ZONING AGRO-CLIMATIC FACTORS AND EVALUATING ADAPTATION ABILITY OF ARABICA COFFEE IN MUONG ANG DISTRICT, DIEN BIEN PROVINCE

Nguyen Ngoc Anh, Nguyen Huu Quyen, Tran Thi Tam, Duong Hai Yen, Duong Van Kham
Viet Nam Institutes of Meteorology Hydrology and Climate Change

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Abstract: *Muong Ang is a mountainous district in the middle of Dien Bien province (the northwest of Viet Nam). Its climatic conditions are quite different compared to the surrounding areas. Specifically, mountainous terrain with a high slope and severe division leads to considerably differentiation in terms of meteorological and hydrological conditions. Muong Ang district is characterised by humid tropical monsoon climate; there are many extreme weather phenomena, e.g. heat wave, unevenly distributed large rainfall, diurnal temperature variation, large seasonal temperature variations. Besides, natural disasters occur quite frequently, such as erosion, landslides, floods and droughts [4]. However, the difference between agricultural meteorology and topography has created a unique landscape in Muong Ang, which is suitable for many kinds of tropical plants with high economic value. Typically, Arabica coffee can adapt very well to the climatic conditions in Muong Ang with high productivity and good quality, which is gradually forming the Muong Ang coffee brand in the domestic and international market.*

In order to confirm the correctness of selecting Arabica coffee to be the main crop in the economic development orientation of Muong Ang district, we need to study the agro-climatic conditions and the agro-climatic zoning of the district and assess the ecological adaptation ability of the coffee in the ecological conditions of Muong Ang, Dien Bien province.

Keywords*: Dien Bien, Arabica coffee, agro-climatic zoning, ecological adaptation, Arabica coffee, Viet Nam.*

1. Introduction

Climate is an irreplaceable component of the living environment. However, the climate is changing towards a detrimental tendency to human and many species. Researching and understanding climate conditions can make the climate invaluable to human life. In relation to agricultural and forestry, the climate is crucially important. Indeed, radiant energy, heat, and water are indispensable climatic factors in creating crop yields and yields. Therefore, the climate is seen as a kind of natural resources. The rational exploitation of climate resource not only provides high and stable crop productivity but also contribute to protecting the ecological environment. In doing so, it is imperative to study the agro-climatic conditions and the agro-climatic zoning

Muong Ang is a mountainous district in the middle of Dien Bien province (the northwest of Vietnam). The district's climatic conditions are quite different compared to the surrounding areas. Specifically, mountainous terrain with a high slope and severe division leads to considerably differentiation in terms of meteorological and hydrological conditions. Muong Ang district is characterised by humid tropical monsoon climate; there are many extreme weather phenomena, e.g. heat wave, unevenly distributed large rainfall, diurnal

Corresponding author: Nguyen Ngoc Anh
E-mail: nguyenanh.imhen@gmail.com

temperature variation, large seasonal temperature variations. Besides, natural disasters occur quite frequently, such as erosion, landslides, floods and droughts. However, the difference between agricultural meteorology and topography has created a unique landscape in Muong Ang, which is suitable for many kinds of tropical plants with high economic value. Typically, Arabica coffee can adapt very well to the climatic conditions in Muong Ang with high productivity and good quality.

Arabica coffee originates from the highlands of southwestern Ethiopia [10]. It accounts for abut 70% of worldwide coffee production. Arabica coffee's optimal temperature range is 18-21^{0}C. It can tolerate mean annual temperatures up to roughly 24^{0}C. The optimal elevation and rainfall for Arabica growth are respectively from 1,300-1,800m (metres above sea level) and from 1,500 to 2,500mm. Coffee can be grown on many different soil types, but the ideal is a fertile, volcanic red earth or a deep, sandy loam. Yellow-brown, high silt soils are less preferred. Avoid heavy clay or poor-draining soils. Coffee prefers a soil with pH of 5 to 6 [4].

In order to confirm the correctness of selecting Arabica coffee to be the main crop in the economic development orientation of Muong Ang district, we need to study the agro-climatic conditions and the agro-climatic zoning of the district and assess the ecological adaptation ability of the coffee in the ecological conditions of Muong Ang, Dien Bien province.

2. Research area

2.1. General geography conditions

The north of Muong Ang district shares the border with Tuan Giao district and part of Muong Cha district. The West is Dien Bien district. The South is Dien Bien Dong district. The East is Tuan Giao district and part of Thuan Chau district (Son La province). Latitude is from 21^{0}24' N to 21^{0}38' N; longitude is from 103^{0}17' E to 103^{0}24' E [10]. Muong Ang terrain is quite complex and divided by high mountain ranges, steep slopes (mostly limestone mountains scattered throughout the area). Located between limestone mountains are narrow and flat valleys. There is not any big river in Muong Ang. Only 4 streams are running through the district, namely Nam Lan, Nam Lich, Nam Co and Nam Ang.

The district has 44,341.2 hectares of natural area and a population of 46,547 people. The rural population include 41,494 people (accounting for 89.1% of the total population of the district) and mainly ethnic minorities. Mostly ethnic minorities are Thai people (78.1%) and Hmong people (11.8%) [8]. The whole district has 9 communes, 1 town and 139 mountainous villages.

2.2. Agro-climatic characteristics in Muong Ang district

Lighting time

Lighting time is assessed through sunny hours. The total number of sunny hours in Muong Ang district is about 2000 hours. The highest number of sunny hours occurs from March to May (about 200 hours/month). The least sunny month is from June to August (130-140 hours/month) [8]. In general, the number of sunny hours in Muong Ang district is quite high compared to other areas in Dien Bien province and the surrounding areas. This condition favour plants that prefer light such as Arabica coffee.

Temperature

The temperature is crucial to the seasonal structure, the time to plant and harvest Arabica coffee. Monitoring data shows that the average annual temperature in Muong Ang district (collected in Tuan Giao station) is about 21.17^{0}C, the coldest month is December (15.9^{0}C), the warmest month is June and July (25.5-25.8^{0}C). The average temperature in January, February, March, November and December is lower than the annual average temperature (21.7^{0}C) [8]. The remaining months have average temperatures higher than the average annual temperature.

