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Applying the integrated model of GIS and AHP for evaluating ecological suitability of Ming aralia (*Polyscias fruticosa*): a case study of Hai Hau district, Nam Dinh province, Vietnam

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Abstract:

The Hai Hau district, located in the southeast region of the Nam Dinh province, belongs to the Red river delta where residents mainly rely on agriculture, fisheries, and handicrafts as their livelihood. In recent years, many households have switched from growing rice to Ming aralia (*Polyscias fruticosa*), a tropical medicinal plant with high economic value. On the basis of analysing the influence of bioclimatological and soil conditions in Hai Hau district, Nam Dinh province on the growth and development of cloves through the integrated Analytic Hierarchy Process (AHP) - Geographic Information System (GIS) model, this study has divided the adaptive thresholds for each climate factor with corresponding weighted values to evaluate the ecological adaptability of Ming aralia to the criteria's in Hai Hau district. The research results show that the Hai Hau district has 25.3% of highly suitable area (S1), 33.8% of moderately suitable area (S2), 23.3% of marginally suitable area (S3), and 17.6% of not suitable area (N) for Ming aralia development. The suitable area for cultivation of Ming aralia with high economic efficiency is about 13,522.37 ha, or 59.1% of the total area, located in the northern communes of the district. This finding is a scientific basis for planning, planting, and exploitation of Ming aralia to improve sustainable livelihoods and promote local socioeconomics.

Keywords: **ecological adaptation, GIS - based AHP, Hai Hau, Ming aralia, *Polyscias fruticosa*.**

Classification number: **5.1**

Introduction

The assessment of ecological suitability determines the overall favourability level of geography such as landscape units, ecological units, land units, etc., for the object of development planning [1]. In Vietnam and around the world, depending on the units and subjects performing the ecological suitability assessment, many methods and models have been proposed. However, the model integrating AHP and GIS, which integrates a large amount of heterogeneous data to obtain the weights of enormous alternatives (criteria) with ease, is applied in this work due to its various advantages in a wide variety of decision-making problems [2]. The three principles of AHP, designed by Saaty (2001) [3], are analysis, comparative judgments, and combining priorities [4]. The process involves various options for decision making, and can analyse the sensitivity of the criteria and sub-criteria. A few important advantages of this technique are the detection of the compatibility and incompatibility of decision making, and identification and prioritization of the elements of decision making [5]. Therefore, the GIS technique and AHP methods have been applied to several studies to analyse the suitability of plants based on natural conditions and the ecological feature of the plant such as weather conditions, nutrients, physical conditions of soil, and economic and social factors. These techniques have been typically used for land suitability assessment in semi-arid regions for wheat and maize farming like in Neyshabur County, Iran (Ahmad, et al., 2020), the spatial assessment of suitable areas for medicinal species of Astragalus in Bahar Mountain, Iran, assessing indigenous cinnamon species suitability in Tra Bong, Quang Ngai, and for land evaluation for coconut trees in Mo Cay Nam, Ben Tre… [6-9].

Ming aralia (*Polyscias fruticosa* (L.) Harms.) is widely grown in Vietnam and other countries in the Pacific region [10, 11]. Ming aralia is one of the most precious medicinal plants and it has been used for a long time as traditional medicine because it has the effect of replenishment, stimulating digestion, detoxifying, anti-bacterial and anti-inflammatory activity, and increasing endurance [10, 12]. In addition, Ming aralia is also known as "fish salad" and is used in culinary dishes in various ways [12].

Currently, in Nam Dinh, Ming aralia is grown mainly in the districts of Hai Hau, Nghia Hung, Giao Thuy, and Xuan Truong. Most of the cultivation areas are lands in gardens and ponds without any planning at larger

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scales. However, Ming aralia is easy to grow and easy to use, with typical medicinal properties of the ginseng family such as enhancing health, resistance, and improving adaptability [11]. Therefore, evaluating the ecological suitability of Ming aralia, with the application of GIS-based AHP for developing and planning Ming aralia in Hai Hau district, has a high scientific and practical significance. This article provides research results on the ecological suitability of Ming aralia with local ecological factors, thereby noting where suitable areas can be found for the growth and development of this plant. This is also the basis for proposing planning of the area for growing Ming aralia for the purpose of improving the livelihood of the residents and contributing to biodiversity conservation in Hai Hau district, Nam Dinh province.

