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Assessment of lands for cassava (*Manihot esculenta* Crantz; Euphorbiaceae, Magnoliopsida) cultivation using the AHP-GIS-Remote Sensing technique

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Abstract. The objective of present study was to assess the physical land capacity for an annual cassava crop, aiming to understanding spatial parameters and environment parameters required for locating potential areas of cassava cultivation. According to FAO guidelines, a spatial model was built to assess the potential land for facilitating sustainable cassava production through the integration of the AHP-GIS-Remote Sensing method. The present study showed that the land analysis indicated that the high potential land was 6101.1 ha (8% total area), concentrated in the middle and eastern part of the study area. These areas face limitations for the cultivation of cassava due to climatic conditions of the minimum temperature of the coldest month ($P_3 < 14°C$), average annual sunny hours ($P_5 < 1500$ h) and potential factors for providing quality products (LULC, annual precipitation and soil pH are the most significant factors). The areas of cassava crop cultivation were simultaneously reduced. Still, the reason for that has been not dependent on the physical environmental conditions, the limiting factors from the domestic market, backward processing technology, and the purchase price of raw cassava may possibly play a prominent role in the local farms.
Keywords: AHP, cassava, crop, soil, GIS, FAO

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INTRODUCTION

The long-term health of a community's food system is an essential indicator of its vitality and sustainability. A logical and appropriate way to revitalize a community is by developing a local food economy (Feenstra, 1997; Anderson, Rivera-Ferre, 2021). Land potential evaluation played an essential role in utility land use, especially for potential crops selected in categories that adapt to climate change. Vietnam is a developing country that could create food insecurity. Cassava is an excellent alternative to mitigate this dependency. This crop plays an important role in rural support the production of food in a sustainable manner (Noerwijati, Budiono, 2015; Campo et al., 2011). Even though cassava production is mostly geared toward the food sector, there are only a few avenues for its commercialization. In some tropical countries, land suitability studies may be used to determine the prospective cassava area, which can then be used to guide long-term cassava production. The integration of multi-criteria assessment and pair-wise comparison matrix revealed that cassava production should be encouraged among Southern Adamawa State farmers to utilize the land for improved cassava output effectively (Zemba et al., 2017). Likewise, one of the most burning issues should be considered to improve cassava cultivation management to increase production on land resource sustainability. It was advised by Akinwumiju et al. (2020) that the best site for cassava production in Nigeria was determined mostly by the soil characteristics, sunlight hours, and amount of rainfall. Cassava played an important role in the development of agriculture, because of its economic importance (Vurro et al., 2010). The production of cassava has been limited by high diversity of the crop's inherent benefits, poor on-farm management (e.g., lack over seeding and planting, poor soil health, and weeds), all of which have had harmed output and the occurrence of mosaic disease in some cultivars (Akano et al., 2002). The knowledge on the social-economic-environmental affecting cassava production is still insufficient, especially compared to other cereals crops (Burns et al., 2012). Several studies reported that the cassava plant played a crucial role in food security and cannot be over-emphasized (Kinshella, 2015; Purnamasari et al., 2019). Its food security within the tropical regions that cassava can combat hunger and address food security issues (Sharma et al., 2017; Adiele et al., 2021). The suitable land for cassava crop was the object of many researches, of which the environmental factors such as climate, soil type, topographic parameters played an influential role in cassava growth, as well as a knowledge of the biophysical constraints that exist in the local environment (Zemba et al., 2017; Akinwumiju et al., 2020; Purnamasari et al., 2019). Ba Thuoc district faced annual agricultural production supply deficiency, an intractable problem in the past decades. The volatility of the market trends affecting crops. Previously, rice gave priority in Ba Thuoc; likewise today, cassava has been given more attention due to its ability to adapt to the ecological condition. However, the variability in yield across the trial locations indicates the influence of some social-economic-environmental factors. Poor knowledge and unreliable data for agricultural planning cause a decrease of production value in the country's market (D'haeze et al., 2005). Likewise, today finding potential fuel resources come from cassava, the factors observed in literature, namely availability of resources, social awareness, capability production, economy, technology, education, and policy (Okudoh et al., 2014; Rewlay-ngoen et al., 2021). These results showed that organic fuel resources are determined by the biggest weight policy factor (Zhu et al., 2015). It means that people who live around organic fuel resources must be supported first by the government policy to transform production into small-scale industry. Cassava is a plant that originates in the tropics and is considered a drought-tolerant plant, but in the growth and development process, cassava also requires a certain amount of water, especially in the sprouting period and seedlings (Santisopasri et al., 2001; El-Sharkawy, 2007). Purnamasari et al. (2019) suggested that GIS technology can be considered a robust tool suitable for discovering agricultural areas. The use of AHP-GIS methodologies provides the ability to integrate linguistic information about annual cropland in the analysis. The datasets on cropland can be used to estimate the size of cassava plantations in other locations. To evaluate land appropriateness, which features might restrict the amount of land accessible for cassava production, the research set out to determine land suitability. Because land features cannot be improved easily, physical land productivity is regarded the most significant factor in obtaining the greatest possible value from the land. Geographic Information System (GIS) technology provides a dynamic approach for land use assessment and geo-environmental analysis based on geographic information (Pereira, Duckstein, 1993). Because multiple map layers are overlaid on over of one other, it enables the user to combine databases created from various sources and evaluate them properly in a spatiotemporal domain. The combination of AHP and GIS technology to model prospective cassava crop production areas in Ba Thuoc district of Thanh Hoa province utilizing FAO standards for land evaluation was carried out in this study. It was also utilized as a tool to choose the number of factors to be included in the modeling process. An instruction for cassava production land evaluation of ISO 8409: 2012 Vietnam Ministry of Science and Technology (2021) was also employed. Considering this existing work, the main objectives of this study were: (1) physical environmental evaluation was being used to map the potential area for cassava crop production, and (2) analyze the spatial variability of this crop in study area and zoning the potential land for cassava crop. In addition, all the data was collected and processed in ArcGIS to visualize geographically. Furthermore, an integrated use of GIS-based AHP can support extend vast vegetation land, which is analyzed from the land-use map to assess the site of cassava crops.

