Application of AHP-GIS Model to Assess the Ecological Suitability of _Codonopsis javanica_ in Kon Plong District, Kon Tum Province, Viet Nam

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ABSTRACT

The Kon Plong district is located in the northeast area of the Kon Tum province, where ethnic people, such as Xo Dang and Hre, are dominant. With the portion of the poor families accounting for more than 50% of the total households, the improvement in the livelihood of ethnic is an emergency. Among the approaches to enhance the economical situation in the mountainous area like Kon Plong, the sustainable utilization of natural resources to produce valuable products is a possibility. The _Codonopsis javanica_ (Blume) Hook.f. & Thomson (native name in the Vietnamese language is Dang Sam) is a precious medicinal plant with many benefits in pharmacological uses for human health. In nature, _C. javanica_ is favorably distributed in the template climate and high mountain area. On the basis of the multi-criteria analysis using AHP (Analytic Hierarchy Process) integrated GIS, the influence of climate factors and soil features in the Kon Plong district on the growth of _C. javanica_ was evaluated. Using AHP evaluation, the four classes of adaptation thresholds (very suitable, suitable, less suitable and not suitable) between the _C. javanica_ growth and climate or soil factors were determined and expressed in weight values. These adaptation values (weight values) were then exported to ecological adaptation maps using the GIS mapping system. The results showed that the most suitable area (called S1 and S2) for the cultivation of _C. javanica_ could be an area of 77 ha, accounting for 55.8% of the study area. The area with high adaptability (S1) for growing _C. javanica_ is mainly located in the Mang Den town and Mang But commune (the south area of the Kon Plong district). These study findings suggested that the growth of _C. javanica_ is suitable in several places in Kon Plong and the production process of _C. javanica_ probably promotes the exploitation of sustainable utilization of local medical plant biomass in the study area.

Keywords: _Codonopsis javanica_, AHP - GIS, ecological adaptation, Kon Plong.

INTRODUCTION

Codonopsis javanica (Blume) Hook.f. is a Vietnamese traditional medical plant that belongs to the _Campanulaceae_ family. It was documented that _C. javanica_ is naturally distributed in the range of 900–2200 m sea level in the template and sub-tropical regions, including China, Korea, Japan, Myanmar, India, Laos and Vietnam (Hong, 2015; Li et al., 2004). Previous studies confirmed that natural compounds in the extracts from the root of _Codonopsises_ have significant effect on attenuating hyperinsulinemia and lipid peroxidation in fructose-fed insulin-resistant rats (Phan et al., 2020; Zhang et al., 2020). With the high consumption in the local market as the traditional medicine, the natural distribution of _C. javanica_ has been sharply declining, which causes the reduction of the _C. javanica_ production yield. Kon Plong is a mountainous district of the Kon Tum province, where ethnic people such as Xo Dang and Hre are dominant. With the portion of the poor families accounting for more than 50% of the total households, the improvement in the livelihood of ethnic people in Kon Plong is an emergency (To et al., 2017). Among the approaches to enhance the

economical situation there, the sustainable utilization of natural resources, such as *C. javanica,* to produce valuable products is a possibility (Grebner et al., 2013; Muralikrishna & Manickam, 2017).

Aiming to evaluate the ecological adaptation of *C. javanica* in artificial farming in Kon Plong to improve the quantity and quality of *C. javanica* production, this study was established using the multi-criteria analysis using AHP and GIS to predict the compatibility between the growth of *C. javanica* and the meteorological factors, soil properties and land use status in the studied area.

MATERIALS AND METHOD

Studied area

Kon Plong is a mountainous region in the Central Highland of Vietnam with 80% of the total area of 137.1 ha is higher than 1000 m above sea level. The geographical location of Kon Plong was simulated as shown in Figure 1.

Soil properties, land use/land cover status and meteorological data

These data were collected from the statical yearbook (2000–2019) of Vietnam (GSO, 2019). Besides, the data from hydrometeorological stations (12 loci) around the studied area was also referred to.