Methods

Research area

The Hai Hau district is located in the southeast of the Nam Dinh province (Fig. 1). The district has the same soil and climate characteristics of the Northern delta with flat land, fertile soil, and tropical monsoon climate with cold winters. The population here is unevenly distributed and primarily concentrated in the coastal area [13]. In Hai Hau, agricultural development is the main focus, which makes this area a large granary of the Red river delta. Besides, fisheries, industry, handicrafts, and tourism attract a lot of domestic and foreign investment.

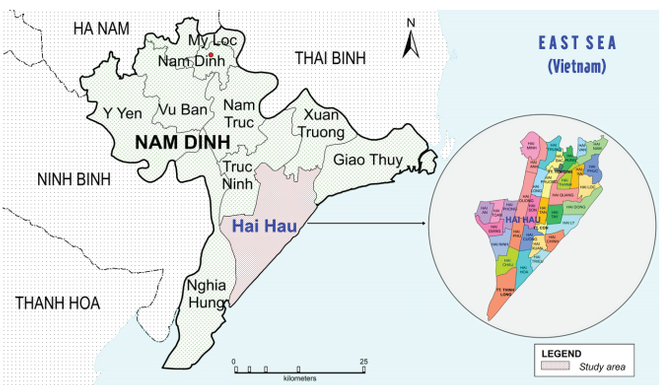

Fig. 1. Location map of the study area.

The climate and soil properties were collected, sorted, systematized, summarized, and analysed using hydro-meteorological data from statistical yearbook of Nam Dinh province [14] and the socio-economic report of Hai Hau district [15].

Characteristics of climate and soil in Hai Hau district, Nam Dinh province:

- *Radiation and daylight*: the average annual hours of sunshine are from 1650 to 1700. The average annual amount of solar radiation is 100 Kcal/cm^2.

- *Temperature*: the average annual temperature is from 23 to 24^{o}C, and the daily temperature amplitude is less than 10^{o}C.

- *Precipitation*: the average annual rainfall is from 1700 to 1800 mm. High rainfall levels mostly occur in July, August, and September accounting for nearly 80% of the total annual rainfall. Highest rainfall level in a day can be up to 200-250 mm.

- *Humidity*: Hai Hau is an area with a relatively high humidity and the average value is between 80 and 85%. The humidity of the area is stable with minor fluctuation. The humidity is highest in February and March at 92% and lowest at 80%, in which there is hot, dry southeast wind.

- *Other weather phenomena*: the study area is influenced by 2 prevailing wind directions - the southeast wind in summer and northeast wind in winter. Every year, Hai Hau is affected by 4-6 storms on average.

- *Soil*: Hai Hau belongs to a young group of soil, mainly alluvial soil with 56.1% natural area formed by the deposition of alluvial materials from the Red river system. The other groups of soils are saline soils (accounting for 19.4%), sandy soils (accounting for 5.7%), and the other groups such as alkaline soils and soils with feralitic products.

Research object

Biological and ecological characteristics of Ming aralia (*Polyscias fruticosa* (L.) Harms.) were summarized from the following documents: list of plant species in Vietnam [10], Vietnamese Medicinal Plants and Medicinal Herbs [11], Medicinal Plants in Vietnam [12], and An Illustrated Flora of Vietnam [16].

The field investigation process method by Nguyen Nghia Thin (2007) [17] was applied. This process includes following steps: determining the route and survey points; setting up standard plots (10x10 m); measuring the indicators of Ming aralia, soil, and climate; then to collect, analyse, preserve, and store samples.

Ming aralia (*Polyscias fruticosa*) grows in bushes of 0.5-2 m in height. Small tree, smooth stem, no spines, no hairs, white bark; edematous roots that look like tubers (Fig. 2). Fragrant leaves, 3-pinnate and 20-40 cm long; leaflets with toothed margin; no sheath, leaves are fragrant. The mace-shaped inflorescence is short, about 7-18 mm, consisting of many crowns, with broad leaves that quickly fall off, small green flowers, petals 5, white, stamens 5, and ovary 2 chambers. Flowers bloom in November - December, slightly flattened round fruit 3-4 mm long, 1 mm thick with existing spigot, silvery white colour.

Fig. 2. Morphology of Ming aralia [12, 18].

Alkaloids, glucosides, saponins, flavonoids, tannins, B vitamins, and amino acids including lysine, xystei and methionine, have been found in Ming aralia.

To evaluate the ecological adaptability of Ming aralia (*Polyscias fruticosa*), the adverse ecological conditions for Ming aralia have been studied as follows:

- *Light-humidity:* Ming aralia is a perennial plant that favours moisture, is photophilic, and thrives in medium humid conditions. Ming aralia is also a shade-tolerant plant, but it can grow slower in shade.

