https://doi.org/10.17221/101/2024-RAE

Modelling for a land suitability analysis of rice terraces on the upland area using the geographic information system (GIS) and analytical hierarchical process (AHP)

Razali[1]*, *Rahmawaty*[2], *Chairani Hanum*[1], *Zulkifli Nasution*[1]

[1]*Faculty of Agriculture, Universitas Sumatera Utara, Padang Bulan, Medan, Indonesia*
[2]*Faculty of Forestry, Universitas Sumatera Utara, Pancur Batu, Deli Serdang, North Sumatra, Indonesia*

**Corresponding author: razali@usu.ac.id*

Citation: Razali, Rahmawaty, Hanum C., Nasution Z. (2025): Modelling for a land suitability analysis of rice terraces on the upland area using the geographic information system (GIS) and analytical hierarchical process (AHP). Res. Agr. Eng., 71: 121–129.

Abstract: Rice fields are the main source of rice production. Rice field expansion is one way to increase rice production. Rice field expansion activities for the upland area in Indonesia are often overlooked due to limited information about the availability of suitable land. In upland areas, rice terraces are often found. Until now, there has been no guideline for determining the suitable location of rice terraces on upland areas. The purpose of this study was to develop a land suitability assessment model for rice terraces using geographic information system (GIS) and the analytical hierarchical process (AHP) on upland areas like the Lake Toba catchment area. There were four important factors for selecting rice terracing plantations: spatial planning, slope, texture, and distance from the river (hydrology). By using the AHP method, a rating has been assigned to each theme layer. To create the suitability map for rice terraces in a GIS setting, all the thematic layers were combined into a single layer using the weighted overlay approach. The results showed that 37.78% were highly suitable, 18.88% were moderately suitable, and 36.95% were marginally suitable for rice terraces. The model can be used to determine the location of rice terraces on upland areas with a high accuracy of about 93%.

Keywords: rice field expansion; upland region; physical characteristics; Lake Toba catchment area

Rice is one of the most important cereal grains in the world, as a food source for more than half of the world's population (Baroudy et al. 2020). Its demand will continue to increase as the population increases. The shrinking area of fertile land for rice is one of the challenges to overcome to increase yields (Anwar et al. 2022). Rice field expansion strategies can be a solution to this problem. Rice field expansion needs location information which is suitable for rice fields. Thus, a land suitability analysis is essential.

A land suitability evaluation is very important for many scientific investigations and policy applications to ensure food security and sustainable development (Han et al. 2021). Any differences in the soil properties, topographical position, and land use in each part of the field cause variations in the land suitability for each type of crop (Ostovari et al. 2019).

Generally, land suitability analyses are carried out by considering the social, economic, and physical elements of the land, but if they are conducted with only the physical elements of the land, they are still allowed (Topuz and Denis 2023). Using many factors may increase the complexity of long-term sustainable management practices. Besides, it is necessary to develop an agro-ecological model for

https://doi.org/10.17221/101/2024-RAE

land suitability based on physical environmental factors (Tashayo et al. 2020). Physical environmental factors are relatively stable compared to social and economic factors. Thus, a land suitability assessment is mainly based on environmental factors (Zhang et al. 2015).

Multiple criteria decision analysis (MCDA) methods have been used for land suitability assessments since the 1980s, and the interest of researchers in integrating geographic information system (GIS) with MCDA has grown steadily (Seyedmohammadi et al. 2019). GIS-MCDA solves complex decision-making problems based on evidence of different quantities, qualities, guidelines, and opinions of experts and considers various decision criteria and constraints. Among all the MCDA methods, the analytical hierarchical process (AHP) method is generally used due to its good understandability, ease of implementation, and interpretability of the results by both modellers and decision-makers. It allows the researchers to represent a full range of human decision-making logic, considering both qualitative and quantitative data, and combine them by decomposing complex problems into systematic hierarchies to rank alternatives based on different criteria (Paul et al. 2020). In recent years, AHP which is an MCDA for a land suitability evaluation, has been preferred in the evaluation of multi-heterogeneous factors, especially in the case of strategic and important crops (Dedeoğlu and Dengiz 2019). Many environmental and agricultural problems have been solved using AHP and GIS (Neissi et al. 2020).

Nowadays, Indonesia is experiencing increased population growth along with rice field shrinkage due to the conversion of rice fields. This contradiction creates a vulnerability to the availability of rice as a staple food crop. Therefore, one of the efforts to meet the national rice needs is by expanding the area of rice cultivation. This activity could work if there was information about the land availability that is suitable for agro-ecological purposes. These days, the expansion of rice fields has been prioritised on lowland areas and guidelines are already available.