Determination of ecological suitability of *C. javanica* in the studied area with the assistance from AHP

There are nine factors of soil properties, land use/land cover and meteorology that were used to evaluate the ecological suitability of *C. javanica*. The AHP (Saaty, 1988) approach was applied to determine the relative weight and priority between positive factors that affect the growth of *C. javanica*.

Integration of AHP results and GIS modeling to export the ecological suitability map of *C. javanica* in the studied area

The ArcGIS (version 10.0) model was employed to describe the layer maps of nine factors that affect the growth of *C. javanica*. The kriging tool was used in ArcGIS to estimate the spatial distribution of 12 loci meteorological data in the studied area. Finally, using the raster calculator tool in ArcGIS, the combination of these layer maps with the relative weight from AHP results was overlayed to export the ecological suitability map for *C. javanica* in the studied area.

RESULTS AND DISCUSSION

Characteristics of climate, soil properties and land use/land cover status in Kon Plong

Kon Plong was targeted in this study due to the annual temperature range of 18.7–24.9°C (Fig. 2a) as well as the native distribution of various Vietnamese herbs, such as ginseng, ganoderma and other unidentified biomass that are used by ethnic people as traditional medicine (Nguyen et al., 2016). In this area, the average annual rainfall is around 1780–2200 mm (Fig. 2b) with the rain season starting from August to February (Fig. 2e). The humidity level is around 82.6–87.0% with the highest data from August to October and the lowest number in
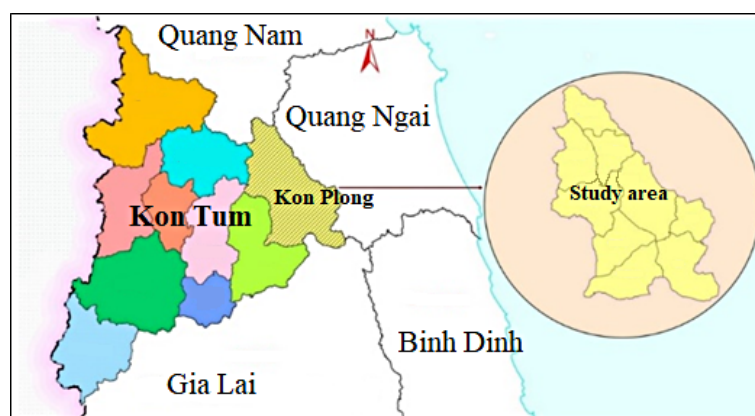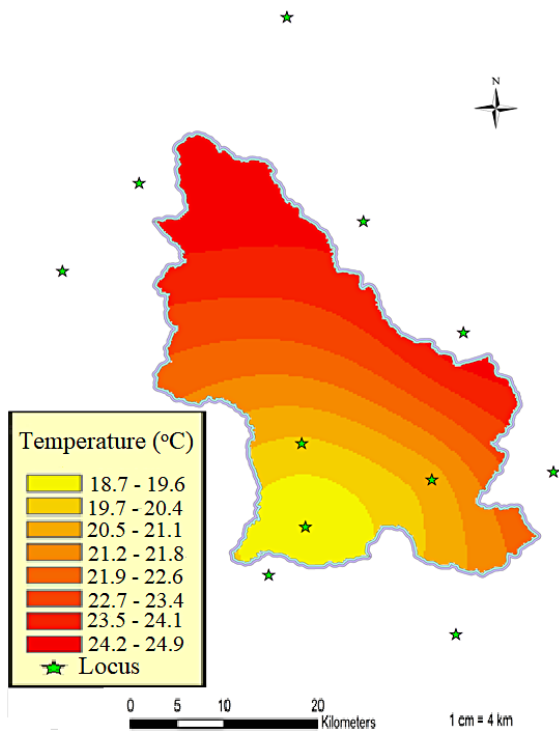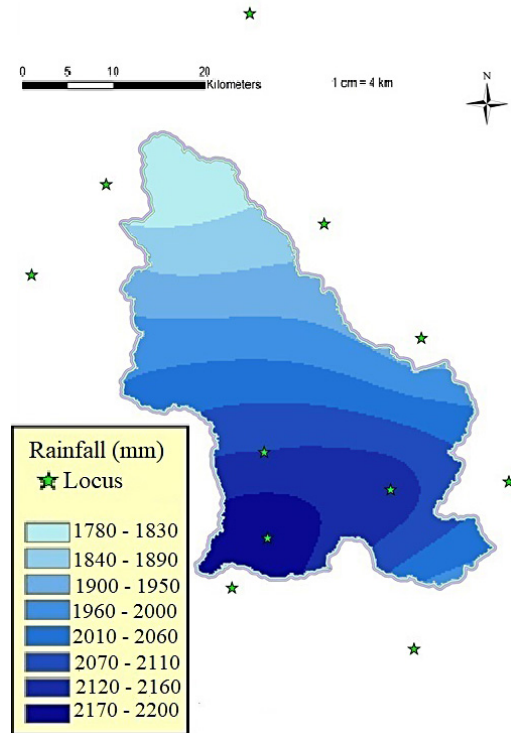