- *Temperature-precipitation:* Ming aralia does not require high rainfall. Ming aralia can withstand mild drought and dislikes stagnant water. Ming aralia cannot bear waterlogging, either. The optimal temperature threshold for the growth of Ming aralia is between 22-27°C.

- *Soil:* Ming aralia is a plant with a wide ecological limit as it can live and grow on many types of soil, particularly sandy soil.

The AHP multi-objective decision making model

Evaluating ecological suitability of Ming aralia includes selecting and classifying criteria, weighting indicators, and summarizing evaluations [3].

Selecting and classifying criteria: based on previously published documents and the evaluation of experts, we selected the main ecological factor (Xi) as the criterion affecting the development and growth of the research object.

Weighting indicators: to calculate the priority between indicators (based on Saaty's priority scale - Table 1), a matrix is established:

	X_1	X_2	…	X_n
X_1	a_{11}	a_{12}	…	a_{1n}
X_2	a_{21}	a_{22}	…	a_{2n}
..	…	…	…	…
X_n	a_{n1}	a_{n2}	…	a_{nm}

where a_{ij} is the priority between the two indices i and j: $a_{ij}>0$, $a_{ij}=1/a_{ji}$, and $a_{ij}=1$ (with $i=j$).

Table 1. Priority scorecard [3].

Priority level	Level
1	Equal priority
3	Fairly equal priority
5	More priority
7	Very priority
9	Extreme priority
2, 4, 6	Average priority

Then using the above matrix creates a new matrix by dividing each value in the column by the sum of the column:

$$\begin{array}{c} \\ X_1 \\ X_2 \\ .. \\ X_n \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & \dots & X_n \end{array} \\ \begin{pmatrix} w_{11} & w_{12} & \dots & w_{1n} \\ w_{21} & w_{22} & \dots & w_{2n} \\ \dots & \dots & \dots & \dots \\ w_{n1} & w_{n2} & \dots & w_{nn} \end{pmatrix} \end{array} \quad w_{ij} = \frac{aij}{\sum_{i=1}^{n} aij}$$

where W_i is the weight of the indicator: $W_i=\frac{\sum_{j=1}^{n} wij}{n}$.

Summarizing evaluation: the consistency index (CR) needs to be calculated and checked for a value to accept the assessment. CR is calculated according to the formula: CR=CI/RI (with CR<0.1 the evaluation is accepted) in which:

$$CI = \frac{\lambda_{max}-n}{n-1} \quad \text{and} \quad \lambda_{max} = \sum_{i=1}^{n} w_i.$$

RI is determined according to Table 2 where n is the number of evaluation criteria.

Table 2. The random index match with number of criteria.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Creating maps

To build multiple layer maps, we use MapInfo 11.5 and ArcGIS 10.0 software following these steps: (1) input and add data, (2) manage and organize data, (3) process and analyse data, and (4) publish output data [19, 20].

Assessment of ecological suitability

Evaluating the ecological suitability of Ming aralia using a combination of AHP hierarchical analysis and a GIS allows the construction of spatial analyses, and the management, integration, and overlay of information layers [21] with the evaluation formula: $S = \sum_{i=1}^{n} M_i$.

where S is the adaptability index; M_i is the coefficient of adapting to the criteria; and W_i is the weight of the indicators.

Results and discussion

Selection and classification of adaptability of Ming aralia to ecological factors

For Ming aralia in Hai Hau district, the study to select X_i for assessment includes 6 main ecological factors:

X_1 - annual average temperature; X_2 - annual average rainfall; X_3 - annual average humidity; X_4 - the length of cold seasons; X_5 - the length of dry seasons; X_6 - type of soil.

The threshold for ecological suitability of Ming aralia to the ecological and soil conditions X_i (Table 3) is given based on evaluation and meta-analysis.

Table 3. Ecological suitability table of Ming aralia to ecological factors in Hai Hau district.

Factors	Symbols	Value	Measures	Details	Suitable level			
					Highly suitable	*Moderately suitable*	*Marginally suitable*	*Not suitable*
					S1	*S2*	*S3*	*N*
1. Annual average temperature	1	<20	℃	Slightly cold				+
	2	20-22		Cool			+	
	3	22-24		Normal	+			
	4	24-28		Slightly hot		+		
	5	>28		Hot				+
2. Annual average rainfall	s	<1500	mm/year	Small		+		
	m	1500-1800		Average	+			
	l	1800-2000		Slightly heavy			+	
	vl	>2000		Heavy				+
3. Annual average humidity	s	<81	%	Normal			+	
	m	81-83		Average	+			
	h	83-85		Slightly high		+		
	vh	>85		High			+	
4. The length of cold seasons	ls	<2	month/ year	Very short		+		
	s	2-3		Short	+			
	m	>3		Average			+	
5. The length of dry seasons	s	<3	month/ year	Short		+		
	m	3-5		Average	+			
	h	5-6		Long			+	
	vh	>6		Very long				+
6. Type of soil	FL			Fluvisols	+			
	FLSm			Molli Salic Fluvisols		+		
	FLSh			Hapli Fluvisols			+	
	FLSg			Gleyi Salic Fluvisols				+