In Indonesia, the upland area is an area located at an elevation of > 700 m a.s.l. and has a hilly or mountainous topography (Djaenudin 2009). Both upland and lowland rice ecotypes are cultivated on upland areas, where lowland rice is a higher priority than upland rice. Hussain et al. (2021) found that lowland rice ecotypes contribute a major portion to the rice production. Lowland rice ecotypes on upland areas are known as rice terraces. On hilly or mountainous regions, rice terraces are often found, and they consist of a series of flat fields. They were cut into sloping land for rice production (Sun et al. 2018). Terracing is common in hilly and mountainous regions and it is used for preventing soil erosion, conserving water, and increasing the arable surface area and agricultural production. It also contributes toward the conservation of plant biodiversity on a local scale (Deng et al. 2021).

Rice field expansion activities for the upland area in Indonesia are often overlooked due to limited information about the availability of suitable land. Until now, there has been no guideline for determining the suitable location of rice terraces on upland areas based on physical environmental factors. This study aims to develop a land suitability assessment model for rice terrace fields using the GIS and AHP on upland areas.

MATERIAL AND METHODS

Study area. The Lake Toba catchment area is one of the upland areas in Sumatera Utara Province, Indonesia. It is a catchment area of the Asahan Toba watershed. Geographically, it is located at 98°20'–99°15' East longitude and 2°10'–3°00' North latitude. It is located in the Bukit Barisan mountains with an altitude of 900–2 200 m. Nasution (2009) stated that this catchment consists of 110 260 ha of water and 259 594 ha of land, with hilly areas (43%) and mountains (30%) (Figure 1).

The average temperature ranges from 20.6 to 23.0 °C. The annual rainfall ranges from 934 to 1 928 mm·year^{-1}. The rainy season's peak occurs in November with 185 mm·month^{-1} of rainfall, and the peak of the dry season occurs in June with 47 mm·month^{-1} of rainfall (Nasution 2009). According to the Oldeman climate, Lake Toba catchment's climate is classified as E. Based on the Oldeman climate type, the Lake Toba catchment area is not suitable for the location of rice fields. However, in reality, there are huge areas of rice fields. This proves that the existing paddy water needs do not only depend on the rainfall, but they can also be obtained from irrigation water sourced from the river. This area is the mainstay for pro-