MATERIAL AND METHODS

Data collection. The collection database of surveys such as: questionnaires, semi-structured interviews and reports. The locations of cassava fields also were recorded by global positioning system (GPS). The cassava planted in the highly suitable areas of district also were determined (Fig. 1). The data were used in this study include climatic parameters (P_1, P_2, …, P_5) from https://www.worldclim.org in format csv, which were processed by the IDW interpolation method in GIS. A collection of 30×30 m digital elevation models (DEMs) from http://srtm.csi.cgiar.org/ were used to study of terrain and slope (P_7). Soil factors: Soil type (P_6), soil texture (P_8), soil layer thickness (P_9) and proportion of stones mixed in the soil obtained from The Soil map of Vietnam's Ministry of Natural Resources and Environment.

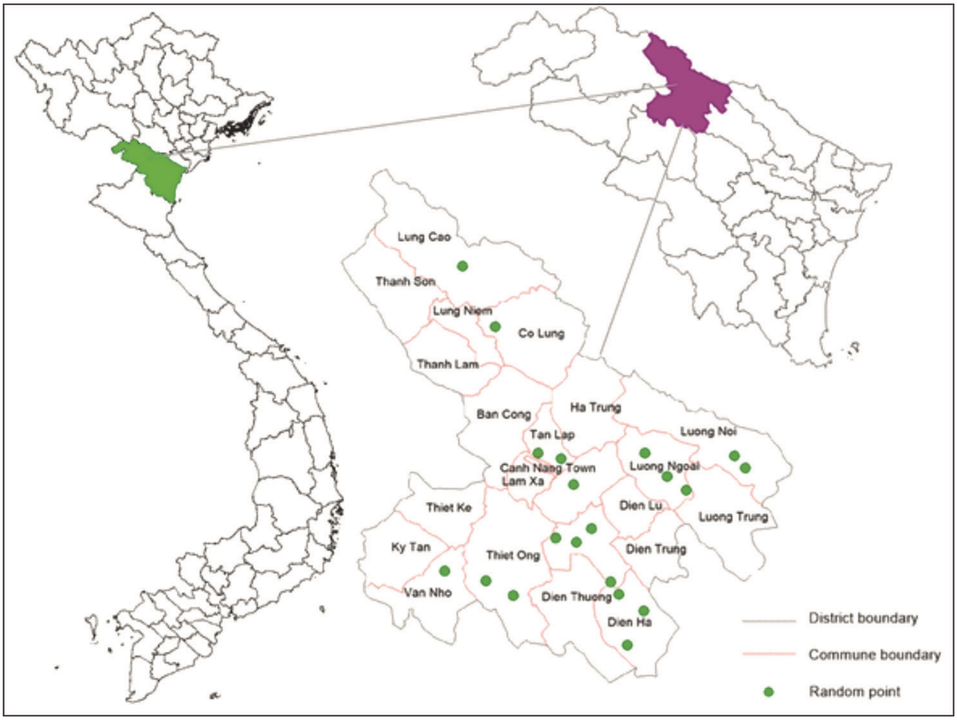


Fig. 1. Map location of study area (The random point is the site of cassava fields, and it utilized in the validation of the model)

The information used in evaluating environmental efficiencies, such as soil pH (P_{10}), N (P_{11}, %N in soil) were gathered through a survey.

Regarding socio-economic variables, it is necessary to consider the impact of main roads on the extent of the cassava stock market as a parameter effect. In addition to facilitating access to transportation infrastructure, distances between fields and roads (P_{12}) also assist farmers and agricultural operations to marketing. To evaluate suitability levels for cassava production, physical variables connected with water supply (P_{13}), such as the distance from water bodies, streams, rivers, and watering zones, were considered. The land use cover map (P_{14}) was collected from the Ministry of Science and Technology Vietnam, 2015, to extract the agricultural land types (Table 1).