Determining the weights of the indicators

The main factors affecting the ecological suitability of Ming aralia in the study area are calculated in correlations using the AHP model through weight values (Table 4). With the value of consistency ratio (CR)=0.02<0.1, the evaluation can be accepted.

Table 4. Table of weight of factors affecting ecological suitability of Ming aralia.

Factor	Annual average temperature	Annual average rainfall	Annual average humidity	The length of cold seasons	The length of dry seasons	Type of soil
Weight	0.304	0.263	0.130	0.101	0.101	0.101

It can be seen that the average annual temperature is the most important factor affecting the growth and development of Ming aralia (30.4%). This is followed by the factors of annual average rainfall (26.3%) and annual average humidity (13%). The factors of length of cold season, length of dry season, and mechanical composition have less influence (a total of 10.1%).

Developing component maps

The main goal of applying GIS software is to process collected data and arrange it using algorithms to create target maps (Figs. 3-8).

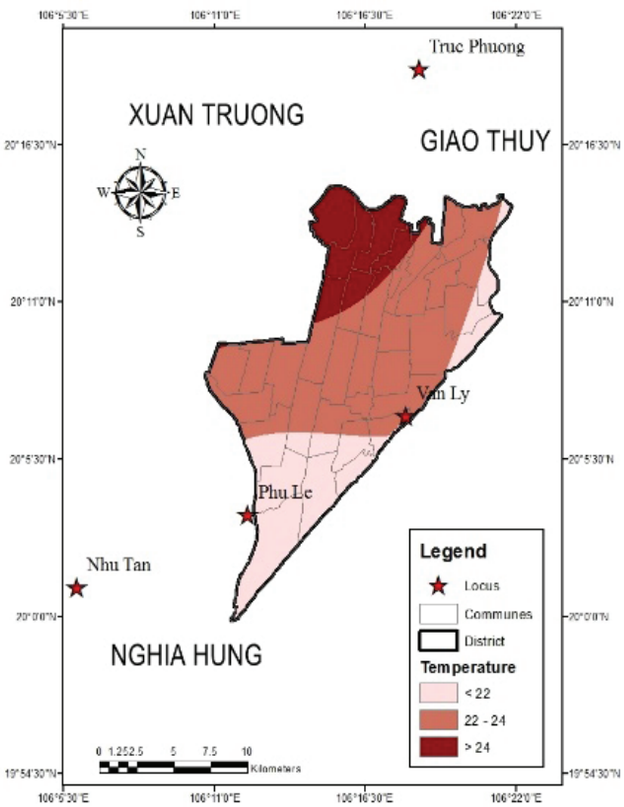

Fig. 3. Annual average temperature map.

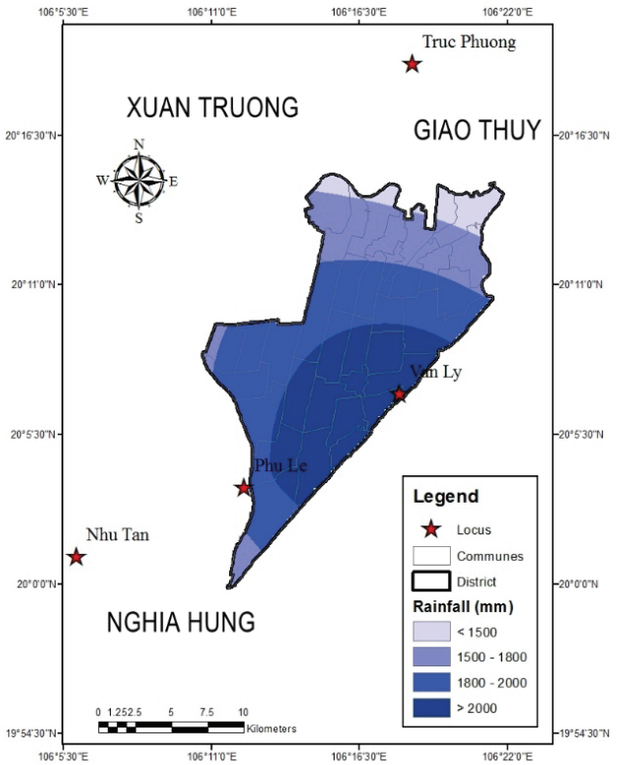

Fig. 4. Annual average rainfall map.