https://doi.org/10.17221/101/2024-RAE

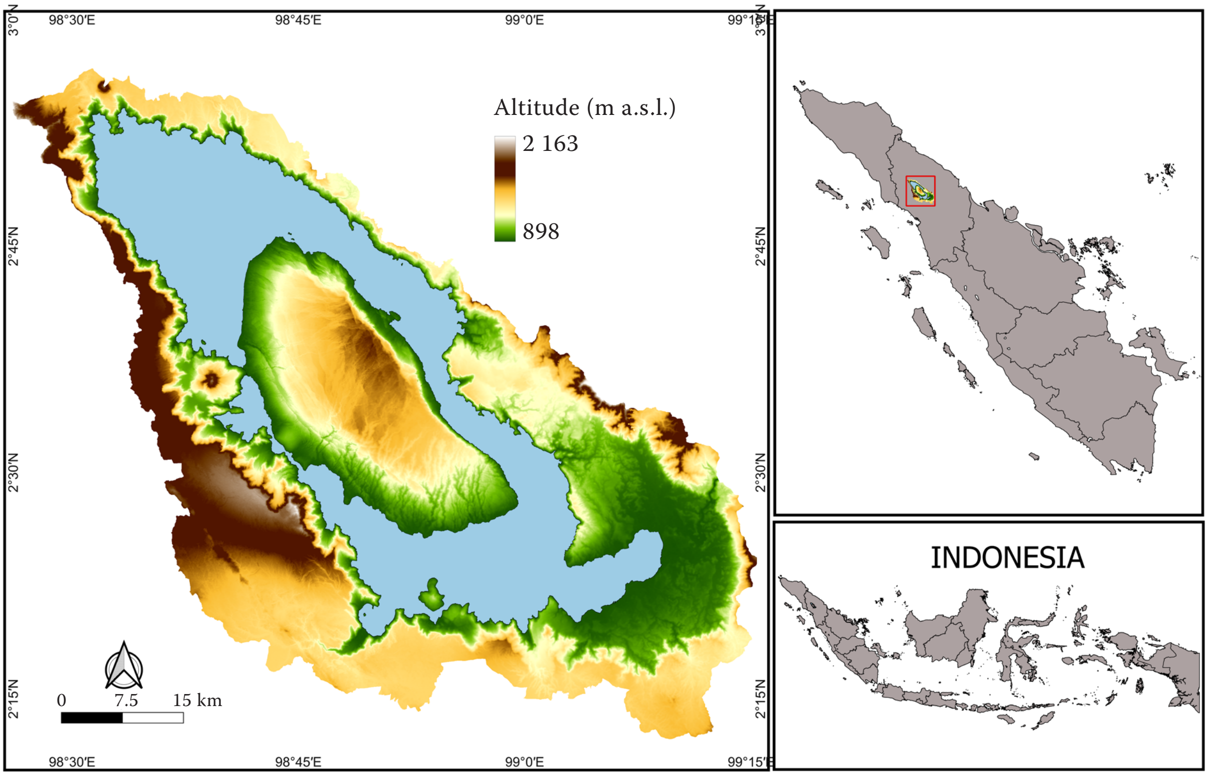

Figure 1. Lake Toba catchment area

ducing rice, especially from rice terraces. One rice planting season lasts for ± 5 months. In the future, this region is expected to be able to increase its rice production. One of the ways is to increase the area of rice terraces.

Data sources. For this study, the primary and secondary data were collected from various sources (Table 1).

Methodology. To begin with, spatial planning, climate, hydrology, topography and soil property factors were selected for the land suitability analysis of the rice terrace cultivation in this study. Then, four land characteristics, including the spatial planning, river network (hydrology), slope and soil texture, were selected based on a literature study for the lowland rice cultivation, as well as the physical and chemical soil properties of the Toba catchment; field observations were also conducted.

(1) Other use areas (Areal Penggunaan Lain/APL) data layer. According to the law of spatial plan-

Table 1. Data sources for the research

Data	Source
ASTER DEM	earthexplor.usgs.gov
Topographic map	analysis of Aster DEM data
Slope map	analysis of Aster DEM data
Distances from river map	analysis of Aster DEM data
Land unit map	explanatory booklet of the Land Unit and Soil map of the Pematang Siantar sheet (0718) and Sidikalang sheet (0618); Center for Soil Research, Agency for Agricultural Research and Development; Department of Agriculture 1989
Physical and chemical soil properties of land unit Lake Toba cacthment area	Nasution (2009)
Spatial planning map	regional spatial planning map of Sumatera Utara Province for 2017–2037
Land use map scale 1:50 000	Indonesia Geospatial Agency (Badan Informasi Geospasial (BIG))

https://doi.org/10.17221/101/2024-RAE

ning in Indonesia, all lands were divided into two groups: land on the forest area and other use area (Areal Penggunaan Lain/APL). Agricultural activities can only be conducted on non-forest areas inside the APL.

(2) Distance from river data layer. The main water sources for terracing rice fields on the upland area come from rivers. The river network and order were generated from the digital elevation model (DEM).

(3) Slope data layer. The slope was generated from the DEM. A lower slope value indicates a flatter terrain, and a higher slope value indicates a steeper terrain.

(4) Soil texture data layer. The soil texture data for Lake Toba catchment area were obtained from the physical and chemical soil properties of the land unit (Nasution 2009).

Later, making the land characteristics maps/layer (other use areas (Areal Penggunaan Lain/APL), distance from the river, slope, category of the texture) and the map that was suitable for the rice terraces was performed with QGIS 3.22 Białowieża open source.

Using the AHP method (introduced by Saaty 1980), the weights and ratings were assigned to each land characteristic layer. In general, the work stages are as follows (AHP analysis with the AHP online calculator):

(1) Developing a pairwise comparison matrix based on the numbers of land characteristics.

(2) Determining the relative importance of the land characteristic to rice field terraces' potential influence.

(3) Calculating the consistency ratio (CR) to check whether the weights assigned are correct or not. If the consistency ratio is less than 0.1, the pairwise comparison matrix is said to be consistent, and if the CR > 0.1, the result has to be revised due to the weights' inconsistency.

Then, the land characteristic vector layers were converted into raster layers. To create the suitability map for rice terrace fields in the GIS setting, all the land characteristics layers were combined into a single layer using the weighted sum overlay analysis. Later, the analysis layer (rice terraces land use suitability map) was divided into four classes of equal ranges according to the land suitability classification of the FAO (1976), namely:

(*i*) Highly suitable: lands having no significant limitations and the level of production is high with the lowest possible costs.

(*ii*) Moderately suitable: lands having moderate limitations which will reduce the production levels, but are still physically and economically suitable for rice field terraces use.

(*iii*) Marginally suitable: lands having a series of limitations that will reduce the production levels such that it is economically marginal for rice field terraces use.

(*iv*) Not suitable: lands not suitable for rice field terraces production.

