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Predictive Modeling of Combustible Water Content of Five Common Tree Species in Central Yunnan Province

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ABSTRACT

The water content of forest combustible material is a key factor affecting forest fire and spread, and is the main reference factor for forest fire prediction and forecasting. The live branches, live leaves, dead branches and dead leaves of cap-dou oak, green oak, Yunnan poplar, Yunnan oil fir and silver wattle in central Yunnan were selected as the research objects, and the slope (x_1), slope direction (x_2), slope position (x_3), elevation (x_4), wind speed (x_5), wind direction (x_6), humidity (x_7), ground diameter (x_8), crown height (x_9), crown width (x_{10}), tree height (x_{11}), depression (x_{12}), and tree species (x_{13}), and used correlation analysis to screen the main modeling factors, and constructed a prediction model of water content of combustible materials by multiple linear regression method. The results show that the correlation between the four factors of slope (x_1), slope direction (x_2), wind speed (x_5) and humidity (x_7) and the water content of combustible materials is significant, the water content decreases when the three influencing factors of slope (x_1), slope direction (x_2) and wind speed (x_5) increase, and the water content is higher when the influencing factor of humidity (x_7) increases, and the water content of combustible materials is constructed into a model of water content of 20 groups by these factors. Compare the predicted value of the water content prediction model with the actual value to analyze the error of the model, and the results show that the established model can be used to predict the water content. The errors were caused by rainfall during sampling, which absorbed water into the combustible materials and resulted in errors in the moisture content, and wind speed measurements, which resulted in inaccurate wind speed measurements. The established water content model can provide a basis for the classification of forest danger level and combustibility of combustible materials, and can provide help and reference for forest fire prevention and management.

KEYWORDS

Forest fire; Combustible moisture content; Multiple linear regression; Modeling

1. INTRODUCTION

Agriculture and forestry intertwined area is a high incidence of forest fires, especially agricultural production fire, living fire is one of the important sources of forest fires, forest fires in the region, the common denominator of the basic for agricultural production, living fire ignited ditch ponds and meadows or weeds after the spread of forest fires triggered in the forest area. In recent years, fires have occurred in the agricultural and forestry intertwined areas in central Yunnan, causing great losses to the local people's life and work and the local economy.In 2020, “3-29” in Baishachong, Chuxiong Prefecture, “3-29” in Lufeng County, “4-1” in Muding County, and “3-29” in Dayao County. Forest fires for the villagers ritual paper burning, smoking triggered. 2020 Kunming Luquan County “3-30”, Chuxiong Prefecture Shuangbai County “3-14”, Wuding County “3-31”, Yuxi Hongta District“2-16” and other forest fires for villagers burning weeds, burning corn stalks to accumulate fertilizer, burning vegetable stalks when the fire accidentally triggered.

Surface combustible material is the main carrier of surface fire, and the size of its water content directly affects the probability of surface fire, fire behavior and combustion spread speed and other indicators [1-3] At the beginning of the twentieth century, foreign countries, represented by the United States and Canada, started the study of forest combustible material water content.Jenison et al. [4-5] took the artificial forest of Hao'er Mountain in Heilongjiang Province as the research object, and used the meteorological and soil indicators to establish a prediction model for the water content of dead combustibles. Water content prediction model, indicating that the main factors affecting water content are temperature, relative humidity, precipitation, solar radiation and wind speed. Julien Ruffault et al [6] used DMC (Duff Moisture Code) and DC (Drought Code) to predict the water content of living combustibles under two response models of Mediterranean shrubs in southern France, namely, high and low, and corrected the Emilio Chuvieco et al. [7] The study of combustible water content in China started late, and the main research methods were meteorological element regression method [8, 9], process modeling method [10, 11, 12], equilibrium water content method [13], and remote sensing estimation method [14-16] to determine 137 sets of relevant data of Yunnan pine forests, indicating that the influence of It was shown that the factors affecting the water content of the withered material in Yunnan pine forests were, from high to low, surface temperature of the withered material, relative humidity of the air, surface temperature of the humus layer, and air temperature. Bao Yulong et al [17] used meteorological factors to establish a T-moment-Logistic combustible water content model to predict the water content at the T+1 moment, with an accuracy of 98%. Liu Jinbo [18] analyzed the equilibrium water content method using Simard, Van Wagner, and other models, showing that factors such as temperature and humidity, wind speed, and time lag affect model accuracy. Li Shiyou et al [19] used a spectrometer to detect characteristic parameters such as spectral absorption index and used curve length index to establish a regression model to predict the water content of combustible materials in different grasslands during the fire protection period. Yin Kun et al [20] used meteorological factors to establish a T-moment-Logistic combustible water content model to predict the water content at the T+1 moment, with an accuracy of 98%.