Diurnal temperature variation is considered as an important indicator for climate classification. It has a great impact on the growth of plants, especially on the process

of photosynthesis. Due to its location, located in the mainland, Muong Ang has a wide diurnal temperature variation (averaging about 10^0C annually). In the winter (December-March), the diurnal temperature variation is quite dramatic (11-13^{0}C). In summer (June - September), the diurnal temperature variation is about 10.3^{0}C [8].

Absolute minimum temperature

During the winter months, due to the influence of the northeast monsoon, the weather is cold and dry. There often appears sudden weather changes after the cold frontier appearance, the average temperature decreases 3-4^{0}C sometimes 5-6^{0}C. The dry weather at the end of the dry season in the valleys reduces the humidity to below 30%. It is sunny during the light time but it is extremely cold at night time. The strong cooling of the ground facilitates the formation of radiation mist, sometimes frost, especially in the high mountains. Absolute minimum temperature year (-1.2^{0}C) has a great impact on the distribution and growth of Arabica coffee [8].

Rainfall and humidity

The average annual rainfall for many years in Muong Ang district is about 2002mm. Rainfall is unevenly distributed over time and space. Normally, the main rainy season is from April to the end of September. The highest rainfall is distributed in 3 months: June, July and August. It can reach about 200-300mm/month, accounting for 75-92% of the annual rainfall. In the rainy season, the maximum daily rainfall reaches more than 100mm/day, even reaching over 400mm/day [8]. During this period, flooding occurs quite often in low-lying areas. On the sharp slopes of the mountain, it can occur landslides, flash floods, mud and rock floods which results in vegetation loss. The number of rainy days in rainy season is relatively high, about 20 days. The growth of Arabica coffee is badly affected when landslides, floods and flooding occur.

The dry season last for 5 months (November to March) with monthly rainfall under 50 mm/month. However, there are no drought months (rainfall <5 mm/month) [9]. This is a period of shortage of water for coffee trees.

Average annual relative humidity in Muong Ang district is about 80-90%. It varies differently in terms of space and time. The lowest humid months are February and March (about 80%). The highest humid months are July and August (about 87-91%) [9].

2.3. Types of extreme weather

Heatwave (average daily temperature > 35^{0}C)

The average number of hot and sunny days in the period 1962-2017 usually occurs from March to September. The peak months are April and May. Then the number of days slightly decreases from June to September. The highlands have a much higher number of hot and sunny days than the lowlands. The severity of heatwave in the period 1962-2017 (above 35, 37 and 39^{0}C) tends to increase. The increase in the highlands much higher than that in the lowlands. The number of days with temperature above 35^{0}C increased by 6.4 days/decade in the highlands while one in the lowlands did not increase significantly, only 1.4 days/decade. The number of days with temperature above 39^{0}C has markedly fluctuated by years in the highlands, but the increase is negligible [9].

Extreme cold (average daily temperature ≤ 15^{0}C) and damaging cold (average daily temperature ≤ 13^{0}C)

The cold weather in the period of 1962-2017 usually occurs from November to March. The peak is usually in January and February. The difference between the highlands and lowlands is very small. The highlands appear to be cold more often than the lowlands (about 1 to 2 days). There is a huge fluctuation in the number of extreme cold and damaging cold days in the period 1962-2017. It can reach over 40 days of extreme cold in some years and be only 5 days in some other years. The average number of damaging cold days is about 5 days/year, and up to 12 days/year in some years. In general, extreme cold and damaging cold tend to decrease. However, the number of extreme cold days in the highlands tends to increase slightly, less than 1 day/decade.

Heavy rain (number of days with rainfall greater than 50 mm)

During the period of 1962-2017, heavy rain usually occurred from April to September, peaked in June-August. The lowland areas often have a larger number of rainy days than that in the highlands. The maximum daily rainfall is from 200 to 600mm, usually occurs from May to August (July is the largest value) [9]. The highlands have an average rainfall of 50-200mm. There is a large difference between locations regarding the number of heavy rainy days in the years: the highlands with 10 days, the lowlands with 16 days. In addition, there is a huge variation in extremely high rainfall between years, ranging from 100mm to 600mm [9]. The lowlands often have this value greater than that of the highlands. However, there is no significant difference in relation to extremely high rainfall in the year between high and low areas.

2.4. The other special weather phenomena

Foehn wind effect, fog, hoarfrost, thunderstorm and hail often occur in the district. They significantly affect the life and health of the people in Muong Ang.

Hail appears almost every year in Muong Ang during the end of winter and beginning of summer. It is 0.2-0.6 days occurs hail every year. Hail mainly appears from February to May. Hail damages the coffee gardens that causes broken branches, flowers and fruits, etc. and could completely destroy the crop. Hail is classified as a dangerous weather phenomenon.

Fog often occurs in the district with uneven distribution depending on the local terrain characteristics. The number of foggy days is about 90 days per year and usually occurs during the winter months, especially in December, January and February. This is also a dangerous weather phenomenon because it can cause coffee plants to die.

Muong Ang often appears thunderstorms. Thunderstorms with strong winds often cause significant damage to local people. On average, there are 70-90 thunderstorms each year. Thunderstorms often appear in April - August with about 6-15 days/month [9]. The thunderstorms here are not serious but can be accompanied by strong winds and hail during the transition period from spring to summer.

It is quite common for the phenomenon of foehn winds. In the lowlands (<500m), there are about 5-30 days of foehn winds per year. The higher it is, the fewer the number of hot and dry days. Hot and dry weather often occurs in the period of February to September, mostly in April and May [9].