RESULTS

APL data layer. According to the law of spatial planning in Indonesia, all the lands were divided into two groups: land on the forest area and APL. The land on the forest area was designated for forestry. The APL was an area outside the forest area set for utilisation in the non-forestry sector, such as agricultural land, settlements, industry, and so on. Based on the law, the Lake Toba catchment area that was permitted for the expansion of rice fields is APL (Figure 2A).

Distance from the river data layer. The main water source for terracing rice fields on the upland area comes from rivers. Watering the rice fields is undertaken by flowing the water through small channels or ditches (simple irrigation) from the river to the fields. There are differences in the buffer area that can flow from the river body. Gholoobi et. al. (2010) stated that the maximum buffer area of terraced rice cultivation is at 120 m from the river body in Iran. Research on terracing rice fields at Ifugao, Philippines by Acabado (2012) stated that ± 75% of terraced rice fields are located 125 m from water sources (rivers and irrigation channels). If there is a terracing rice field that does not have an irrigation channel, it is likely that the area has a spring as a water source.

Through the order analysis of the river flow, it is known that the Lake Toba catchment area has a river order from 1 to 9. A 4^{th} river order and above have influences on the existing rice fields. Therefore, in this study, the river orders that were used ranged from order 4 to 9. Orders 4 and 5 only use a 50 m buffer; the others use a buffer of ≤ 100 m (highly suitable), 100–200 m (moderately suitable), 200–300 m (less suitable), and bigger than 300 m (lowest suitable) (Figure 2B).

Slope data layer. On hilly areas, rice fields formed as terraces might be found with various