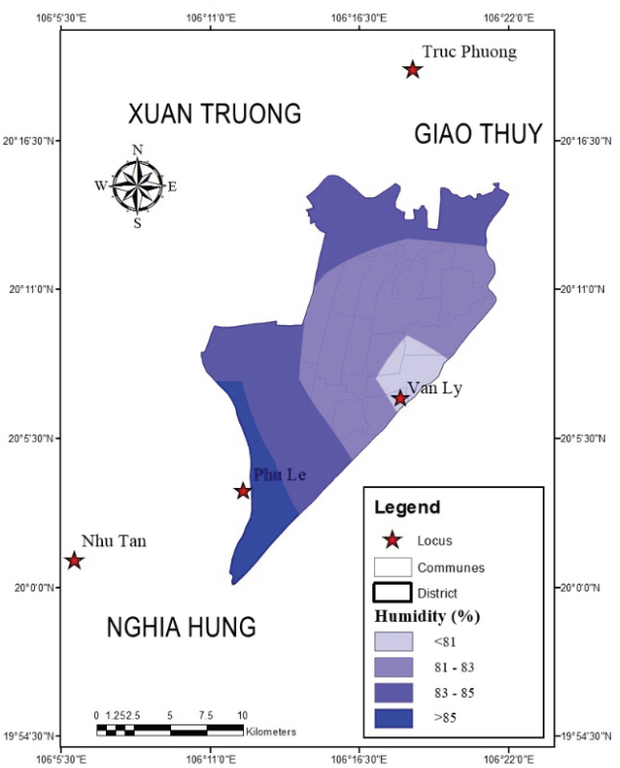

Fig. 5. Annual average humidity map.

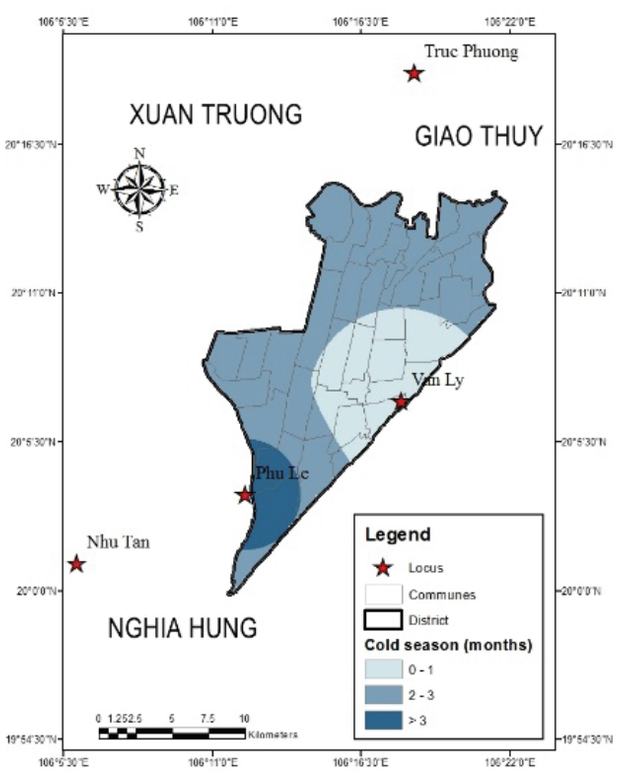

Fig. 6. The length of cold seasons map.