Collection of soil sampling and analysis. Soil samples were taken from agricultural regions in Ba Thuoc district between the years 2020 and 2021, and the results were analyzed. The research field was divided into grid squares of 11 km by 11 km. A total of 300 soil samples were collected from the surface soil (0–20 cm) of each grid crossroad point in cultivable fields, ranging from 0 to 20 cm in depth. The sampling was carried out after the harvesting season in the fall and before the following cropping season to reduce the influence of cultivation and agricultural operations carried out during the previous growing season, such as irrigation, fertilization, traffic and the soil. It was determined that certain sample sites would be captured on a portable global positioning system device (Garmin).

Table 1. Data were used in the analysis

Data	Unit	Description	Source	Data
P_1: Annual mean temperature	Celsius degree	30 m resolution	https://www.worldclim.org	Raster
P_2: Max Temperature of Warmest Month	Celsius degree	30 m resolution	https://www.worldclim.org	Raster
P_3: Min Temperature of Coldest Month	Celsius degree	30 m resolution	https://www.worldclim.org	Raster
P_4: Annual precipitation	Millimeter	30 m resolution	https://www.worldclim.org	Raster
P_5: Average annual sunny hours	Hours	30 m resolution	https://www.worldclim.org	Raster
P_6: Soil type		Extracted from Soil map of scale 1:100.000. Survey (2021)	Vietnam General Department of Land Administration, 2010. Research team	Shape file
P_7: Slope	Degree	Extracted from DEM, 30 m resolution	http://srtm.csi.cgiar.org/	Raster
P_8: Soil texture		Extracted from Soil map of scale 1:100.000. Survey (2021)	Vietnam General Department of Land Administration, 2010. Research team	Shape file
P_9: Soil depth	Centimeter	Extracted from Soil map of scale 1:100.000. Survey (2021)	Vietnam General Department of Land Administration, 2010. Research team	Shape file
P_{10}: pH		Survey (2021)	Research team	Raster
P_{11}: Nitrogen (N)	%	Survey (2021)	Research team	Raster
P_{12}: Distance from roads	Meter	Extracted from traffic map of scale 1: 100.000	Vietnam Ministry of Science and Technology, 2010	Shape file
P_{13}: Distance from rivers	Meter	Extracted from traffic map of scale 1: 100.000	Vietnam Ministry of Science and Technology Vietnam, 2010	Shape file
P_{14}: Land use cover		Sentinel 2 (2020)	Google Earth Engine	Raster

Analytic hierarchy process (AHP). The decision-making problem can be a complex issue regarding the involvement of multiple objectives and parameters (Multi criteria Decision Analysis/MCDA). One of the tools used for the selection of suitable candidates or ordering priorities in the MCDA problem is the Analytical Hierarchy Process (AHP). The AHP method is the potential way of solving the problem of important unequal factors in nature by giving weight to the experts. Still, expert opinions remain uncertain, due to human behavioral bias or even because of experts' backgrounds. This technique was used to determine the most potential alternative for idea solution based on the weight of importance of each parameter in the relation with others (Saaty, 2008). A focus group discussion held among the farmers and committee members were completed. Information from interviews to determine factors influencing cassava crop land suitability. Furthermore, this work also aimed to weight these factors. Overall priorities can be made through synthesizing or pooling together the judgment made in the pairwise comparisons (Table 2, Fig. 2). Each factor is categorized into 4 levels (S1, S2, S3, N) based on ecological requirement of cassava crop of Instruction for agricultural production land evaluation of Vietnamese Standard (ISO 8409: 2012 (Ministry of Science and Published technology, 2021)). The integration of AHP-GIS was used in this model. A consistency ratio is taken as the ratio of the consistency of the results. CR is calculated from the ratio between CI, which is derived from the comparison matrix and the random consistency index (RI). The RI is the consistency index of a randomly generated pairwise comparison matrix, simply obtained from the random inconsistency indices. If a consistency ratio of less than 0.10, the results are sufficiently accurate and there is no need for further evaluation. However, if the consistency ratio is greater than 0.10, the results may be arbitrary, and preferences must be reassessed (MacCormac, 1983; Saaty, 2008).

Table 2. Nine-point scale using in expert judgement

Scale	Degree of preference
9	Absolute importance
7	Very strongly importance or preferred
5	Strong importance or strongly preferred
3	Weak importance, moderately important or preferred
2, 4, 6, 8	The two judgements that are adjacent to each other have intermediate values
1	Equally important or preferred is favored over more important or recommended