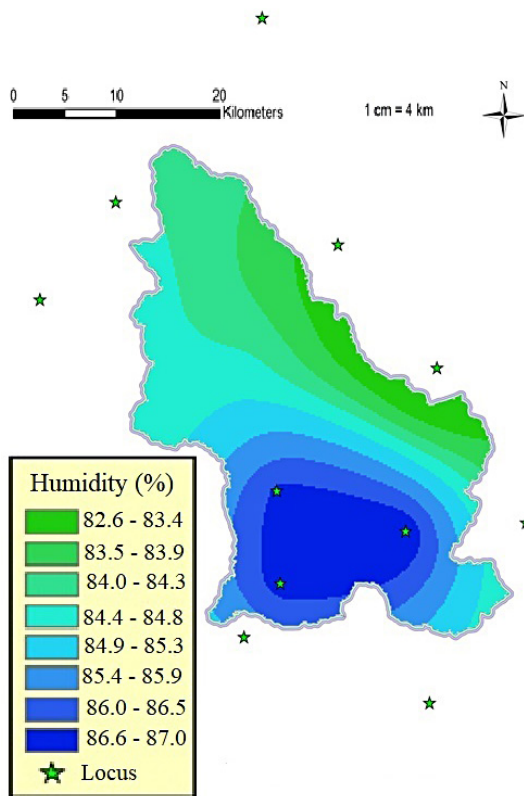**Figure 1.** The stimulation of the studied area

a)   The map of annual average temperature

b)   The map of annual average rainfall

c)   The map of annual average humidity

d)   The map of annual average cold season
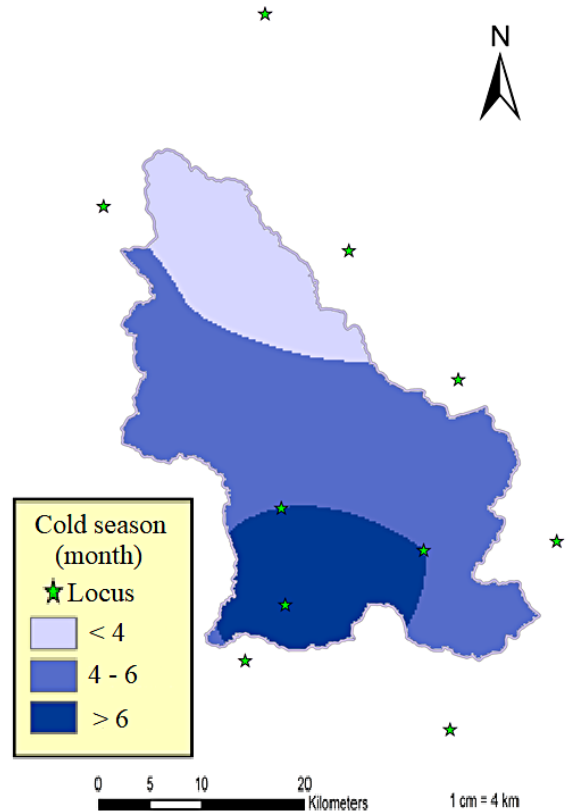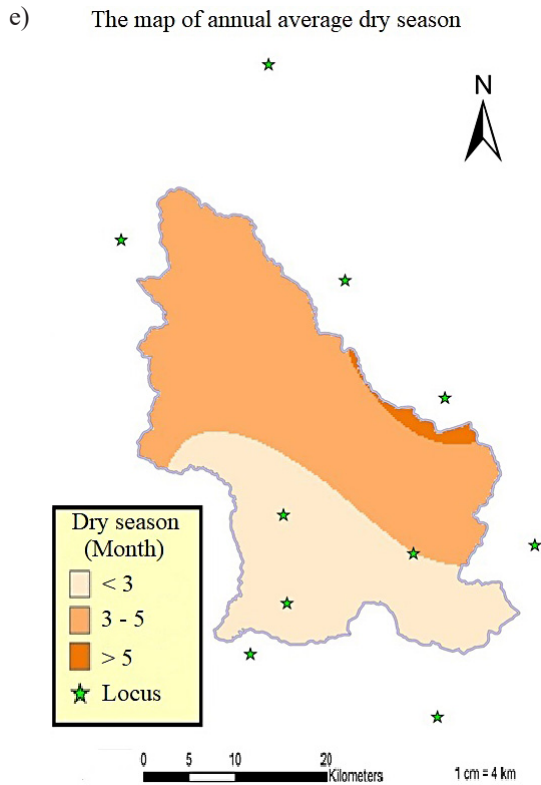