https://doi.org/10.17221/101/2024-RAE

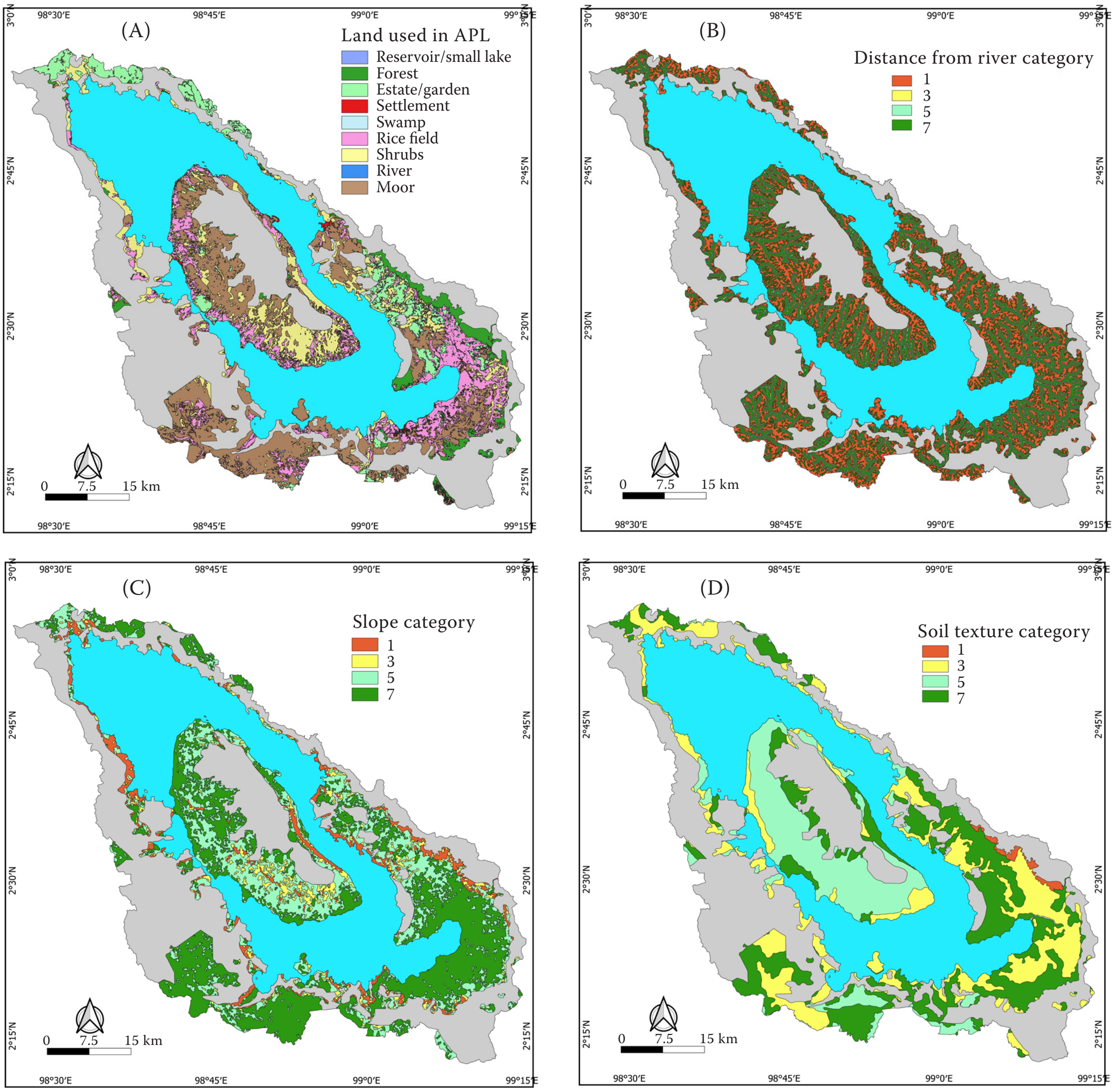

Figure 2. Lands used (A), distance from the river category (B), slope category (C), soil texture category (D) in APL of the Lake Toba catchment area

APL – Areal Penggunaan Lain (other use area)

slope levels. Acabado (2012) stated that the average slope of rice terraces in Ifugao, Philippines, was 17.9°, while most of the fields were on a slope between 11.59° to 25.1°. Bokings et al. (2013) stated that rice terraces in Jatiluwih, Bali had a slope diversity ranging from 15–30% (sloping) to > 65% (very steep). The Japanese Ministry of Agriculture, Forestry, and Fisheries stated that rice terraces are terraced rice fields with an average slope of ≥ 5% (Kobayashi and Harada 2010).

The slope classification for the Lake Toba watershed rice fields is: < 16% (highly suitable), 16–30% (moderately suitable), 30–50% (less suitable), and > 50% (lowest suitable) (Figure 2C).

Soil texture data layer. According to Djaenudin et al. (2011), soil factors of land characteristics that need to be considered for irrigated rice cultivation are the physical properties (drainage, texture, soil depth) and chemical properties (pH, cation exchange capacity (CEC), base saturation). The land unit's value of the

https://doi.org/10.17221/101/2024-RAE

Table 2. Four-point weighing scale for the pair-wise comparison

Description	Scale
High suitability	7
Moderate suitability	5
Low suitability	3
Lowest suitability	1

physical-chemical properties for all the Lake Toba catchment area was still a suitable category for irrigated rice cultivation, except for the texture (Table S1 in Electronic Supplementary Material (ESM)).

Rice is commonly grown in soils that contain a high amount of clay, which is the most important component of mineral soil due to its very high specific surface area, also due its ability to hold nutrients and water (Hamoud et al. 2019). Fine-medium soil textures (sandy clay, clay, silty clay, clay loam, sandy clay loam, silty clay loam, sandy loam, loam, silt loam, and silt) are suitable for use as rice fields. Soils that have a class of coarse textures (sand, loamy sand) are declared unsuitable for rice fields because the soils have a high percolation rate, so water usage becomes inefficient. In addition, nutrient losses on such lands are also high (Dariah and Agus 2007).

The texture classification for the Lake Toba watershed terracing rice fields was: clay, sandy clay, silty clay, clay loam, silty clay loam, sandy clay loam (highly suitable), loam, silt loam, silt (moderately suitable), sandy loam (less suitable), and loamy sand (lowest suitable) (Figure 2D).

AHP analysis. For determining the suitability of the land, scores and weights were given for each selected criterion. Higher weights were assigned according to their suitability for rice terraces, and vice versa. Zhang et al. (2015) determined the weight of each factor that influences the land suitability, which is a key step in a land suitability assessment for crop production.

The fundamental scale for pairwise comparison used in AHP was introduced by Saaty (1980). It used scales from 1 to 9. In this study, a scale modification was used on Saaty's AHP analysis, from nine to four scales (Table 2), and its suitability levels (Table 3) can be seen as shown below.

Through the matrix comparison, according to AHP analysis, the weight of each criterion can be seen in the following (Table 4):

A further AHP analysis with the AHP online calculator produced a CR value of 0.056 (CR value < 0.1 means consistent and can be continued), with the weight values of each criterion:

Distance from the river: 0.709 (ranking 1)

Slope: 0.179 (ranking 2)

Soil texture: 0.113 (ranking 3)

Land suitability map. All the used criteria maps were combined and overlapped (overlay), and the final results of the suitability map for rice terraces in the Lake Toba catchment area were determined by the equation model:

$$\text{Land suitability map} = \Sigma\ [\text{criteria map} \times \text{weight}]$$

$$\text{Suitability index} = (0.709 \times \text{hydrology}) + (0.179 \times \text{slope}) + (0.113 \times \text{texture})$$

Table 3. Suitability levels of three criteria in the determination of the rice terraces suitability analysis