3. Data and research methods

3.1. Data

Meteorological data

Meteorological data in Muong Ang district and surrounding areas were collected at 6 meteorological stations including Dien Bien, Tuan Giao, Pha Din, Son La, Song Ma and Lai Chau in the period 1961-2017. The representative data was collected at Tuan Giao station due to the fact that this station shares similar natural conditions to Muong Ang district. The data system is summarized in Table 1 and Figure 1.

Remote sensing data

Muong Ang is one of the mountainous districts of Dien Bien Province. Its terrain characteristics reflect a complex division. A high slope and severe division lead to considerably differentiation in terms of meteorological and hydrological conditions. Therefore, in order to increase the objectivity and scientific foundation for analysis, it needs to supplement the temperature and humidity data interpolated from MODIS and NOAA satellite images in the period of 2000-2018. In addition, data and trends of temperature, precipitation, humidity and atmospheric pressure in the different areas of Muong Ang can be accessed through the website [10].

Survey data on the current state of agricultural production

Field survey to collect documents and data related to agricultural production includes seasonal structure, cultivated area, productivity, output, land use map, soil distribution map, the status quo of natural disasters and epidemics in

Muong Ang district. These documents and data are then used for the assessing and classifying agro-climatic zones in Muong Ang district.

Other data

Documents for establishing single maps, maps of agro-climatic zones we collected from the national database provided by the Ministry of Natural Resources and Environment - the maps detailed at commune levels with the scale of 1: 25,000.

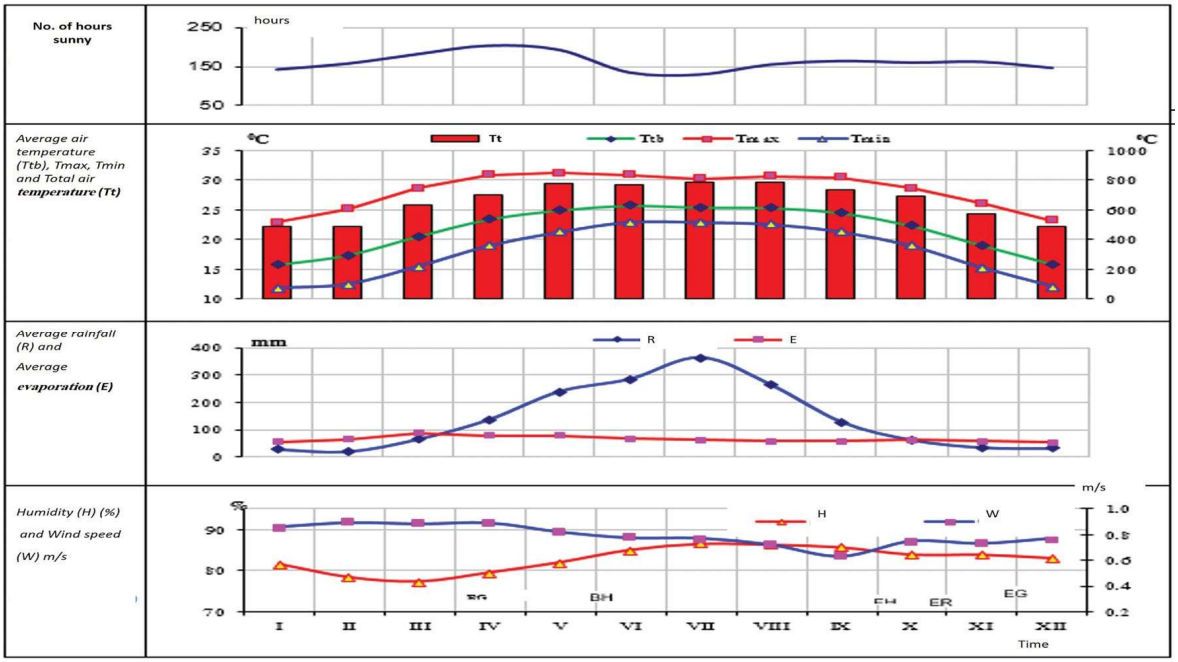

Figure 1. Climate condition graphs of Muong Ang district at Tuan Chau station, 2017.

Table 1. Meteorology climate data in Muong Ang district

Climate factor	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Average temperature	15.7	17.4	20.5	23.4	25.0	25.8	25.5	25.4	24.5	22.4	19.1	15.9	21.7
Temperature range	11.1	12.7	13.2	12.0	9.9	7.9	7.3	8.1	9.1	9.8	10.8	11.1	10.3
Lowest temperature	10	12	14	18	19	22	22	22	20	17	14	10	10
Number of cold days	4.4	2.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.6	4.4	1.1
Number of sunny hours	141.2	156.8	182.1	204.5	193.6	133.4	127.8	154.3	163.8	159.5	161.5	145.3	1923.8
Average rainfall	29.4	21.3	66.4	137.5	239.6	285.0	363.1	263.0	128.5	63.1	36.0	33.1	138.8
Number of rainy days	18.0	4.5	4.1	7.0	12.6	17.8	21.5	23.8	20.5	13.2	7.7	5.4	-
Relative humidity	82	78	77	80	82	85	87	86	86	84	84	83	83

Source [9]

3.2. Research Methods

3.2.1. Calculating values

The degree of change:

Determining the average value $\left(\overline{x}\right), \overline{x} = \frac{1}{n}\sum_{t=1}^{n} x_t$

Determining the maximum value (Max and Min) by filtering $Max_{xt} = Max\ (x_1, x_2,...x_n)$; $Min_{xt} = Min\ (x_1, x_2,...x_n)$; In which t is the time series (t = 1, 2, ..., n-1, n); x_t is a series of data observed over time ($x_t = x_1, x_2, ..., x_{n-1}, x_n$).

The trend of change

The tendency of changes in past climate factors is often assessed by identifying (a) in the regression line equation:

$X = a_0 + a_1 t$. In which, X is calculated from the series of observational data over time (x_t); t is the time series (can be month, year, decade, etc.), a0 is the cutting coefficient, a1 is the corner coefficient. If $a_1 > 0$, the tendency is to increase, if $a_1 < 0$ then the tendency is to decrease.