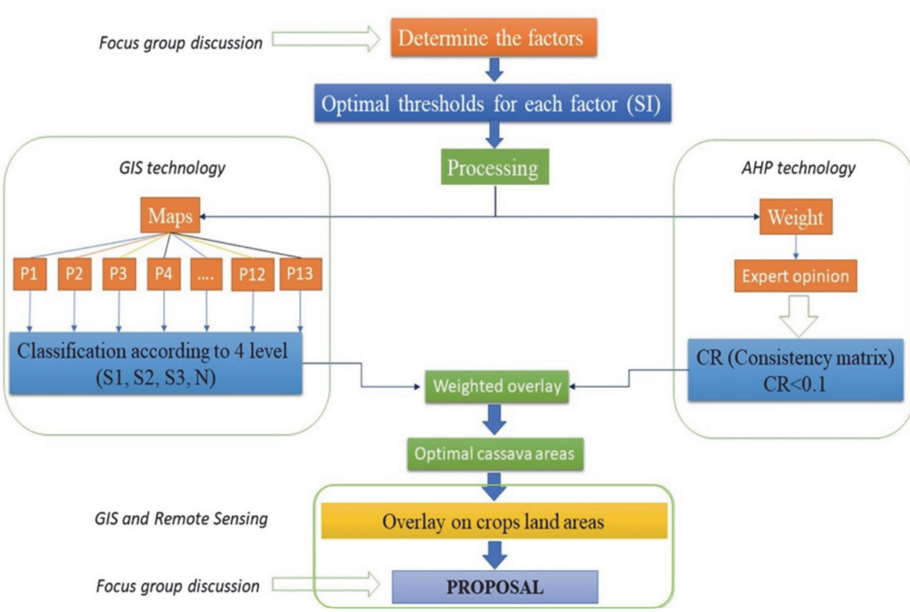


Fig. 2. The process to select optimal land for cassava production in Ba Thuoc district, Thanh Hoa province, Vietnam

Remote sensing technique. QGIS 3.12.1 software was used to capture the normalized difference vegetation index (NDVI). Rouse et al. (1974) discovered that NDVI is the most common indicator in the cultivation study. The NDVI has two main bands: the NIR and the Red Band. The land use cover and the map of yield monitoring were frequently utilized in agriculture. The NDVI was computed using the band combination for the red and NIR reflections using band 4 and band 8 from every accessible cloud-free Sentinel-2 scenes (2016–2020). Similarly, Purnamasari et al. (2019) revealed the places near significant water resources such as big rivers and water bodies, rice fields were found to be abundant, but cassava crops were found to be abundant on sloping terrain in areas distant from water resources. The normalized vegetation difference index (NVDI) has been developed to assess changes in the vegetation index because of satellite observations (NDVI). The Normalized Difference Vegetation Indicator (NDVI) is a vegetation index connected to various biophysical parameters and used to produce several agricultural indices. Regarding to crop area, the NDVI was calculated using temporal information from Sentinel-2 (Google Earth Engine, 2020), gathered near the end of the cassava growing season and just before harvest.

GIS technique. In the present work, GIS was used to map the potential land for cassava crop. The data of factors which were inputted to the model classified according to 4 levels. Weight of each factor was obtained by experts (Table 3). Integrated using the Boolean operations and the weighted linear combination to create component maps in raster form. ArcGIS 10.2 was used to map potential cassava cropland by overlaying raster component maps. Finally, a map of potential cassava cropland was created, which was divided into four classifications (SI1, SI2, SI3, N) in agreement with Equation (1) and the FAO's framework for land suitability (FAO, 1993). This technique makes use of a combination and manipulation of geographical data as well as decision-maker opinions in accordance with given decision rules, whereas the parametric method simply makes use of multiplication for the score of all elements.

$$SI = \sum_{i=1}^{n}(W_i \cdot X_i) \quad (1)$$

Score of each factor (X_i) was obtained on each land mapping unit, importance of factor *i* are converted to factor weight (W_i), *i* ranges from 1 to *n*, *n* was the total number of factors in the model. The weighted linear combination of W_i and X_i, was calculated by Equation (1), give suitability index (*SI*) which was an evaluation for each land mapping unit. Land mapping unit is a unit of land which have the same characteristic.

Table 3. The weights of parameters in land analysis of cassava cultivation in Ba Thuoc district of Thanh Hoa province, Vietnam

Parameters	S1	S2	S3	N	Weight (W)
1	2	3	4	5	6
P_1: Annual Mean Temperature	> 22–25	> 20–22	> 25, > 18–20	< 18	0.038
P_2: Max Temperature of Warmest Month	> 30	> 27–30	> 24–27	< 24	0.038
P_3: Min Temperature of Coldest Month	> 17–20	> 14 – 17	> 20	< 14	0.038

Table 3. Continuation

1		2	3	4	5	6
P_4: Annual Precipitation		1500–1900	1100–1500	1900–2300	> 2300, <1100	0.089
P_5: Average annual sunny hours		> 2500	2000–2500	1500–2000	< 1500	0.036
Soil characteristics	P_6: Soil type	Ft, Fk, Fu, Fv, Fn, Ru, Rv, Fj, Fs	Fa, Fq, Fp, Fs, X, Pbe, Pbc, Py	Pf, Hk, Hu, Hj, Hs, Ha, Hq	0.204	0.204
	P_7: Slope	3–8	0–3, 8–15	15–25	0.051	0.051
	P_8: Soil texture	Clay	Sandy loam	Loam	0.068	0.068
	P_9: Soil depth	> 70	50 – 70	30–50	0.068	0.068
	P_{10}: pH	6.5–7.5	5.5–6.5	7.5–8.2	< 5.5 and > 8.2	0.086
	P_{11}: Nitrogen	0.17	0.17–0.09	0.09–0.045	< 0.045	0.060
P_{12}: Distance from roads		< 1000	1000–2000	2000–3000	> 3000	0.035
P_{13}: Distance from rivers		< 500	500–1000	1000–1500	> 1500	0.048
P_{14}: Land use cover		Vegetation in fertile soils	Rice field; intercropping	Plantation forests land	Settlements, residents. Water bodies; Natural forest	0.179