Scale	Distance from river (m)	Slope (%)	Soil texture
High suitability	< 100	< 16	clay, sandy clay, silty clay, clay loam, silty clay loam, sandy clay loam
Moderate suitability	100–200	16–30	loam, silt loam, silt
Low suitability	200–300	30–50	sandy loam
Lowest suitability	> 300	> 50	loamy sand, sand

Table 4. Pairwise comparison matrix of the criteria

	Distance from river	Slope	Soil texture
Distance from the river	1.00	5.00	5.00
Slope	0.20	1.00	2.00
Soil texture	0.20	0.50	1.00

https://doi.org/10.17221/101/2024-RAE

Table 5. Land suitability for rice terraces in the APL Lake Toba catchment area

Land suitability	area (ha)	(%)
Highly suitable (S1)	44 965.71	37.78
Moderately suitable (S2)	22 474.76	18.88
Marginal suitable (S3)	43 976.81	36.95
Currently not suitable (N)	7 596.12	6.38
Total	119 013.40	100.00

APL – Areal Penggunaan Lain (other use area)

The obtained interval value of the conformity index was divided into four classes as FAO land suitability categories (highly suitable, moderately suitable, marginally suitable, and currently not suitable) with the same interval distance, so that the class division for rice terraces was obtained. Based on this analysis, the total APL of the Lake Toba catchment area was 119 013.40 ha, but only 7 596.12 ha (6.38%) were not suitable for rice terraces (Table 5 and Figure 2A).

DISCUSSION

For rice terraces, hydrological factors (distance from water sources) were the most important factor, with the biggest weight value at 0.709. Followed by the slope factor with a weight value at 0.179. Then the soil factor (texture) had a weight value at 0.113. The results were in line with the ecological principles of irrigated rice fields, which require a guarantee of water availability during the growth period, which made it different compared to the other rice cultivations. On hilly or mountainous areas, the slope factor had a large influence for determining the location that could possibly be used to irrigate rice fields. It was different on flat areas, where the usage of irrigated rice fields was limited to a slope of ≤ 8%. However, on hilly or mountainous areas, a slope of ≤ 50% may still be utilised, although some researchers said irrigated rice fields could still be established up to a 70% slope (Acabado 2012; Boking et al. 2013).

The results were compared with the current rice terrace area according to Badan Informasi Geospasial (BIG) land use and land cover maps (Table S2 in ESM). Currently, on the APL of the Lake Toba Catchment Area, there are 25 659.80 ha of rice terraces (Table 6 and Figure 2B). Field observations were performed to obtain information about the actual state of the field.

In Table 6, it can be seen that from 25 659.80 ha of the existing rice fields, 98.95% were in the suitable areas as rice terraces according to the GIS-AHP method on the APL of the Lake Toba Catchment Area. There were 18 906.81 ha (73.68%), including those in the categories of highly suitable and moderately suitable.

From BIG land use maps, it is known that the APL Lake Toba catchment area currently has 25 659.80 ha of rice fields. This area might perhaps increase because the results of the rice terrace suit-

Table 6. Rice terraces land suitability with GIS-AHP, the existing and reserved for the APL Lake Toba catchment area

Land suitability	GIS-AHP		Existing (BIG)		Reserve	
	area (ha)	(%)	area (ha)	(%)	area (ha)	(%)
Highly suitable (S1)	44 965.71	37.78	12 850.66	50.08	32 115.05	34.40
Moderately suitable (S2)	22 474.76	18.88	6 056.15	23.60	16 418.61	17.59
Marginal suitable (S3)	43 976.81	36.95	6 484.62	25.27	37 492.19	40.16
Currently not suitable (N)	7 596.12	6.38	268.37	1.05	7 327.75	7.85
Total	119 013.40	100.00	25 659.80	100.00	93 353.60	100.00

GIS – geographic information system; AHP – analytical hierarchical process; APL – Areal Penggunaan Lain (other use area); BIG – Badan Informasi Geospasial