Figure 2. The simulated maps of meteorological conditions in the studied area: a) annual average temperature; b) annual average rainfall; c) annual average humidity; d) annual average cold season; e) annual average dry season

e) The map of annual average dry season

Figure 2e. Cont. The simulated maps of meteorological conditions in the studied area: d) annual average cold season; e) annual average dry season

March and April (Fig. 2c). In general, the tropical monsoon climate in the Kon Plong highland is a suitable condition for temperate crops and other medicinal plants that prefer growing in the range of 18–20°C with high humidity and require the dry season (Fig. 2d) for rooting formation.

The soil type in the studied area was classified into four main types, including ferralsol, gleysol, fluvisol and acrisol (Fig. 3a). Besides, the thickness of the soil layer (> 30 cm) also was analyzed in Fig. 3b. The slope of the land surface (Fig. 3c) and the land use/land cover in Kon Plong (Fig. 3d) were examined.

Evaluation of the ecological suitable level of *C. javanica* in the studied area

In nature, *Codonopsis* prefers growing under the shade of trees in high mountain area (Gao et al., 2018). Under the cultivation conditions, the suitability of nine factors (Fig. 2–3) for the growth of this vital herb was analyzed into four classes (high suitability, suitability, low suitability and unsuitability) as Table 1.

The positive factors above were paired, compared to each other and the weight number that