RESULTS AND DISCUSSION

Spatial distribution of potential area

These highly potential (S1) areas concentrated in some characterized including annual mean temperature from 22–25ºC, yearly precipitation from 1500–1900 mm, average annual sunny hours above 2500 hours: Slope degree from 3 to 8º, soil depth above 70cm, texture class clay (Table 3). Three parameters have the most suitable land area for a crop, such as P_2 (Max Temperature of Warmest Month), P_1 (Annual mean temperature) (Table 3). The land of low potential (N) located in the large areas with slope degree >30^0 also was classified due to the presence of settlements, water bodies, natural forest land, and residences that cannot replace with cassava fields. The area with climatic conditions ranges in minimum temperature of the coldest month (P_3 < 14°C), average annual sunny hours (P_5 < 1500 h), which were the most significant areas not potential for cassava. This result is similar to Akinwumiju et al. (2020), who showed that climatic conditions exert the most limiting effects on cassava production.

According to focus group interviews, literature reviews, and local people's knowledge, a limited number of physical environment characteristics were selected for the model. The assessment process was an application taking into cassava environmental requirements regarding local conditions based primarily on the physical element of soil, topography, climate and geographical condition. LULC, annual precipitation and soil pH are the most significant factors among these.

Based on the weighted overlay maps used to find appropriate cassava production sites, as shown in (Fig. 3), the land suitability maps may serve as a potential map for forecasting instrumentation that could assist measures to increase local food production in the Ba Thuoc district. Results indicated that the amount of land areas allocated to each category was as follows: highly potential land (S1: 6101.1 ha, 8%), moderately potential land (S2: 20826.40 ha, 27%), marginally potential land (S3: 32288.77 ha, 42%), and not potential (N: 18305.75 ha, 24%) (Table 4, Fig. 4). Therefore, the study suggested the cassava area proposal for cultivation in the high potential area (S1). In contrast, diversification of marginally potential (S3) and not potential (N) areas to other idea solutions than cassava potentially adapted to the environmental requirements. In the model, several contents (Planted area, yield, production) were collected from the General Statistics Office of Vietnam from 2015 to 2019. These data revealed that the size of cassava cultivation decreased from 1470 ha to 918 ha (37.5%); Production of cassava decreased from 24402 to 15494 tons (36.5%) from 2015 to 2019; Yield of cassava increased 1.68% (Table 5).

This study produced information on the importance of each parameter useful for future studies on cassava crops of other regions, especially the approach that can provide a framework for another crop of this region. Therefore, to enhancing food security, the annual cassava production capacity can be increased by extending the cultivation to the other areas reasonably favorable for the root crop. Edet et al. (2015) found that the plant growth parameters of cassava at 4–6 months after planting all contributed to enlarge the fresh root biomass at 12 months after growing harvest. Furthermore, Amarullah et al. (2017) reported that growth traits' most excellent vegetative phase began to show a significant positive contribution to the tuber weight.

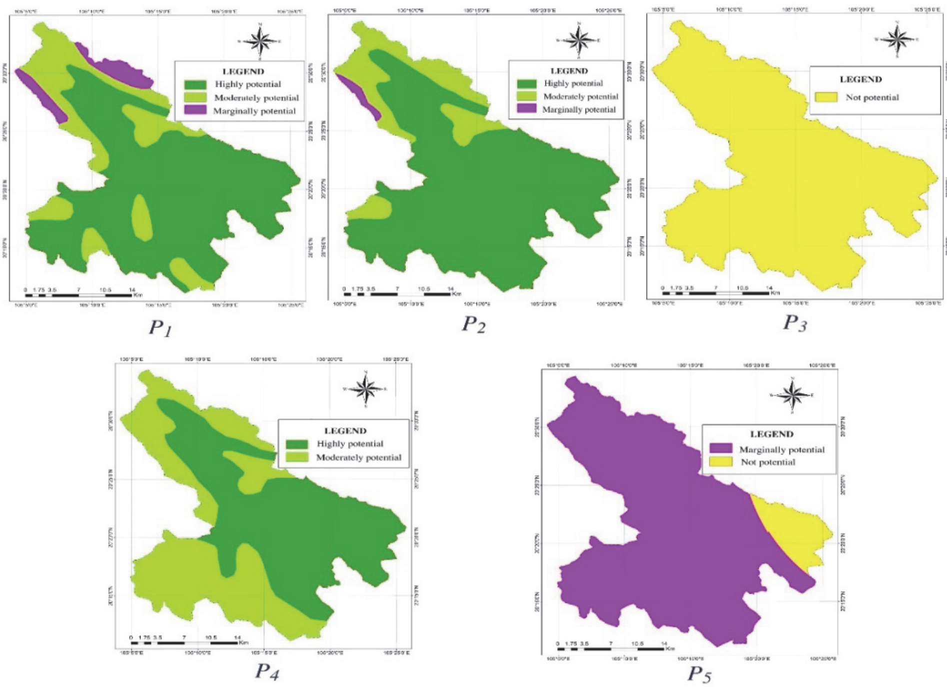


Fig. 3. Reclassification of parameters of model (P_1 – P_{14}): P_1 – Annual mean temperature, P_2 – Max Temperature of Warmest Month, P_3 – Min Temperature of Coldest Month, P_4 – Annual precipitation, P_5 – Average annual sunny hours