https://doi.org/10.17221/101/2024-RAE

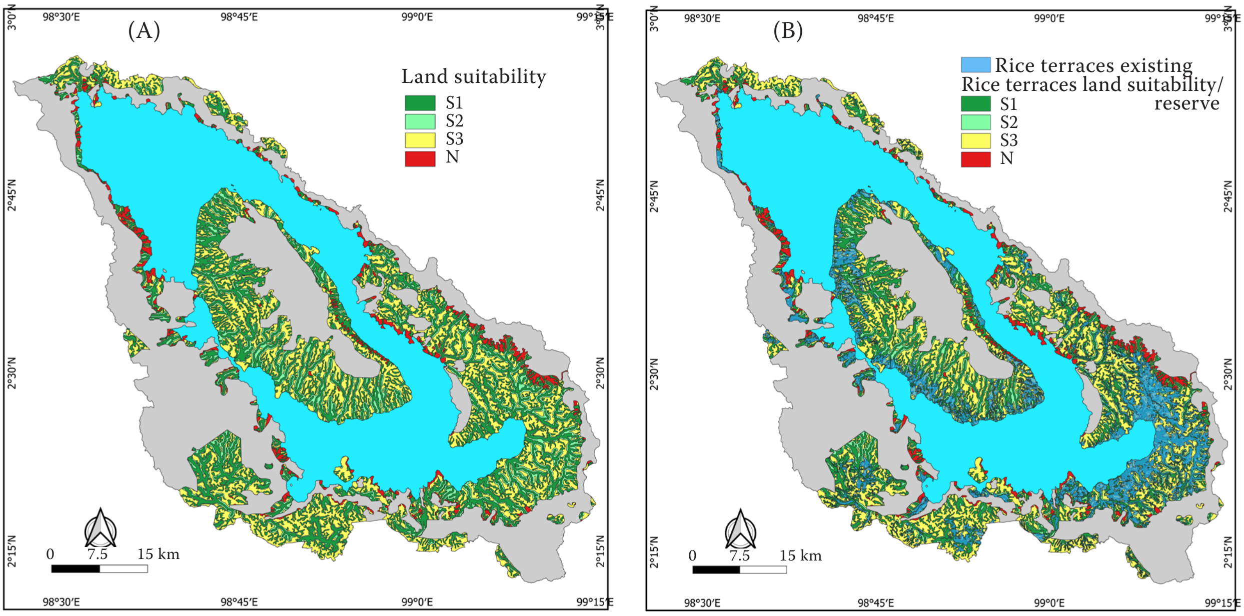

Figure 3. Land suitability for rice terraces (A), existing and reserved rice terraces (B)

ability analysis using the GIS-AHP method proved that there were still suitable areas for new rice fields. The S1 and S2 classes were developed as priorities because their limiting factors had a small influence on production. From all of the land use types, the land used for shrubs was the most potential to be developed into new fields. By overlapping the map of the rice terraces' suitability in the GIS-AHP method (S1 and S2 classes as priorities) with land use (shrubs), the potential land that might possibly develop into new fields was 13,995.70 ha (Figure 2B).

In the current study, the use of GIS-AHP modelling to generate a land suitability map for rice terraces was analysed for the Lake Toba Catchment area (upland areas). The results of this study are a good starting point for future rice terrace cultivation expansion on upland areas. The results showed that water was the most important factor for rice terraces, more than the slope, which is the main characteristic of upland areas. This result is in line with another earlier study that highlighted water availability is the most important factor for developing rice planting areas (Makungwe et al. 2021).

CONCLUSION

Upland regions possess unique physical attributes, which have a promising condition to be developed into new land for the expansion of rice field production. In order to develop a model for deciding the suitability of terraced rice fields on upland locations based on the physical characteristics of the land, this research used the AHP-GIS method. The important variables in determining the model were the soil texture, slope, and distance from the river (hydrology). The results showed that 37.78% were highly suitable, 18.88% were moderately suitable, and 36.95% were marginally suitable for rice terraces. The model can be used to determine the location of rice terraces on upland areas with a high accuracy of about 93%. This method provides an excellent model to find the appropriate area for the rice terraces construction in the research region.

REFERENCES

Acabado S. (2012): The Ifugao agricultural landscapes: Agro-cultural complexes and the intensification debate. Journal of Southeast Asian Studies, 43: 500–522.

Anwar K., Joshi R., Morales A., Das G., Yin X., Anten N.P.R., Raghuvanshi S., Bahuguna R.N., Singh M.P., Singh R.K., van Zanten M., Sasidharan R., Singla-Pareek S.L., Pareek A. (2022): Genetic diversity reveals synergistic interaction between yield components could improve the sink size and yield in rice. Food and Energy Security, 11: e334.

https://doi.org/10.17221/101/2024-RAE

Baroudy A.A.E., Ali A.M., Mohamed E.S., Moghanm F.S., Shokr M.S., Savin I., Poddubsky A., Ding Z., Kheir A.M.S., Aldosari A.A., Elfadaly A., Dokukin P., Lasaponara R. (2020): Modeling land suitability for rice crop using remote sensing and soil quality indicators: The case study of the Nile delta. Sustainability, 12: 9653.