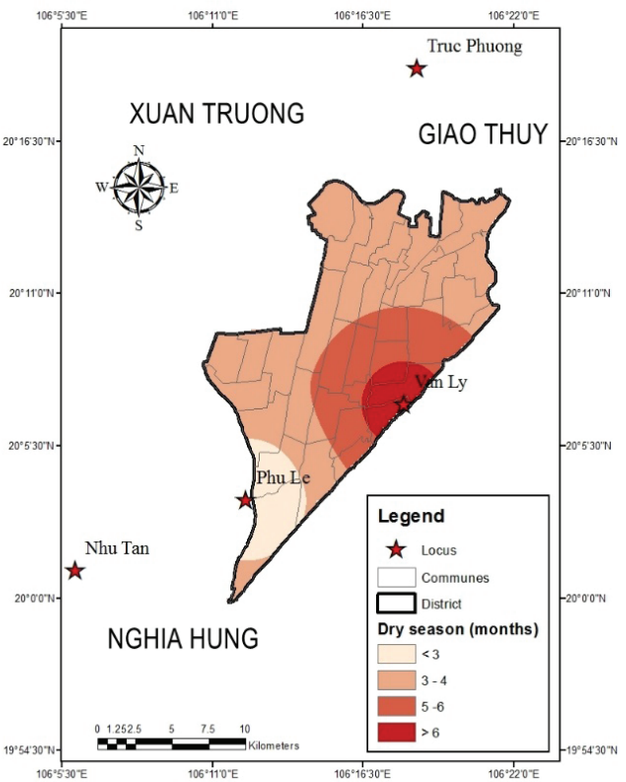

Fig. 7. The length of dry seasons map.

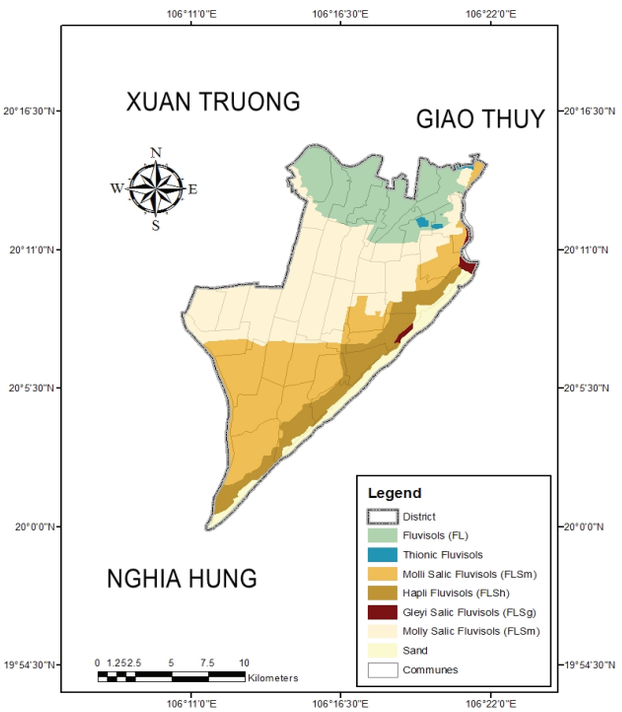

Fig. 8. Type of soil map.

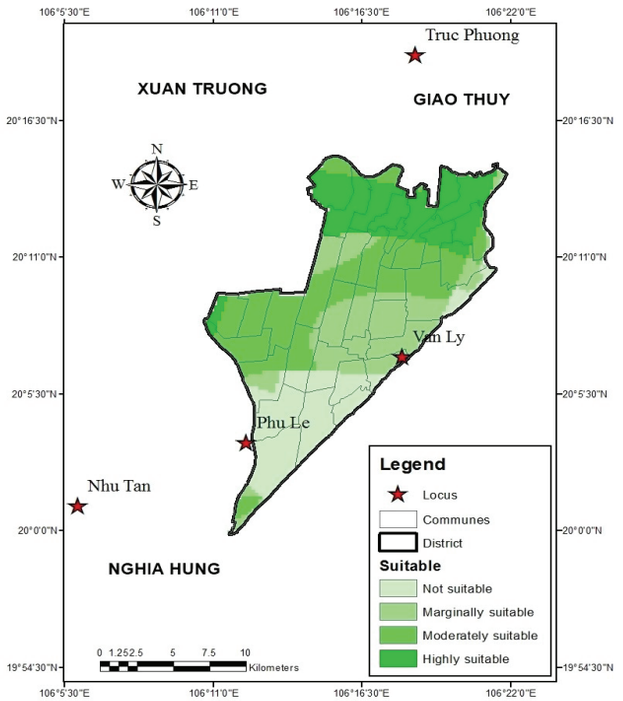

Fig. 9. Suitability level map of Ming aralia in Hai Hau district.

Evaluation of the ecological suitability of Ming aralia

The ecological suitability is divided into 4 levels based on the average score rate (S): S1 (highly suitable): average suitability score rate is above 80%; S2 (moderately suitable): average suitability score rate from 66 to 80%; S3 (marginally suitable): average suitability score rate from 50 to 65%; N (not suitable): average suitability score rate is less than 50%.

The map of the suitability of Ming aralia in Hai Hau was developed based on applying the AHP model to determine the weights, then overlaying the corresponding map on ArcGIS software (Fig. 9).