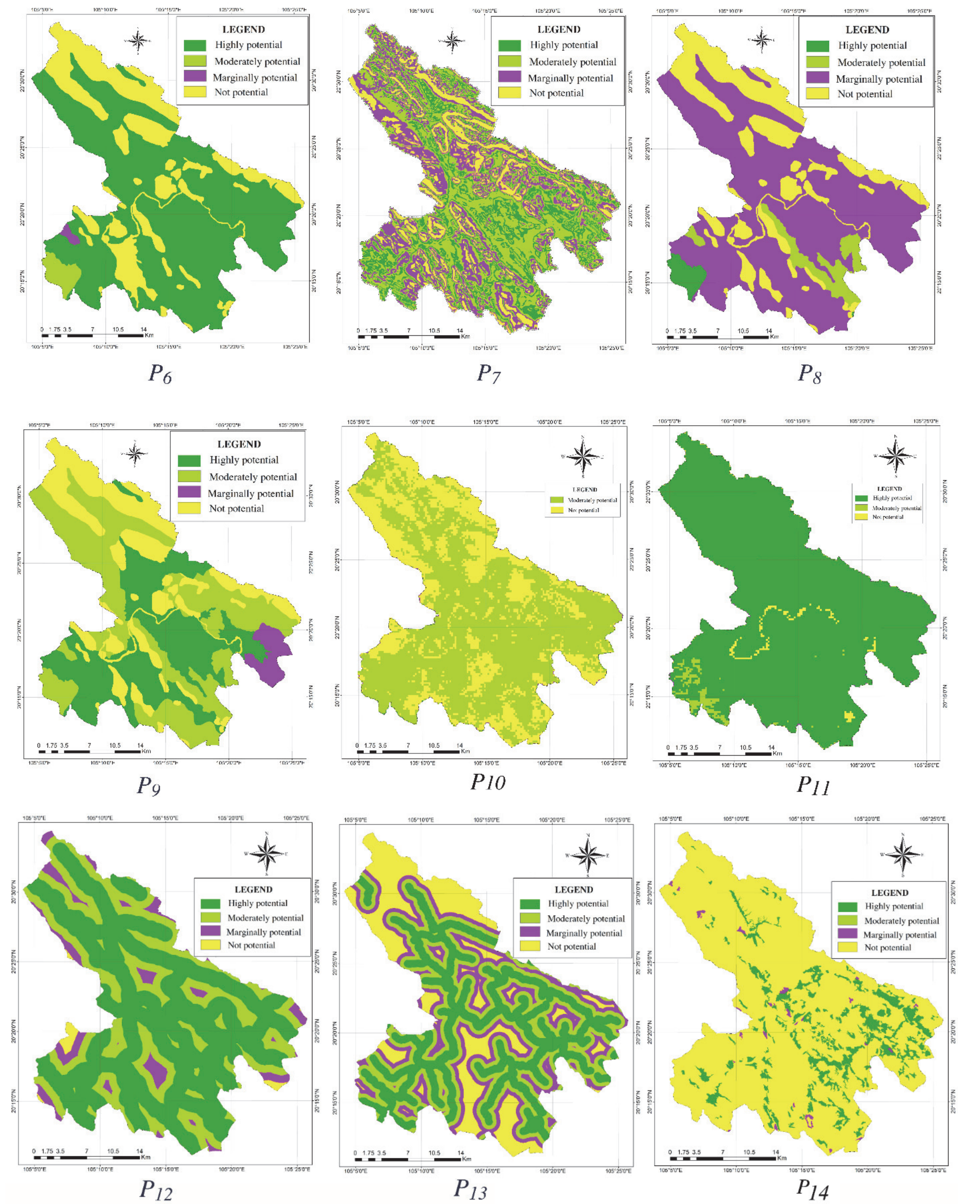


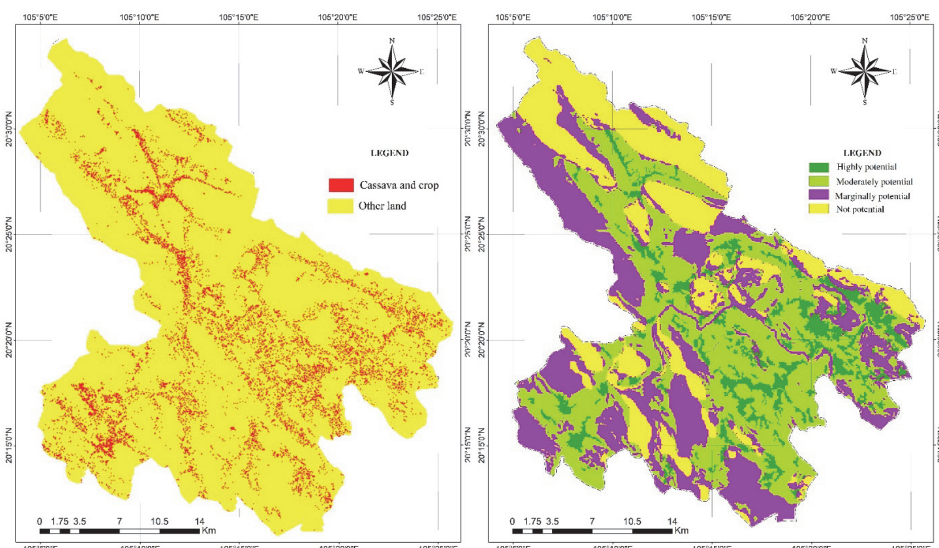
Fig. 3. Continued. P_6 – Soil type, P_7 – Slope, P_8 – Soil texture, P_9 – Soil depth, P_{10} – Soil pH, P_{11} – Nitrogen, P_{12} – Distance from roads, P_{13} – Distance from rivers, P_{14} – Land use cover