Revising the reliability of the correlation coefficient

The correlation coefficients is often used in climate research to provide objective conclusions regarding the correlation relationship between variables provided the following formula to revise the reliability of the correlation coefficient [5]:

$$-t_{\frac{a}{2},n-1} S_r < r_k < t_{\frac{a}{2},n-1} S_r$$

with $S_r = \frac{1}{\sqrt{n}} - t$

r_k is the correlation coefficient between two chains; S_r is the standard error of the autocorrelation coefficients r_k; α is the value in the object distribution with n-1 degrees of freedom. In climate research, normally α is 0.01 or 0.05 [7].

Interpolation of temperature and rainfall distribution

Based on the average monthly air temperature data in the period 2001-2017 collected at 6 meteorological stations (T_obs) and the surface coating temperature value (LST) were analyzed by image data (MOD11A2), which were set up at the same time and same location. The relationship between T_obs and LST with sample size n = 72 (12 months x 6 stations) is used to interpolate the temperature distribution for Muong Ang district and surrounding areas..

Similarly, the total annual rainfall is interpolated. Used data includes the average monthly rainfall value collected 6 stations (R_obs) in the period 1981-2017 and the rainfall from the CHIRPS data set (R_Chirps).

3.2.2. Method of classifying agro-climatic zones

The agro-climatic zones of Muong Ang district were classified in 5 steps:

Step 1: Determining the partition criteria. The total annual heat index indicates the degree of tolerance of the climate to plants. It also reflects the annual temperature range and related natural disasters (e.g. heat wave, extreme cold). Normally, the total annual temperature is usually proportional to the average seasonal temperature and the number of warm and sunny days while it is inversely proportional to the number of cold days.

Step 2: Determining boundaries between the zones based on the isothermal lines 8500^0C (D.V. Kham et al. 2012). The areas with total temperature higher than 8500^0C and average elevation under 100m are called 'lowlands'. The areas with total temperature lower than 8500^0C and average elevation higher 100m are called 'highlands'. The terms 'low and highlands' are often used by local people. Determining the boundary between sub-zones based on the 2000mm isometric line with the distance between the isosceles lines is 500mm [7].

Step 3: Overlay the maps. The thematic maps (precipitation, temperature, topography, slope, traffic, waterways and administrative boundaries at commune level) are overlapped using GIS technology. The map of agro-climatic zones was established are in lines with the VN2000 reference system, the international UTM projection grid, Ellipsoid WGS84 adapted to Viet Nam [2]. The map was established at the scale 1:50,000.

Step 4: Designing map legend.

Step 5: Edit and finalize the map consulting experts and local officials [1],[7].

3.2.3. Evaluating cultivation potential in agro-climatic zones and sub-zones

The evaluation was based on the instruction of FAO's soil assessment which is coded in the LUSET model [1],[7]. The model consists of two modules: module 1 is for inputing data related to the plants and soil; module 2 is for processing and outputing data.

Using GIS technology to divide Muong Muong district into land units (LU) with a resolution of 100x100m resulting 44,515 LU. In order to assess the relevance of each LU regarding the needs of different crops, the information in each identified LU must reflect similar information to the needs of the crops. Climate data including average monthly temperature and monthly rainfall are interpolated for each LU. Slope data is calculated from topographic maps (DEM). Soil data is determined from the soil map and encoded according to the unit system required by the LUSET model. The identified soil characteristics referencing to ecological requirements of arabica were interpolated for determining suitable areas for Arabica. The outputs of the LUSET model are integrated with the agro-climatic zones map (Figure 2).

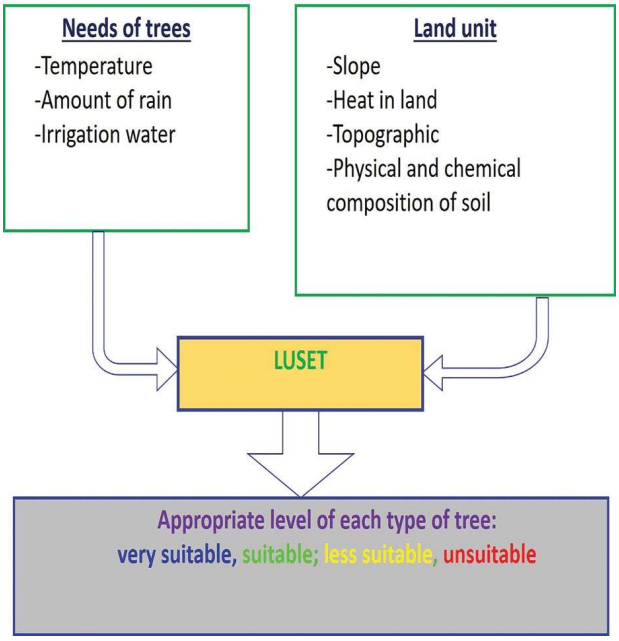

Figure 2. Process of determining the cultivate potential in agro climatic sub-zones, Source [1, 2]

Selecting a calculation method

Select a calculation method

Based on the needs of the crop and the factors related to soil, temperature, and water resources in each LU, the LUSET model can calculate the suitability (OVS) for each element and integrated elements into index synthesized OVS through 4 methods: Minimum, Maximum, Average and Redundant so that users can choose an appropriate method depending on the purpose of use. Natural disasters often occur in Muong Ang, e.g., heavy rain, flooding, heat wave, droughts, cold and extremely cold weather. In addition, agricultural production has not been developed. Most of the cultivated area strongly depends on rain. Therefore, the method selected is "Minimum". This is the assessment method with the highest safety level among the four methods. Appropriate index is defined as the lowest score of all factors considered. OVS is calculated according to the formula:

OVS = Min (SF1, SF2, SF3,... SFn). In which: OVS is the appropriate value; SF1, SF2, SF3,... SFn is the appropriate score (ranging from 0 to 100) of the n selected elements.