a) The map of soil type

b) The map of soil layer
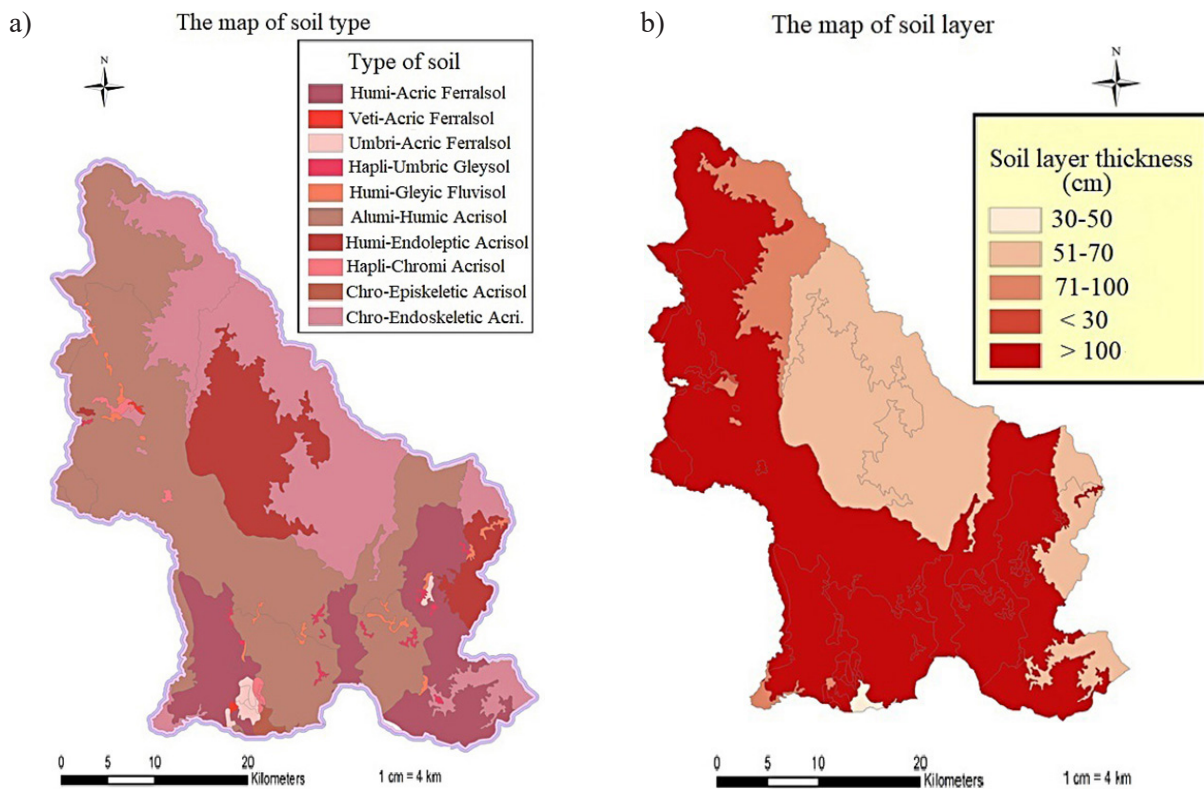
Figure 3. The simulated map of soil and land use in the studied area: a) soil type; b) soil layer; c) land surface slope; d) land use/land cover
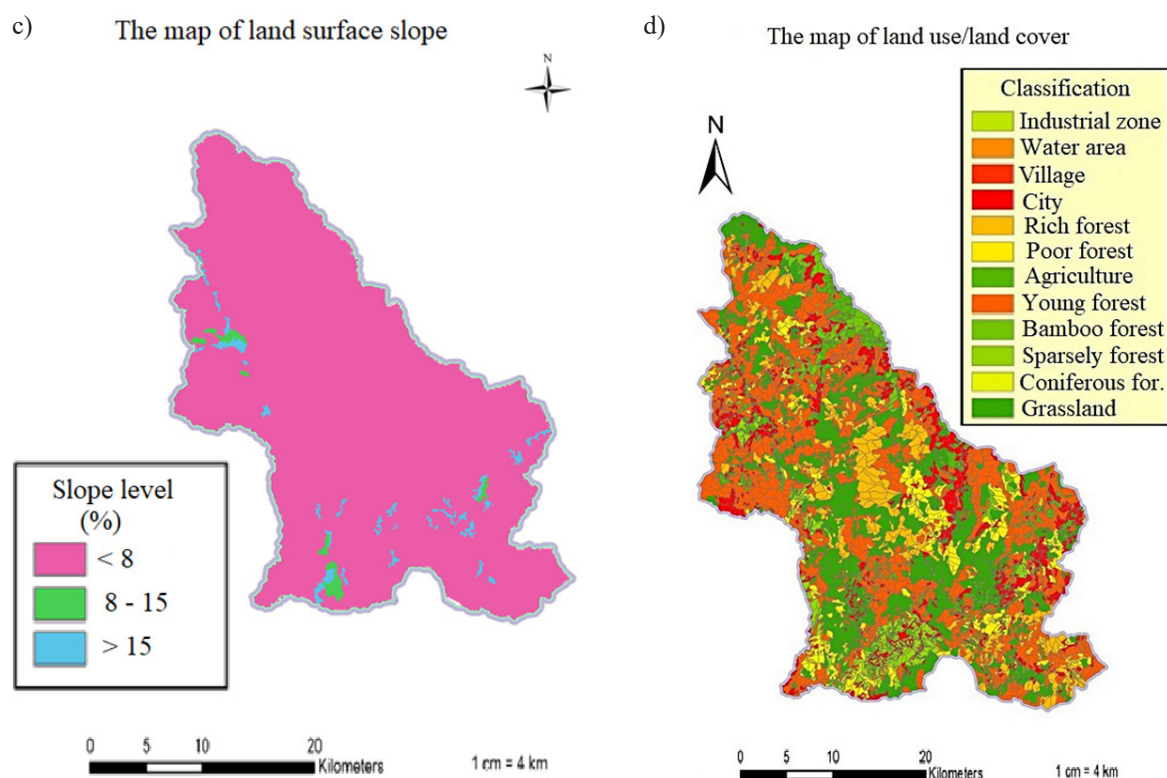
Figure 3c & 3d. Cont. The simulated map of soil and land use in the studied area:
a) soil type; b) soil layer; c) land surface slope; d) land use/land cover