Table 4. Potential area for cassava production in Ba Thuoc district, Thanh Hoa province, Vietnam

Potential class	Area, ha	Percentage area, %
Highly potential (S1)	6101.10	8
Moderately potential (S2)	20826.40	27
Marginally potential (S3)	32288.77	42
Not potential (N)	18305.75	24
Sum	77522.02	100

Our result analyzed the contributions of yield and cassava production in Ba Thuoc district, Vietnam. During this period, the yield increased while the planted area and production decreased. Although, Boansi (2017) used the short and long-run models, cassava yield was affected by standard climate variables and within-season rainfall variability. But our research results showed that the areas of cassava crop cultivation simultaneously reduced, and the reason for that has been not dependent on the physical characteristic environmental conditions, which have been very potential factors for providing quality products. Especially the potential land was illustrated by the map result with a larger area (6101.1 ha) than present area cassava planting (918 ha). The status of cassava plants was cultivated fragment. The big farms never planned to be established yet. Thus, the limiting factors from the domestic market, backward processing technology, and the purchase price of raw cassava will play a prominent role in the local farms.

The agricultural land potential was affected by asymmetries caused by climatic and socioeconomic systems, which may worsen present productivity (Fischer et al., 2005). Therefore, restoring bare land, reforestation, soil water conservation strategies, and policies for developmental agricultural output must be encouraged. In recent years, the in-



a *b*

Fig. 4. Actual cassava and crop cultivation area, 2020 (*a*) and potential cassava cultivation area (*b*)

creasing urbanization rate, and the need for land usage of different projects have caused a decline in the quantity of agricultural land (Bravo, 2017). In the meantime, our results showed the potential area for cassava production is many times larger than the actual area in the study area. In addition, a suitable land category for agriculture confirmed by farmers has a greater probability, especially when agricultural land is challenged by climate change and unplanned human growth (Fischer et al., 2005). Hence, national, and regional policies on land management techniques influence agricultural output, both directly and indirectly.

Table 5. Status of cassava cultivation (General Statistics Office of Vietnam, 2019)

Category	Explication	Unit	2015	2016	2017	2018	2019
Planted area	When the plant begins its growth process for each cropping season, the annual planted area is recorded. If crops are replanted several times in the same place owing to being dead, the area is also recorded only once in that location	Ha	1470	1544	995	915	918
Yield	The primary product per one area unit of a certain agricultural crop or set of agricultural crops collected in a production season or in a year on average planted area is referred to as crop yield	Quintal / ha	166	166.40	170.90	167.46	168.79
Production	Cassava production is measured in the form of fresh bulbs	Ton	24402	25693	17005	15323	15495

Methodological Challenge

Some of the criteria evaluated for mapping the PI land include continuous numerical data (e.g., soil depth, rainfall, temperature, etc.), leaving this difficult to accurately relate such data to the high potential area (Zhang et al., 2015). All these variables have distinct magnitudes, making them incomparable for usage. Furthermore, determining the appropriate weight of all criteria is difficult due to the apparent uneven effect on cassava growth. Those data derived from physical environmental data (soil, climate), which may result in some issues and barriers in the result obtained because micro-scale analyses are required to address the significant ecological variability and distinguish between the influences of anthropogenic activities (Papastergiadou et al., 2010; Lamsal et al., 2019). Another cause of current problems is a disparity between the spatial-temporal resolution of satellite images and the socioeconomic-ecological aspects. Due to their spatial resolution, current soil maps and climate data cannot reveal spatial variation at fine resolution. Hence, a fine scale is required to analyze stream stability, accumulation, and soil degradation that occurs in the cassava planting area. As a result, fine - scale spatial resolution remote sensing products and field research are suggested for upcoming investigations.

Field-level crop monitoring employed Sentinel-2 MSI vegetation index (VI) datasets and NDVI data. Satellite-based normalized differential vegetation index fluctuations were assessed. (NDVI). The NDVI generates crop indices and is connected with numerous biophysical parameters. Sentinel 1A and 1B satellites and Sentinel 2A and 2B satellites provided data. ESA's Scientific Data Hub provided all orbital data: https://scihub.copernicus.eu/dhus/#/home.