The calculation of OVS index is done in 2

steps.

Step 1: Calculating OVS separately for each element (OVSg), OVSg can be soil (slope, soil depth, soil type), temperature (average temperature per month) or water (monthly rainfall, assumed irrigation or not).

OVSg = f (S1, S2, ..., Sn).

S1, S2, ... Sn are the appropriate score of elements in a group; f is a function to calculate the overall suitability (Min function).

Step 2: Calculating the overall fit from three groups of factors (soil, temperature, water).

OVS = f (Ss, Sh, Sw). In which: Ss, Sh, Sw are OVSg values corresponding to soil, temperature and water element.

The scores and weights in calculating OVS index:

Due to the different ecological characteristics of each crop, the role of each element in the crop is different. Therefore, determining the appropriate score for an element is divided according to the weights from 1 to 3 (1 is the most important, then 2 and 3). This study uses FAO weighting sets [1]. The score for the 4 appropriate levels corresponds to the three weights shown in Table 2.

Table 2. Appropriate levels corresponding to the weight factors [7]

Suitability levels	weight number = 1	weight number = 2	weight number = 3
S1	85	95	100
S2	60	65	70
S3	40	45	50
S4	0	10	15

Combining the appropriate elements and weighting factors to create a value that ranges from 0 to 100. This value is the OVS score of the elements considered for a particular crop in a LU. Using the minimum method to determine an overall suitable value and then to classify the suitability levels from S1, S2, S3 to N (Table 3).

Table 3. Classification of overall suitability [7]

No	Score	Suitability levels	Legend
1	≥ 85	S1	Very suitable
2	≥ 60 and < 85	S2	Suitable
3	≥ 40 and < 60	S3	Less suitable
4	< 40	N	Not suitable

Calculating the cultivation potential area in the zone and sub-zones: Based on the adaptive conditions of Arabica coffee, the map ecological adaptive ability was built.

Applying GIS technology with Krigging method - distance inversion algorithm (IDW) in spatial interpolation and overlaying information level to establish thematic maps.

4. Results

4.1. Classifying agro-climatic zones in Muong Ang

The climate and agro-climatic climate are decisive in forming agricultural production areas. Therefore, classifying agro-climatic zone is a scientific basis for rational distribution of crop structure. It helps to classify agro-climatic zones and sub-zones based on climatic features and the conditions of agricultural production. The map of agro-climatic zones is the scientific basis for many purposes. For example, planning agricultural and forestry production; assessing the adaptation of crops in general and Arabica coffee in particular; assessing water resources; assessing the impact of climate change on people's lives and production; helping people identify appropriate cultivation measures; calculating potential yield of crops in regions and sub-regions; determining the structure of crops.

4.1.1. Identifying agro-climatic sub-zones in Muong Ang district

- *Criterion 1*: The first indicator to delineate the agro-climatic sub-regions is the total annual temperature. The total amount of temperature in a year is directly related to the annual average temperature and somehow related to the annual variation of temperature. The annual variation of temperature indicates the thermal season, the growing season of plants. This is the foundation for determing planting/harvesting seasons.

- *Criterion 2*: Total annual rainfall is important to the growth of crops, especially Arabica coffee in Muong Ang where the irrigation water depends mainly on rainwater. This indicator is used to assess the available water supply for agricultural production and then for selecting rational crops structure and proposing appropriate irrigation solutions.

- *Criterion 3:* Temperature decreases with increase in altitude.

- *Criteria 4*: the reduction of rainfall according to the terrain, wind direction, air masses with high moisture content.

Synthesizing the above criteria to classify agro-climatic zones. The results are presented as follows:

- Thermal background of the district is divided into 4 thermal zones as shown in Figure 3:

+ Zone T1 (elevation above 1,500m): Total annual temperature is below 7,000^{0}C, the annual average temperature is below 20^{0}C. This region is located in the northwest of Muong Dang commune, east of Xuan Lao commune, south of Cang Cang commune and Nam Lich.

+ Zone T2 (800-1,500m): Total annual temperature is from 7,000-7,500^{0}C, annual average temperature is from 20- 21^{0}C. This area is mainly concentrated in the northern edge, west and south of the district.

+ Zone T3 (600-800m): Total annual temperature is from 7,500-8,000^{0}C, the annual average temperature is from 21-22^{0}C. This region accounts for the largest portion and is distributed in most communes in the district.

+ Zone T4 (lowlands, valleys along rivers and streams, altitudes from 400-600m): Total annual temperature is from 8,000-8,500^{0}C, the annual average temperature is over 22^{0}C. This area is distributed along the valley of rivers and streams in Ang To, Bung Lao, Xuan Lao and Muong Lan communes.

- The number of sunny days in the district is divided into 4 sub-regions on the map of Figure 4. The map shows that the number of sunny days (over 35^{0}C) with the value over 15 (days) occupies a fairly wide range in the whole district. Overall, Muong Ang receives a large amount of heat, concentrating on the district centre. In the edge of the district, the number of sunny days gradually decreases. This is an important basis for the district to make appropriate crop structure choices.

- The number of cold days in the district is shown in figure 5 with 4 areas. The areas featuring the number of cold days at over 25 days include the highlands of Xuan Lao commune, south of Ang Cang commune, and west and northwest of Muong Dang commune. The remaining areas have a number of cold days less than 15 days.

- The humidity in Muong Ang is presented in Figure 6.

+ Zone R1: Total annual rainfall is over 2,000mm. This area is located in a mountainous area (>1,000m) in the northwest of Muong Dang commune. It is easy to happen flash floods when it has unusually heavy rain. This is a remote area for people to access and develop agriculture and forestry. Therefore, forest in this area is preserved quite well and it is difficult to grow Arabica coffee here.

+ Zone R2: Total annual rainfall from 1,900 to 2,000mm. This area is distributed in mountainous areas with an altitude of 800-1,000m, belonging to communes of Coong Cay, Muong Dang, Ang Nua, Ang Cang and Nam Lich.

