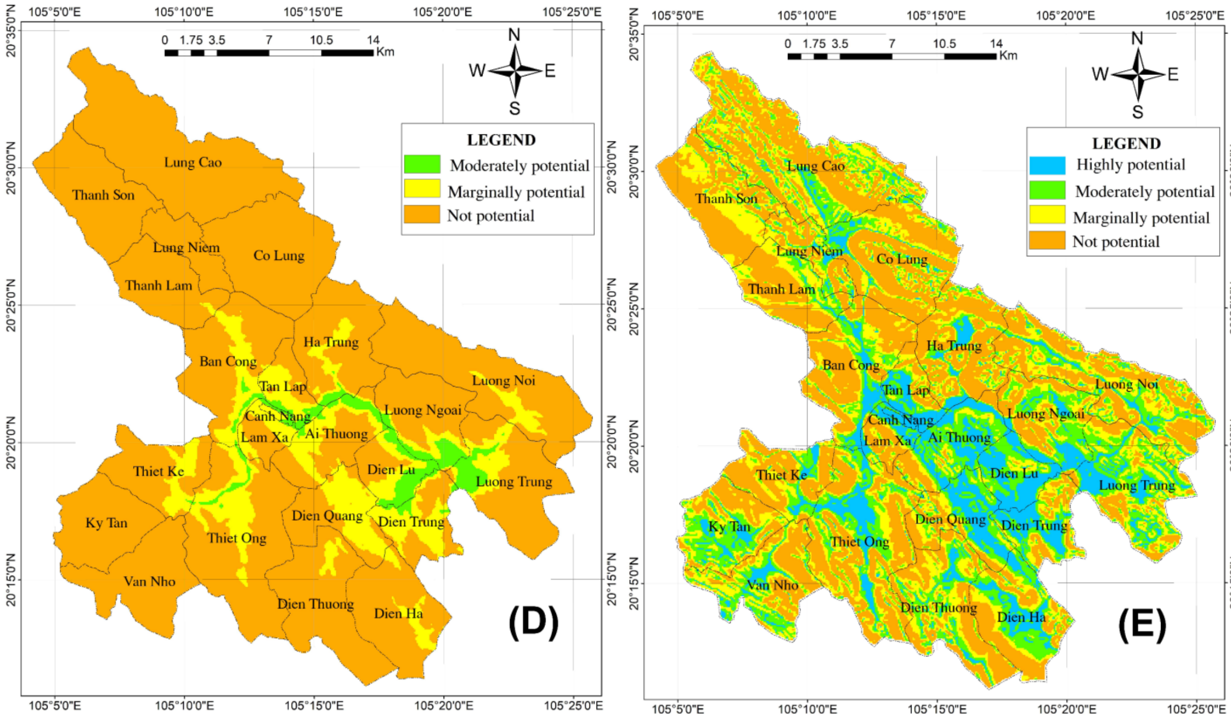

Figure 3. Evaluation of land potential for paddy based on topography criteria (D) elevation, (E) slope.

Table 7. Potential areas of climatic factors.

	Mean annual temperature		**Mean annual maximum temperature**		**Mean annual minimum temperature**		**Mean annual precipitation**		**Monthly average number of daylight hours**	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**
High potential	0	0	61,972	80	0	0	0	0	0	0
Moderately potential	73377	95	15554	20	0	0	73377	95	71291	92
Low potential	4255	5	0	0	72084	93	4256	5	6231	8
Not potential	0	0	0	0	5549	7	0	0	0	0