Semi-structured interviews and field data were collected during cropping seasons using Sentinel-2 MSI taken at the end of the growing period and before harvest. NDVI describes land surface vegetation, water, and natural surfaces... Given irregular field patterns and small field sizes, different management approaches, extremely heterogeneous growing environments, and other mapping issues associated with smallholder farming systems, crop type mapping in study area smallholder settings are hard. During the growing season, frequent cloud cover makes crop-type mapping, particularly intercropping, difficult.

Thus, freely available European Copernicus Program satellite data, notably S2A/B, enable considerable breakthroughs in mapping and monitoring crop kinds in smallholder farming systems of the study areas. This study added cassava and intercropping combinations to crop type mapping. Our crop mapping approach had an 82% ROC curve for complex smallholder cropping systems. (Field data were collected during the cropping seasons and used to test the accurate ratio of the NDVI map). This is essential to understanding Sentinel-2 data's potential and limitations for monitoring smallholder agricultural systems.

However, our crop maps are good enough for informed land-use change, broad-scale early warning systems, and regional crop production monitoring. In smallholder systems with high intercropping, similar methodologies could be used due to similar climatic circumstances, satellite data frequency, cloud cover, management, and agricultural practices.

Validation

According to GPS coordinates for high-yielding cassava fields recorded in Survey 2021, most cassava planting sites are in the central and eastern sections of the country. This ground reference information is used to validate the land potential model using ROC Analysis (www.jrocfit.org) (Eng, 2014). The results' validation demonstrates this study results application of the model through in-situ observations. Using Receiver Operating Characteristic (ROC) curve analysis, the results were validated by using site selected from the survey. The results showed an area under the ROC curve value of 82%, indicating that the AHP method accurately predicts and models potential land in the study area and that the method is appropriate for assessing and modeling potential land in the study area. Significant knowledge of the impact of optimal cassava area on sustainable land use management and development in the district is given by this analysis (Fig. 5).

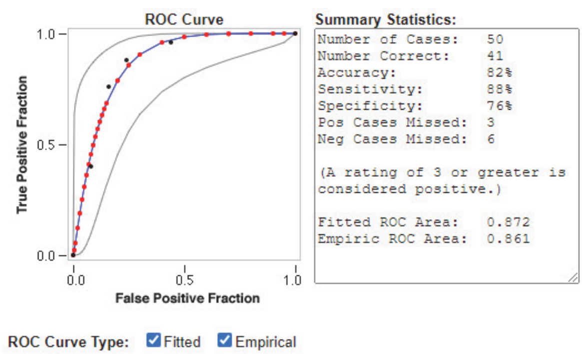


Fig. 5. Receiver operating characteristic (ROC) curve (Key for the ROC Plot: RED symbols and BLUE line: Fitted ROC curve; GRAY lines: 95% confidence interval of the fitted ROC curve; BLACK symbols ± GREEN line: Points making up the empirical ROC curve)

CONCLUSIONS

In this study, the primary purpose of the land evaluation was to predict the potential or limitations of land for cassava production. The study revealed an assessment model to determine the land suitability for planting cassava. Cassava crop is not an indigenous product, Vietnam has been and continues to be the world's second-largest exporter of this product. Our results suggest that the potential land area for cassava production is still quite huge, eight times larger than the current cassava area. The results also highlighted that these areas face limitations for the cultivation of cassava due to climatic conditions of the minimum temperature of the coldest month ($P_3 < 14$°C), average annual sunny hours ($P_5 < 1500$ h); Land use, land cover, annual precipitation and soil pH are the most significant factors. The high potential area was 8% concentrated in the study area's middle and eastern part. Although, the research showed the areas of cassava crop cultivation simultaneously reduced, the reason for that has not been dependent on the physical environmental conditions, which have been very potential factors for providing quality products. Product prices, farmer psychology, and agricultural product development policies are just a few of the market factors that must be considered.

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Оценка земель для выращивания маниоки (*Manihot esculenta* Crantz; Euphorbiaceae, Magnoliopsida) с использованием метода анализа иерархий, ГИС и дистанционного зондирования

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Аннотация. Цель настоящего исследования – оценить характеристики земель для выращивания однолетней маниоки с целью выбора пространственных свойств и параметров окружающей среды, необходимых для указания перспективных участков для выращивания маниоки. В соответствии с руководящими принципами ФАО была построена пространственная модель для оценки перспективных земель для устойчивого выращивания маниоки посредством интеграции метода AHP-GIS-Remote Sensing. Анализ земель показал, что земли с высоким потенциалом составляют 6101.1 га (8% от общей площади), они сосредоточены в средней и восточной части изучаемой территории. Эти районы имеют ограничения для выращивания маниоки из-за климатических условий: минимальная температура самого холодного месяца (P_3 < 14°C), среднегодовое количество солнечных часов (P_5 < 1500 ч) и ряд потенциальных факторов обеспечения качественной продукции (наиболее важные факторы – годовое количество осадков и pH почвы). Площади посевов маниоки сократились, но причина этого не зависела от физических условий окружающей среды. Возможно, на местных фермах играют важную роль ограничивающие факторы внутреннего рынка, устаревшие технологии переработки и низкая закупочная цена на сырую маниоку.
Ключевые слова: AHP (метод анализа иерархий), маниока, урожай, почва, ГИС, ФАО

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