affects the growth of *C. javanica* was calculated by following AHP (Table 2). The previous studies confirmed that AHP is a powerful approach to evaluating the ecological vulnerability (Wu & Tang, 2022) or estimating the ecological adaptation of important bioresources under climate change (Zhang et al., 2021) and also to determine the potential suitability of valuable plants in the designed area (Ersan & Başayiğit, 2022). In this study, the AHP method was expected to predict the priority factor that affects *C. javanica* among nine selected criteria.

With the CR index being 0.042 for all positive factors, the calculated weights were considered reliable (Saaty, 1987). The AHP results decided that annual average temperature is the most effective to the ecological suitability of *C. javanica* (26.7%) and followed by annual average rainfall (18.2%) and type of soil (17.6%).

Integration of AHP and GIS to construct the ecological suitability map

Even *C. javanica* is a valuable herb, however, the study about the evaluation of farming conditions for this plant in Vietnam is still limited. Aiming to promote the cultivation in Kon Plong, in this study,

the combination of ArcGIS software and the AHP weight of positive factors (Table 2) was performed using the raster calculator tool to construct the overlayed ecological suitability map (Fig. 4).

The suitability map indicated the high suitable area (S1) is 11.6 ha, accounting for 8.4% of the studied area. This S1 area is mostly distributed in the south of Kon Plong where the soils are acrisols with an annual temperature around 18.5–20.5°C and rainfall higher than 2100 mm per year.

In addition, the suitable area (S2) portion is 65.4 ha, equivalent to 47.4% of the studied area. The S2 area is indicated from the northeast to the south of Kon Plong. The less suitable area (S3) is 20.8 ha (15.1% of the total studied area). The S3 is randomly distributed in Kon Plong and several areas are interspersed between S1 and S2. The limiting ecological factors in the S3 area are the type of soil (fluvisols, gleysols) and high annual average temperature (>23°C).

Finally, the unsuitable area (N, 40.2 ha) corresponds to around 29.1% of Kon Plong where the land was used for cities and villages. Besides, the place with the soil type ferralsols and/or soil thickness less than 30 cm was indicated as unsuitable for the growth of *C. javanica*. With the total number of S1 and S2 being 55.8% of the

Table 1. The classification of ecological suitability of *C. javanica* with cultivation conditions in Kon Plong

Factors	Values	Measures	Suitable level			
			High suitability	Suitability	Low suitability	Un-suitability
			S1	S2	S3	N
Annual average temperature	<20	°C	+			
	20-23			+		
	>23				+	
Annual average rainfall	<1800	Mm			+	
	1800–2000			+		
	2000–2200		+			
	>2200			+		
Annual average humidity	<84	%			+	
	84–86		+			
	>86			+		
The length of cold season	<4	Month/year			+	
	4–6		+			
	>6			+		
The length of dry season	<3	Month/year	+			
	3–5			+		
	>5				+	
Type of soil	Hapli-Chromi Acrisols Chromi-Endo Skeletic Acrisols	Soil	+			
	The other of Acrisols			+		
	Ferralsols					+
	Fluvisols, Gleysols				+	
Thickness of soil layer	<30	cm				+
	30–70				+	
	70–100			+		
	>100		+			
Slope of soil	<8	Degree	+			
	8–25			+		
	>25				+	
Status of land use	Rich, medium forest	Land	+			
	Poor and other forest			+		
	Land for agri, industry				+	
	Cities, villages, the other					+

Kon Plong district area, the growth of *C. javanica* is promising, based on the study on climate, soil properties and land use/land cover status.