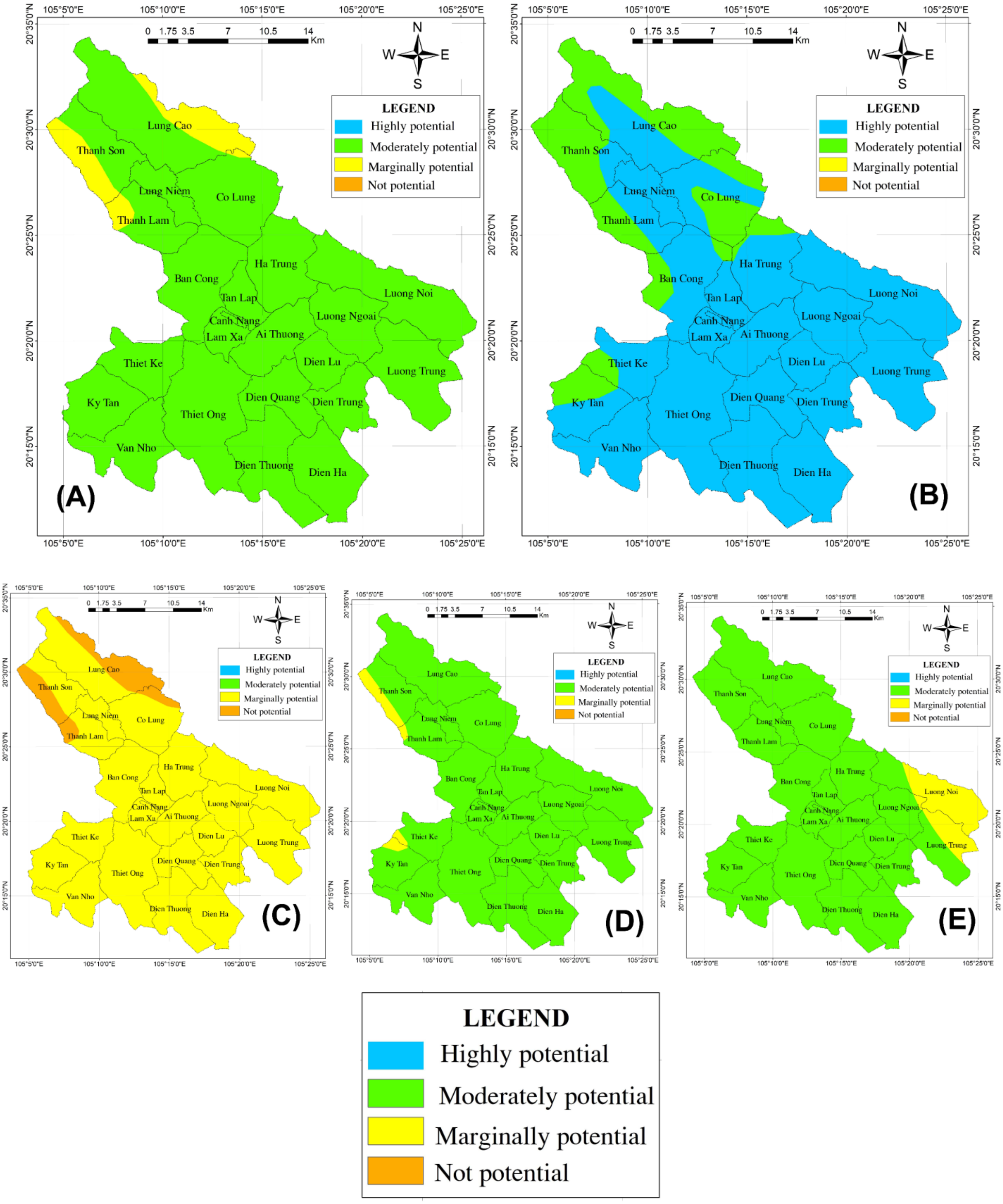

Figure 4. Evaluation of land potential for paddy based climate criteria

(A): Mean annual temperature (°C); (B): Mean annual maximum temperature (°C); (C): Mean annual smallest temperature (°C); (D): Mean annual precipitation (mm); (E): Monthly average number of daylight hours.

3.4. Hydrological analyses

Water is a critical criterion for rice growth because it is a water-loving plant. Water assists in transporting nutrients to plants while decreasing the concentration of salt, alum, and toxins in the soil. In addition to water from annual rainfall, the water supply for rice fields comes from the area's river system. The advantage of having several big and small streams and a system of ponds, lakes, and dams distributed across the district has given a significant amount of water to meet agriculture's output. Because Ba Thuoc is far from the sea, it is not affected by the saline intrusion. Table 8 illustrates the findings of the adaptation evaluation and mapping of distances to rivers and saline intrusion. Oñate-Valdivieso and Sendra (2010) revealed the associations among variations and explicative variables are deliberate in imperative to stochastically model future land use maps.