+ Zone R3: Total annual rainfall from 1,800-1,900mm. This region is distributed in areas with elevations between 600-800m, belonging to communes in the central area to the west of the district.

+ Zone R4: Total annual rainfall is less than 1800 mm. This region is distributed in eastern communes of the district.

- The annual average number of heavy rainy days in the district is shown in Figure 7. Mostly areas of two communes of Cang Cang and Ang Nưa belong to the region with few heavy rainy days (2-3 days). This is a positive indicator for the development of Muong Ang Arabica coffee. Through the map of Figure 7, it is found that the annual average number of heavy rainy days is concentrated in the edge of the district such as the easternmost area of Xuan Lao commune,southwest and south of Phung Cang commune, North and Northwest of Muong Dang commune. The central part of the district has less rainy days than the outer border.

4.1.2. The map of agro-climatic zones

Most of the district's area is hilly and mountainous in different directions and with highly differentiated elevations. This is the reason why the district has many sub-zones (6 sub-zones) as shown in Figure 3. This map is the final result of the process of researching, analysing and evaluating climate conditions for the purpose of classifying agro-climatic zones of the district.

Temperature variation of the sub-zones is visualized in the diagram in Figure 3,4.

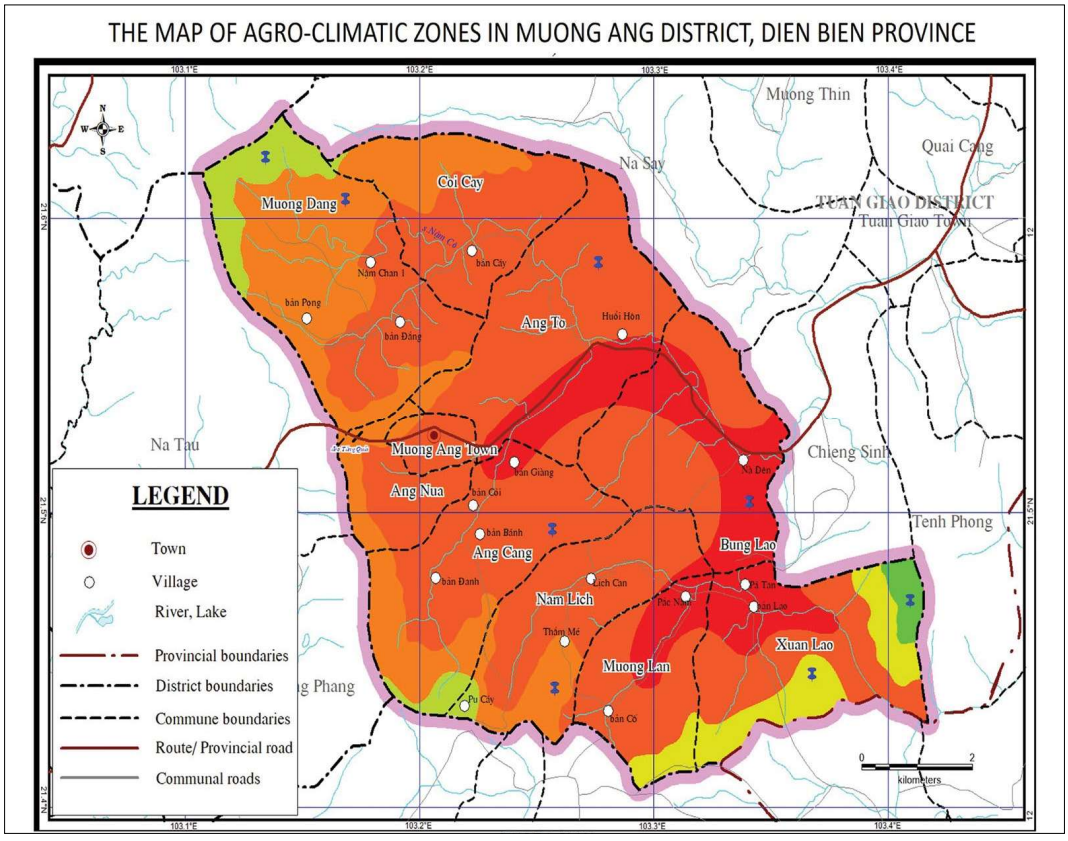

Figure 3. Map of Agro-climatic zoning

The diagram shows that the temperature in the sub-zones is quite consistent and in line with a rule. The sub-zones all reach their maximum temperature in June and minimum in December and January. The temperature differentiation is also consistent with the space distribution of the sub-zones. This explains the correctness of the analysis.

The rainfall of the sub-zones is also quite uniform. Rainfall is highest in July and gradually decreases in November, December, and January. Rainfall is minimum in February.

- Sub-zone 1: the total annual heat below 7,000^{0}C, the annual average temperature is under 20^{0}C; Total annual rainfall is from 1,800-1,900mm. The average number of hot and

sunny days (T>35^{0}C) is about 5days per year; the number of extremely cold days (T<15^{0}C) is about 45-60 days/year; the number of damaging cold days (T≤13^{0}C) is about 25-35 days/year; the number of days with heavy rain (R>50mm) is about 3-4 days/year. This sub-zone is distributed at the eastern edge of Xuan Lao commune.

- Sub-zone 2: The total annual heat, temperature and average number of hot sunny days are the same Sub-zone 1; The total annual rainfall is greater than or equal to 1,900mm. the number of extremely cold days is from 30-45 days/year; the number of damaging cold days is about 15-25days/year; the number of days with heavy rain is about 3-4 days/year. This sub-zone is distributed in the northwest of Muong Dang commune and a small part of the mountain area above 1500m in Ang Cang commune and Nam Lich.

- Sub-zone 3: The total annual temperature from 7,000-7,500^{0}C, the annual average temperature of 20-21^{0}C; Total annual rainfall is under 1,800mm. The average number of hot sunny days is similar Sub-zone 1. The number of extremely cold days is about 30–45 days/year; the number of damaging cold days is about 15-25days/year; the number of days with heavy rain is about 2-3 days/year. This sub-zone is mainly distributed in the highlands above 800m in Xuan Lao and Muong Lan communes.