Bokings D.L., Sunarta I.N., Narka I.W. (2013): The characteristic of wetland terracing in the hillside area and its management at Subak Jatiluwih, Sub-district of Penebel, Regency of Tabanan. Jurnal Agroekoteknologi Tropika (Journal of Tropical Agroecotechnology), 2: 175–183. (in Indonesian)

Dariah A., Agus F. (2007): Management of physical properties of new open rice fields. In: New Wetland Rice Fields. Bogor, Indonesian Center for Agricultural Land Resources Research and Development. (in Indonesian)

Dedeoğlu M., Dengiz O. (2019): Generating of land suitability index for wheat with hybrid system approach using AHP and GIS. Computers and Electronics in Agriculture, 167: 105062.

Deng C., Zhang G., Liu Y., Nie X., Li Z., Liu J., Zhu D. (2021): Advantages and disadvantages of terracing: A comprehensive review. International Soil and Water Conservation Research, 9: 344–359.

Djaenudin U.D. (2009): Prospects for research on potential land resources in Indonesia. Pengembangan Informasi Pertanian, 2: 243–257. (in Indonesian)

Djaenudin D., Marwan H., Subagjo H., Hidayat A. (2011): Technical Guidelines for Land Evaluation for Agricultural Commodities. Bogor, Center for Agricultural Land Research and Development, Agricultural Research Agency. (in Indonesian)

FAO (1976): A Framework for Land Evaluation. FAO, Rome.

Gholoobi M., Tayyebi A., Taleyi M., Tayyebi A.H. (2010): Comparing pixel based and object based approaches. In: Land Use Classification in Mountainous Areas. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, Vol. 38, Part 8, Kyoto, ISPRS: 789–794.

Hamoud Y.A., Guo X., Wang Z., Shaghaleh H., Chen S., Hassan A., Bakour A. (2019): Effects of irrigation regime and soil clay content and their interaction on the biological yield, nitrogen uptake and nitrogen-use efficiency of rice grown in southern China. Agricultural Water Management, 213: 934–946.

Han C., Chen S., Yu Y., Xu Z., Zhu B., Xu X., Wang Z. (2021): Evaluation of agricultural land suitability based on RS, AHP, and MEA: A case study in Jilin Province, China. Agriculture, 11: 370.

Hussain T., Hussain N., Ahmed M., Nualsri C., Duangpan S. (2021): Responses of lowland rice genotypes under terminal water stress and identification of drought tolerance to stabilize rice productivity in Southern Thailand. Plants (Basel), 10: 2565.

Kobayashi K., Harada C. (2010): Conservation of rice terraces in Japan – roles of the Sakaori rice terrace conservation association. Revija za Geografijo, 5: 91–100.

Makungwe M., Chabala L.M., Van Dijk M., Chishala B.H., Lark R.M. (2021): Assessing land suitability for rainfed paddy rice production in Zambia. Geoderma Regional, 27: e00438.

Nasution Z. (2009): The Ecology of Lake Toba Catchment Area for Sustainable Agriculture Development. Medan, Universitas Sumatera Utara (USU) Press.

Neissi L., Albaji M., Boroomand Nasab S. (2020): Combination of GIS and AHP for site selection of pressurized irrigation systems in the Izeh Plain, Iran. Agricultural Water Management, 231: 106004.

Ostovari Y., Honarbakhsh A., Sangoony H., Zolfaghari F., Maleki K., Ingram B. (2019): GIS and multi-criteria decision-making analysis assessment of land suitability for rapeseed farming in calcareous soils of semi-arid regions. Ecological Indicators, 103: 479–487.

Paul M., Negahban-Azar M., Shirmohammadi A., Montas H. (2020): Assessment of agricultural land suitability for irrigation with reclaimed water using geospatial multi-criteria decision analysis. Agricultural Water Management, 231: 105987.

Seyedmohammadi J., Sarmadian F., Jafarzadeh A.A., McDowell R.W. (2019): Development of a model using matter element, AHP and GIS techniques to assess the suitability of land for agriculture. Geoderma, 352: 80–95.

Sun W., Xiao E., Pu Z., Krumins V., Dong Y., Li B., Hu M. (2018): Paddy soil microbial communities driven by environment-and microbe-microbe interactions: A case study of elevation-resolved microbial communities in a rice terrace. Science of the Total Environment, 612: 884–893.

Tashayo B., Afshin H., Mohammad A., Mobin E. (2020): Land suitability assessment for maize farming using a GIS-AHP method for a semi-arid region, Iran. Journal of the Saudi Society of Agricultural Sciences, 19: 332–338.

Topuz M., Deniz M. (2023): Application of GIS and AHP for land use suitability analysis: Case of Demirci district (Turkey). Humanities and Social Sciences Communications, 10: 115.

Zhang J., Su Y., Wu J., Liang H. (2015): GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China. Computers and Electronics in Agriculture, 114: 202–211.

Received: December 27, 2024
Accepted: May 7, 2025
Published online: June 16, 2025