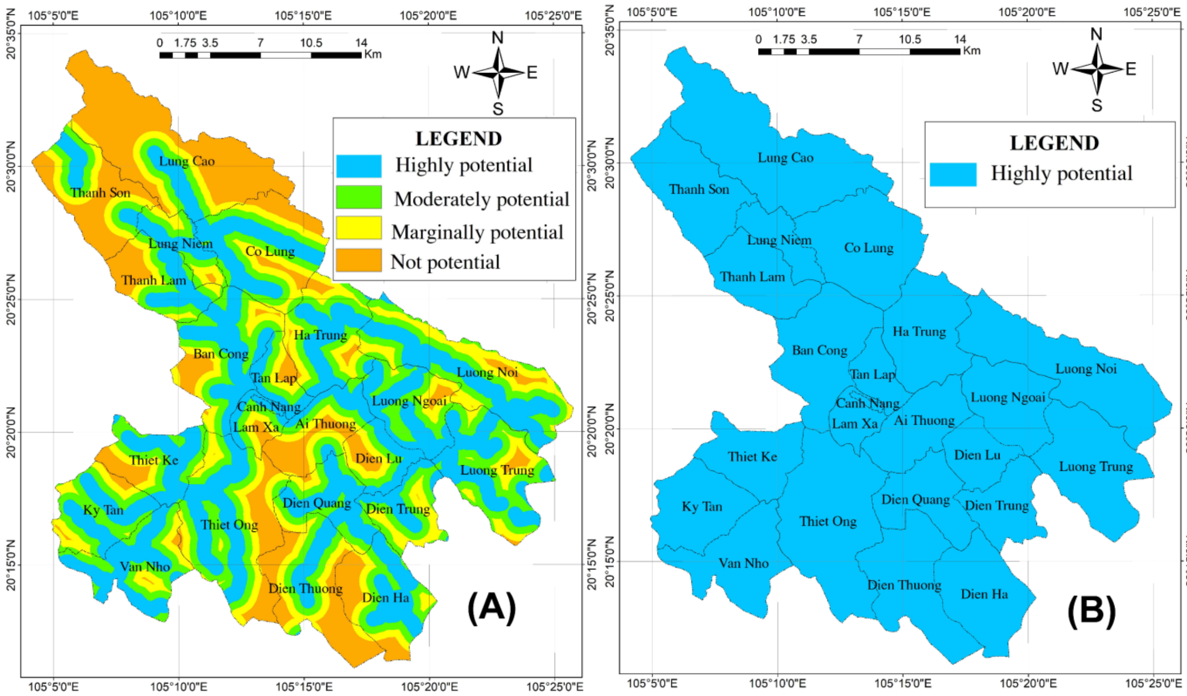

Figure 5. Evaluation of land potential for paddy based hydrology criteria

(A): Distance to river and stream; (B): Salinization.

Table 8. Potential areas of hydrology factors.

	Distance to river and stream		Salinization	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**
High potential (S1)	26107.74	33	77522.02	100
Moderately potential (S2)	20935.56	27	0	0
Low potential (S3)	14472.95	19	0	0
Not potential (N)	16005.77	21	0	0

3.5. Map of potential adaptation of paddy in Ba Thuoc district

Soil type and rainfall are the two most critical factors in rice adaptation, followed by soil physical composition, slope, elevation, saline intrusion, climate and soil depth. Soil types in the area are mainly red-yellow soil on clay rocks and yellow-brown soil on basalt rocks, which pose significant limitations to rice adaptation. The topography includes steep hills and high altitudes characteristic of mountainous regions, reducing the plant's water holding capacity. Despite this, there are certain benefits to paddy production in terms of precipitation and temperature, river vicinity, salt intrusion, layer thickness, and other climatic components. The results of the classification for potential adaptation of paddy show that the area of High adaptability (S1) occupies a small (8%) and moderately adaptable (S2) occupies 26%. Those are concentrated in the central and southeast districts, such as Dien Quang, Dien Lu, Canh Nang town, and Luong Ngoai commune (Fig. 6). Ding et al. (2020) noted that the yields losses in temperate zones are related to increased crop development rates with higher temperatures, nonetheless in subtropical areas, the decrease is more connected to the harm of heat stress throughout paddy spike and/or anther formation.

Table 9. Ecological requirements of paddy in Ba Thuoc district, Thanh Hoa province.

	Categories			
	S1	**S2**	**S3**	**S4**
[X1] Soil type	P, Pb, Pf, Pg, Pe, Pc	Fk, Fl, Fp, Fs, Mi, D, Py	Fa, Fv, Fq, Pj, Ba	Other
[X2] Soil texture	Loam	Sandy loam	Clay	Sand
[X3] Soil depth (cm)	> 100	> 70 - 100	> 30 - 70	< 30
[X4] Elevation (m)	>3-20	>20-50, <3	>50-100	>100
[X5] Slope (^{0})	0 - 3	3 - 8	8 - 15	> 15
[X6] Distance to river and stream (m)	<500m	500-1000m	1000-1500m	>1500m
[X7] Salinization	0	< 3 months	> 3 months	Permanent
[X8] Mean annual temperature (°C)	> 25 - 30	> 20 - 25	> 30; > 15 - 20	< 15
[X9] Mean annual maximum temperature (°C)	> 30 - 35	> 25 - 30	> 35; > 20 - 25	< 20
[X10] Mean annual minimum temperature (°C)	> 20 - 25	> 15 - 20	> 25; > 10 - 15	< 10
[X11] Mean annual precipitation (mm)	> 2000 - 2500	>1500-2000; > 2500	>1300 - 1500	< 1300
[X12] Monthly average number of daylight hours	> 200	>150-200	>100 - 150	< 100