- Sub-zone 4: This sub-zone is the same Sub-zone 3 by heat, temperature, extremely cold days, damaging cold days and heavy rain day. There is a different at the total annual rainfall is from 1,900 to 2,000mm. The average number of hot and sunny days is about 5-10 days/year. This sub-zone is mainly distributed in areas with elevations below 1,000m in the northern edge, west and south of the district.

- Sub-zone 5: The total annual temperature from 7,500-8,000^{0}C, the annual average temperature of 21-22^{0}C; Total annual rainfall is from 1,800 to 1,900mm. The average number of hot and sunny days is 10-15 days/year; the number of extremely cold days is about 15-30 days/year; the number of damaging cold days is about 6-15 days/ year; the number of days with heavy rain is about 1-2days/year. This sub-zone is mainly distributed in the area of 600-800m belonging to most communes in the district.

- Sub-zone 6: The total annual temperature higher than 8,000^{0}C, the annual average temperature higher than 22^{0}C. Total annual rainfall is less than 1,800mm. The average number of hot and sunny days is higher than 15 days/year; The number of extremely cold days, damaging cold days and heavy rain day are similar the sub-zine 5. This sub-zone is mainly distributed in areas with elevations below 600m and river valleys in Ang To, Bung Lao, Xuan Lao and Muong Lan communes.

Table 4. The legend for Agro-climatic zone

Region	Sub-region	Symbol	Total heat (oC)	Tavr (oC)	Total rainfall (mm)	Characteristics of adverse weather conditions
Highland	Sub-region 1		< 7000	< 20	1800 - 1900	Hot and sunny day (>=35 celsius) appears about 5 days/year for sub-region 1,2,3; 5-10 days/year for sub-region 4; 10-15 days/year for sub-region 5 and over 15 days/year for sub-region 6 Strong cold day (<=15 celsius) appears about 60-80 days/year for sub-region 1; 45-60 days/year for sub-region 2; 30-45 days/year for sub-region 3,4 and 15-30 days/year for sub-region 5,6. Harmful cold day (<=13 celsius) appears about 35-50 days/year for sub-region 1; 25-35 days/year for sub-region 2; 15-25 days/year for sub-region 3,4 and 6-15 days/year for sub-region 5,6. Heavy rain day (>=50 mm) appears about 4-5 days/year for sub-region 1; 3-4 days/year for sub-region 2; 2-3 days/year for sub-region 3,4 and 1-2 days/year for sub-region 5,6.
	Sub-region 2				>=1900	
	Sub-region 3		7000 - 7500	20 - 21	< 1800	
	Sub-region 4				1900 - 2000	
Lowland	Sub-region 5		7500 - 8000	21 - 22	1800 - 1900	
	Sub-region 6		> 8000	> 22	< 1800	

On the website https://www.meteo-blue.com, extract values of temperature and precipitation corresponding to the location of sub-regions on the map of agro-climatic zone in Muong Ang, to determine the interplay of temperature and rainfall. The results are reflected in the graphs shown in Figures 4, 5 [10]:

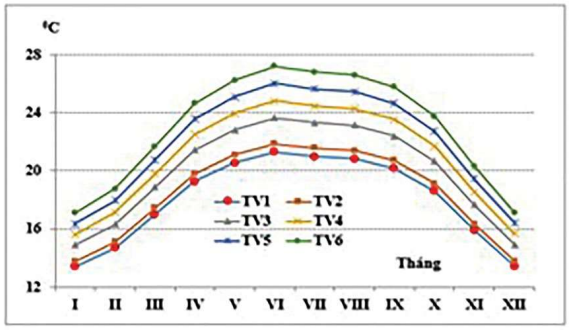

Figure 4 . Temperature variation in sub-zones

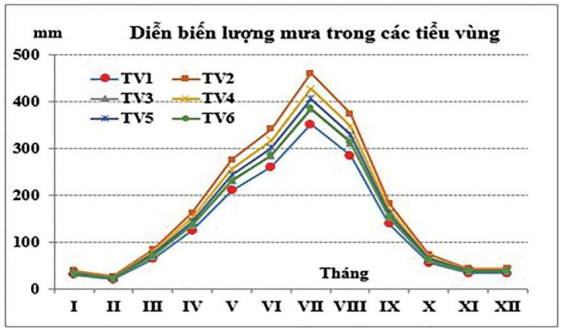

Figure 5. Rainfall variation in sub-zones

Through the diagrams in Figures 1, 4, 5 and the map on Figure 3, the high compatibility between the partition results, the actual monitoring data at Tuan Giao station and the information extracted from the website.

The application of GIS and remote sensing technology to build a map of the agricultural climate zone is an important achievement and a new scientific product for socio-economic planning and development at Muong Ang district, Dien Bien province.

4.2. Classifying zones depending on ecological adaptation of Arabica coffee

Ecological and growth characteristics of Arabica coffee is analyzed carefully for interpolating ecological adaptation. The result is shown in Figure 6. The map shows that the coffee can adapt very well in sub-zones 4, 5 and 6. Sub-zones 1, 2 and 3 are not suitable for planting the coffee [4]. Based on the map, data on the area of adaptive levels can be extracted (Table 5 and Figure 7).