CONCLUSIONS

C. javanica is a valuable herb in Vietnam with many applications in traditional medical treatment. On the basis of the ecological characteristics, the study has predicted four classes of the suitability of *C. javanica* in Kon Plong (including high suitability – S1, suitability – S2, low suitability – S3, and unsuitability – N) with nine factors (soil properties, land use/land cover status as well as meteorology).

The AHP approach was used to evaluate the weight ratio among nine criteria that effects the growth of *C. javanica*. The AHP outcome concluded that annual average temperature has the greatest effect on the growth of *C. javanica*. With the integration of AHP results and ArcGIS modeling, the suitability map for *C. javanica* growth in the study area was exported. The

Table 2. The results of the Analytic Hierarchy Process for the positive factors that affect the growth of *C. javanica* in Kon Plong

Factors	1	2	3	4	5	6	7	8	9
1	1.000	2.000	3.000	5.000	5.000	2.000	3.000	7.000	6.000
2	0.500	1.000	3.000	4.000	4.000	1.000	2.000	6.000	5.000
3	0.333	0.333	1.000	1.000	0.500	0.333	0.500	5.000	4.000
4	0.200	0.250	1.000	1.000	2.000	0.333	0.500	4.000	3.000
5	0.200	0.250	2.000	0.500	1.000	0.250	0.333	3.000	2.000
6	0.500	1.000	3.000	3.000	4.000	1.000	2.000	6.000	5.000
7	0.333	0.500	2.000	2.000	3.000	0.500	1.000	5.000	4.000
8	0.143	0.167	0.200	0.250	0.333	0.167	0.200	1.000	2.000
9	0.167	0.200	0.250	0.333	0.500	0.200	0.250	0.500	1.000
Weight (Total = 1.000)	0.267	0.182	0.075	0.07	0.059	0.176	0.114	0.028	0.028
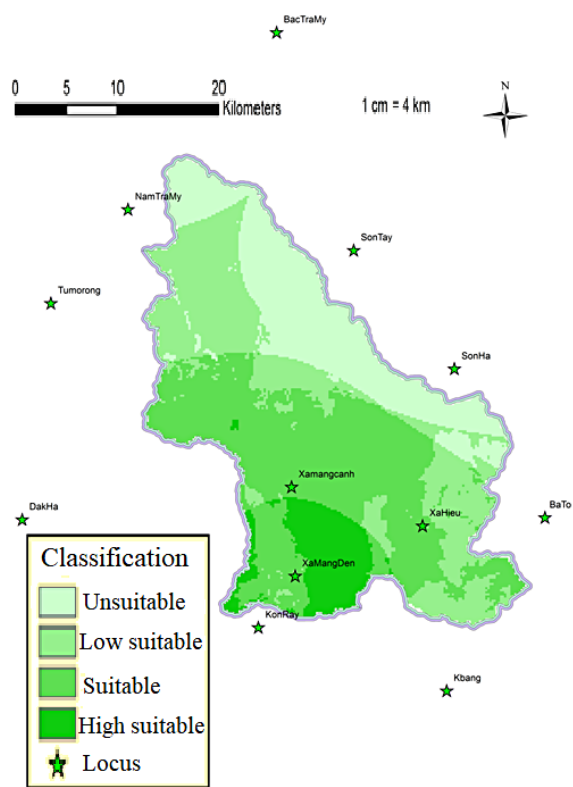
Figure 4. The simulated map of ecological suitability of *C. javanica* in Kon Plong district, Kon Tum Province, Viet Nam

total area that is suitable for the cultivation of *C. javanica* (S1 and S2) is 77.0 ha, counting for 55.8% of the study area. These areas are mostly located in the south of the Kon Plong district. The findings of the study are expected to be used as a reference for the planning of mountainous economic development in Kon Plong, especially pursuing the ecological economics strategy for local ethnic people.

Acknowledgments

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