The evaluation results by the AHP-GIS method and the evaluation formula show that:

- The highly suitable area (S1) has a total area of 5,781.62 ha, which accounts for 25.3% of the Hai Hau district and is distributed to the north of the district in which the communes of Hai Anh, Hai Bac, Hai Van, Hai Nam, Hai Trung, and Hai Minh are located. The soil in this area is mostly alluvial; the ecological factors are within the moderately suitable - highly suitable threshold. This is a favourable area for the growth, development, and rooting of Ming aralia.

- The moderately suitable area (S2) has a total area of 7,740.75 ha accounting for 33.8% of the Hai Hau district. These regions extend from the east to the southwest of Hai Hau and is located along the communes of Hai Thanh, Hai Long, Hai Duong, Hai Phong, Hai Toan, and Hai An. This area has annual ecological factors, which have a slight influence on Ming aralia.

- The marginally suitable area (S3) has a total area of 5,321.61 ha accounting for 23.3% of Hai Hau. These areas are in Hai Tay and Hai Son communes and these areas contain land plots with small/moderate areas that are isolated or located between the distribution zones of the moderately suitable (S2) and highly suitable (S1) areas. This area has an adverse ecological factor of heavy average annual rainfall.

- The not suitable area (N) has a total area of 4,051.61 ha accounting for 17.5% of Hai Hau and is distributed to the south along the Hai Xuan, Hai Cuong, and Hai Hoa communes, and a small part of the eastern of Hai Hau district. These areas possess mainly saline soils (FLSm and FLSh). The adverse ecological factors are the average annual temperature and the length of the cold season.

Thus, the climatic and soil conditions in Hai Hau district (Nam Dinh province) are suitable for the cultivation and development of Ming aralia as nearly 60% area is assessed as highly suitable and moderately suitable. However, the actual scale of planting Ming aralia in the area is still not high compared to the potential realized through this study. According to the documents summarized above, Ming aralia is easy to grow, easy to care for, and can be harvested from 3 years of age. After harvesting, good stems can be selected for breeding while other parts such as roots, stems, and leaves can be sold in fresh form or processed immediately. Currently, companies and businesses in the Hai Hau district also focus on promoting people to build high-yield Ming aralia farms and to approach GACP standards to produce medicinal herbs. Therefore,

the planning of potential areas and the construction of Ming aralia growing areas should be of focus to enhance and ensure local livelihood, which aims to improve living standards and contribute to biodiversity conservation in the Hai Hau district, Nam Dinh province.

Conclusions

Based on the assessment of the adaptability of ecological factors to the growth and development of Ming aralia, a table of ecological suitability of Ming aralia to ecological factors in Hai Hau district, Nam Dinh province has been developed to summarize four suitability levels of highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

Using the AHP model, the development of Ming aralia in Hai Hau district, Nam Dinh province has been evaluated under the influence of 6 factors: average annual temperature, average annual rainfall, average annual humidity and relative humidity, length of cold season, length of dry season, and soil mechanical composition with the following weights: 0.034; 0.263; 0.130; 0.101; 0.101; 0.101, respectively. In addition, corresponding component target maps has been established.

Hai Hau, Nam Dinh has the most suitable area for the development of Ming aralia (S1 and S2), which is located in the north of the district with 13,522.37 ha accounting for 59.1% of the study area. The area with high adaptability for growing Ming aralia is fairly large and located along the communes of Hai Anh, Hai Bac, Hai Van, Hai Nam, Hai Trung and Hai Minh. This area has alluvial soil with ecological factors that are highly suitable for the growth, development, and tuber production of Ming aralia. It can be seen that the total area of Hai Hau district is quite large, but the suitable area for growing Ming aralia is mainly concentrated in the northern area of the district because of the complexity of the soil as well as the climatic conditions in the area. However, Ming aralia generates great economic value that can stabilize livelihoods, so potential areas should be expanded in the future.

The method of integrating the AHP hierarchical analysis model into GIS for assessing the adaptability of Ming aralia is an effective approach to local research and the assessment of the ecological suitability of plants for planning in potential regions. The scoring and weighting methods for each ecological factor with quantitative values has partly eliminated the subjectivity in the assessment of plant ecological suitability.

In the future, with the method of integrating the AHP hierarchical analysis model into GIS, the implementation of studies to assess the potential of bioclimatological and soil resources in localities to determine the degree of ecological adaptation while serving as the planner of cultivation areas of medicinal plants is effective and feasible. Enhancing livelihoods, improving lives, promoting sustainable socio-economic development, and creating a premise for the formation of potential areas for the cultivation of high-yielding varieties, species, specialties for each locality will all be gradually brought into reality by using this method.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] N.C. Huan, N.A. Thinh, P.Q. Tuan (2004), "An integrated ALES-GIS model in landscape evaluation for cultivated crop development in Sa Pa district, Lao Cai province", *VNU Journal of Science: Natural Sciences and Technology*, **4,** pp.43-50 (in Vietnamese).