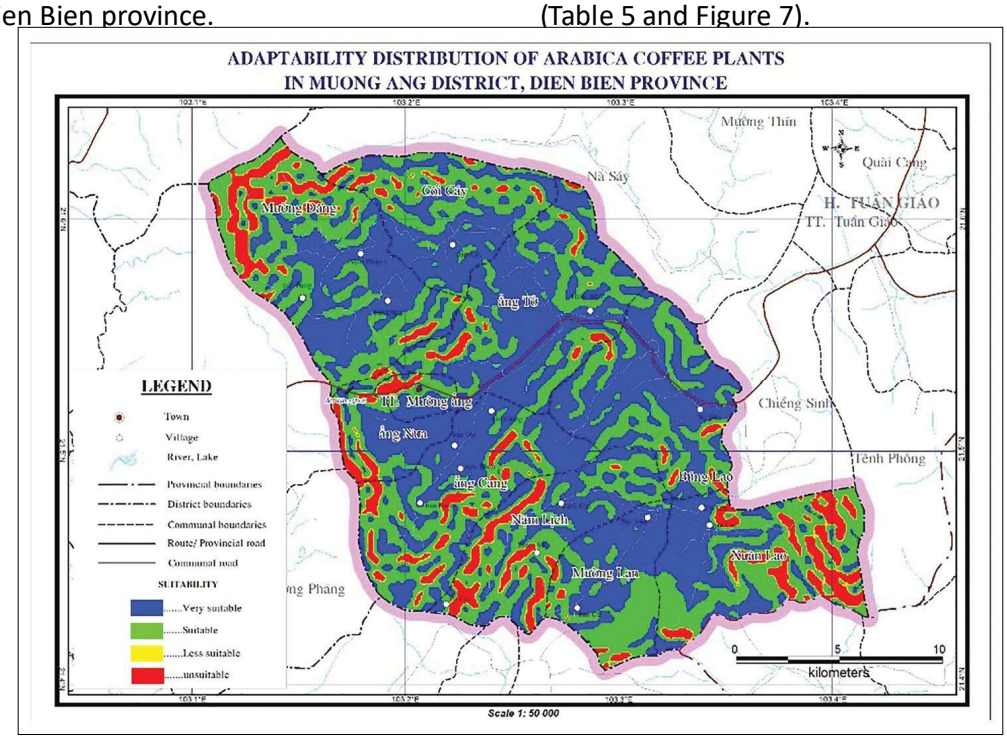

Figure 6. Map of ecological adaptation of Arabica coffee in Muong Ang district

The area and productivity of Arabica coffee in Muong Ang are presented in Table 6.

In 2017, after applying the results of scientific research into the production process, the output of Arabica coffee in Muong Ang increased significantly from 4,965 tons (in 2013) to 7,244.9 tons (in 2017). In the meanwhile, the area for planting decreased slightly. This confirms the effectiveness of agricultural development in the district.

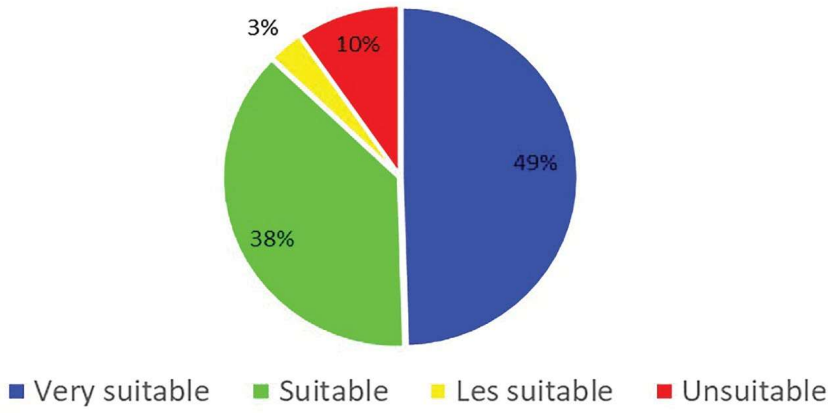

Figure 7. Structural levels of the ecological adaptation of Arabica coffee trees

Table 5. Soil structure by adaptive capacity of Arabica coffee

Levels	Area (ha)	Proportion (%)
Very suitable	21,955.77	49.52
Suitable	16,703.18	37.67
Moderate	1,416.44	3.19
Unsuitable	4,266.06	9.62

Table 6. Area and production of Arabica coffee in Muong Ang district [8]

Year	2013	2014	2015	2016	2017
Planting area (ha)	3,318.2	3,349	3,428	3,449.3	3,311
Area for harvesting (ha)	1,655	1,951	2,999	3,200	3,154.1
Coffee production (ton)	4,965	3,200	5,700	3,094	7,244.9

5. Conclusion and recommendations

The agro-climatic zone of the district is divided into 6 sub-zones based on the criteria of temperature, rainfall, humidity and algorithms and spatial interpolation methods. This research aims at serving the crop selection, planning and, most importantly, socio-economic development planning of Muong Ang district.

The communes selected for the pilot study include Ang Nua and Ang Cang. In which, Ang Nua commune is in sub-zones 4 and 5, Ang Cang commune is located in sub-zones 2, 4 and 5. The area of sub-zone 2 of Ang Cang commune is quite small. Both communes share quite a similar agro-climatic condition.

Sub-zones 4 and 5 are the most beneficial for growing industrial crops and perennial crops, typical Arabica coffee, citrus fruit, longan, plum and cashew. Annual crops should be corn and peanuts. Rice is slightly adaptable.

Still there exist some shortages in this research:

+ Due to the fact that there is no monitoring station in Muong Ang district, the data for analysis is collected in a neighbouring station (Tuan Giao station) and interpolation data from satellite images and GIS. This affects

the accuracy of the results. However, the result is still acceptable.

+ When establishing ecological adaptation maps of some main trees, it lacks a number of soil criteria such as soil thickness, pH, chemical components in the soil. It is for the reason that the there is no available data in the district. However, thanks to other criteria such as temperature, precipitation, humidity, experience and expert knowledge, the findings are highly reliable.

We have some recommendations as follows:

- It is imperative to build a monitoring station in Muong Ang district. It can be located in Ang Nua commune or Yen Cang commune to monitor and provide data for the whole district serving researching, planning and for other research-related purposes.

- The district should establish a soil map system with a scale of 1: 50,000 or more detailed in order to identify accurately soil characteristics serving agricultural and forestry production.

- Expanding research areas for other communes regarding interdisciplinary development throughout the district.

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