Table 10. Land potential for paddy in Ba Thuoc district, Thanh Hoa province

Categories	**Area (km^2)**	**(%)**
High potential (S1)	6401.45	8.26
Moderately potential (S2)	20380.37	26.29
Low potential (S3)	33608.83	43.35
Not potential (N)	17131.36	22.10

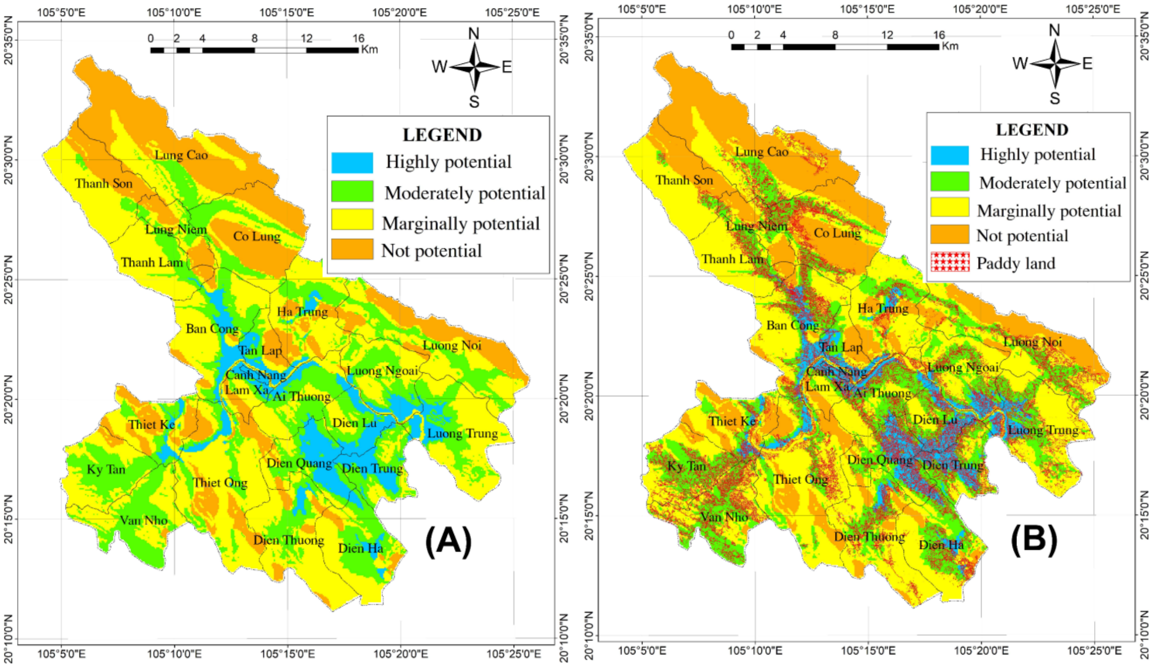

Figure 6. Potential adaptive classification map for paddy in Ba Thuoc district (A), and Potential adaptive overlay map for paddy land and agriculture area (B)

(The red region represents the current agricultural land as determined by Sentinel-2 studies).

According to the categorization findings obtained from remote sensing images, the present paddy land area in the district is 6401.45 ha, which accounts for 8.26% of the district's total land area (Fig. 6b, Table 10). According to a statistics report from the General Statistics Office, the area under paddy cultivation in the district is 4972.08 ha, secretarial for 6.0% of the district's total land area. In this respect, the potential adaptation for paddy in Ba Thuoc district is a reliable material for administrators, planners, and the government, in general, to utilize land to increase efficiency and labor productivity strategically. Tong et al. (2021) indicated that decision maker should link the variables of rice crop growing utilizing a mixture method that can be successfully used based on GIS performance.

4. Conclusion

The study conducted an adaptive assessment for rice plants based on applying AHP and GIS techniques for Ba Thuoc district, Thanh Hoa province. Research results show that soil type and water source perform a prerequisite part in the growth and development of rice. Soil type is the most challenging factor to improve, so to ensure rice productivity; it is necessary to plant in places with relatively good terrain, such as those not affected by tides and floods. The terrain is not too high for favourable conditions. Beneficial for irrigation water, the relatively gentle slope makes farming easy. To reduce the impact of weather factors such as temperature and humidity, choosing suitable seasonal rice varieties is necessary. Some communes (Ky Tan, Van Nho, Lung

Cao, Luong Noi) have a relatively large rice cultivation area. However, according to this study, the current rice area is only moderately adapted. These findings suggest that managers and scientists are more interested in soil improvement to improve the adaptability of rice plants in the four communes mentioned above. Based on the findings, it can be recommended to apply adaptive evaluation of rice plants in each province to increase yields through the informed selection of land plots and suitable seasonal rice varieties. Future-proof research could be to automate this process to find informed solutions more quickly.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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