[2] Y. Chen, J. Yu, K. Shahbaz, E. Xevi (2009), "A GIS-based sensitivity aalysis of multi-criteria weighs", *18th World IMACS/ MODSIM Congress, Cairns, Australia*, pp.3137-3143.

[3] T.L. Saaty (2001), "Fundamentals of the analytic hierarchy process", *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*, Springer, **3**, pp.15-35.

[4] H. Alipor, M. Zare, S. Shojaei (2016), "Assessing the degradation of vegetation of arid zones using FAO-UNIP model (case study: Kashan zone)", *Model. Earth Syst. Environ.*, **2**, pp.1-6.

[5] J. Bigelow, Z. Mobaraki (2009), "Land suitability comparison of Ghazvin to cultivate saffron based on the multi-criteria decision methods", *Nat. Geog. Res.*, **66**, pp.101-119.

[6] R.P. Ahmad, R.M. Hamid, S. Akbar, S. Feridon (2020), "Integrated fuzzy, AHP and GIS techniques for land suitability assessment in semi-arid regions for wheat and maize farming", *Ecological Indicators*, **110**, pp.1-8.

[7] P. Issa, M. Mahboobeh, Z.T. Ali, A. Hamid, S. Saeed, A.M. Sayed (2019), "The spatial assessment of suitable areas for medicinal species of Astragalus (Astragalus hypsogeton bunge) using the analytic hierarchy process (AHP) and geographic information system (GIS)", *The Egyptian Journal of Remote Sensing and Space Science*, **22(2)**, pp.193-201.

[8] N.H. Cuong (2018), "Integration of GIS and decision tree in land evaluation for coconut trees in Mo Cay Nam district, Ben Tre province", *VNU Journal of Science: Earth and Environmental Sciences*, **34(1)**, pp.66-76 (in Vietnamese).

[9] N.V. Loi, T.K. Ngoc, P.D. Hung (2020), "Application of GIS, AHP, and FAPH in assessing indigenous cinnamon species suitability in Tra Bong, Quang Ngai", *Hue University Journal of Science: Agriculture and Rural Development*, **129(3D)**, pp.5-19 (in Vietnamese).

[10] Hanoi National University, Vietnam Institute of Science and Technology (2005), *Checklist of Plant Species of Vietnam*, Agriculture Publishing House, 1248pp (in Vietnamese).

[11] D.T. Loi (2004), *Vietnamese Medicinal Plants and Medicinal Herbs*, Medical Publishing House, 1294pp (in Vietnamese).

[12] P.H. Ho (2006), *Medicinal Plants in Vietnam*, Tre Publishing House, 718pp (in Vietnamese).

[13] Department of Natural Resources and Environment of Nam Dinh Province (2016), *Decision 722 / QD-UBND On Approval of Land Use Plan in 2020 Hai Hau District* (in Vietnamese).

[14] Nam Dinh Statistical Office (2013), *Nam Dinh Statistical Yearbook* (in Vietnamese).

[15] Hai Hau District People's Committee (2020), *Report on the Implementation of the Socio-Economic Development Plan in 2019 and Objectives, Tasks and Solutions in 2020* (in Vietnamese).

[16] P.H. Ho (2003), *An Illustrated Flora of Vietnam*, Tre Publishing House, 1027pp (in Vietnamese).

[17] Nguyen Nghia Thin (2007), *Methods of Plant Research*, Hanoi National University Publishing House, 166pp (in Vietnamese).

[18] WHO/WPRO Manila, Institute of Materia Medica Hanoi (1990), *Medicinal Plants in Vietnam*, Science and Technology Publishing House, 435pp (in Vietnamse).

[19] T.T. Duc (2002), *Basis GIS*, National University Publishing House, 200pp.

[20] N.D. Ky, et al. (2005), "ALES-GIS integrated model in assessing ecological adaptation to crops (sample study: coffee and rubber areas in Dak Lak and Dak Nong provinces)", *Journal of Soil Science*, **23**, pp.97-102 (in Vietnamese).

[21] E. Memarbashi, H. Azadi, A.A. Barati, F. Mohajeri, S.V. Passel, F. Witlox, (2017), "Land-use suitability in northeast Iran: application of AHP-GIS hybrid model", *ISPRS International Journal Geo-Information,* **6(12)**, DOI: 10.3390/ijgi6120396.