The purpose of the study on water content is to establish a prediction model of water content of its tree species by using the water content data obtained from experiments in reality. The moisture content of forest combustibles is a key factor that affects whether a forest will catch fire and whether it can spread in a forest fire after catching fire. The moisture content of forest combustibles affects how long it takes for combustibles to reach the ignition point when a forest fire occurs and how much heat is released from combustibles when a forest fire occurs, which is directly related to the occurrence and spread of forest fires, and the flammability and severity of combustibles [21]. The higher the moisture content of forest combustibles, the more heat is consumed to evaporate them during combustion, which decreases the combustion efficiency and makes them less likely to burn and spread. On the contrary, at lower moisture content, combustible material drying increases combustion efficiency, combustion occurs more readily, diffusion rates are faster, and flame intensity is stronger. Combustible materials with high moisture content content, in the combustion process will evaporate a large amount of water vapor, will produce a large amount of smoke, but also produces toxic gases, not only pollution of the atmosphere, but also forest fire fighting work to increase the difficulty. So the prediction and modeling of water content can provide help for the prevention and control of forest fires.

The prediction of the moisture content of forest combustible material can provide some help for the burning plan of forest combustible material clearing, and the prediction can be used to plan the scope of burning and improve the efficiency of burning. The water content of forest combustibles can be used to classify the forest fire danger level, and to determine whether or not wildfires are allowed according to the danger level. The study of combustible moisture content can promote the development of forest fire prevention, provide assistance for forest fire behavior, so as to better prevent and control combustible materials in the forest, and provide a certain reference for forest fire prevention.

2. INTRODUCTION TO THE STUDY

2.1. Geographic Overview

The geographic location studied in this paper is located in the central part of Yunnan, also known as central Yunnan. Yunnan Province is located in the southwest of China, which is the border of China. Yunnan is connected to Guizhou and Guangxi in the east, Sichuan in the north, and Tibet in the northwest [22]. Yunnan has three neighboring countries in the south, namely Vietnam, Laos, and Myanmar; there are 25 border counties with a border of 4060 km, which is one of the provinces with the longest border in China. The central Yunnan region consists of four cities in Yunnan, namely Kunming, the capital of Yunnan Province, Qujing, the “throat of Yunnan”, Chuxiong, the “gateway to the province and the throat of western Yunnan”, and Yuxi, the “town of Yunnan cigarettes”. “Yuxi. The specific sampling address is the mountain named Wildcat Mountain on the right side of Dazhou Village, Shui Tuan section of the northern urban area of Panlong District, Yunnan Province, which is at an altitude of about 2,300 meters, with an average annual temperature of 14 ℃ and an annual precipitation of 950 millimeters. Maichong Village, Jinhun Road, Panlong District, Yunnan Province, with Yunnan Safari Park at its back, Expo Park in front of it, Jinden National Forest Park in the west, and Wild Duck Lake Holiday Town in the east, is at an elevation of about 2,030 m, with an annual mean temperature of 12 ℃ and an annual precipitation of 526 mm. Both sampling sites are located in Kunming City, so the latitude and longitude service is 102°10'~103°40'E, 24°23'~26°22'N. The latitude and longitude spanned is not very large, so it is not listed as an impact factor.2.2 Resource profile.

Central Yunnan is mainly a mesic wet evergreen broadleaf forest, and the dominant tree species that make up the community are mainly species of the family Crustacea, which generally have obvious dry characteristics. Most of the tree species in the wildcat mountain on the right side of Dazhou Village in the Shuituan section are capitular oak, Yunnan pine, Huashan pine, etc., with 12,585 mu of forested land. Maichong Village has a lot of vegetation species, including Yunnan oil fir, green oak, Yunnan poplar, dry winter melon, rush cypress, Yunnan pine, Huashan pine, etc., with 26,190.20 acres of forested land, and the forest coverage rate reaches more than 70%.

2.2. Selection of Combustible Material Types

Yunnan has a variety of vegetation, and five common tree species in central Yunnan were selected for this study, namely, cap-dou oak (Quercus guyavaefolia H. Leveille), cycloidal oak (Cyclobalanopsis glauca (Thunb) Oerst), Yunnan poplar (Myrica nana A. Chev), Yunnan oiled fir (Keteleeria evelyniana Mast), and silver thorn (Acacia dealbata Link), Yunnan oil fir (Keteleeria evelyniana Mast), and silver wattle (Acacia dealbata Link). There are two types of combustible moisture content classified as live combustible moisture content and dead combustible moisture content [21]. Live combustible moisture content refers to the moisture content of combustible materials that are in a growing state with life, and dead combustible moisture content refers to the moisture content of dead combustible materials [21]. Therefore, live branches, live leaves, dead branches, and dead leaves of these five tree species were collected separately to predict the moisture content.

2.3. Multiple Linear Regression (MLR)

The following steps were used in this thesis: (1) Correlation analysis using SPSS software; (2) Multiple linear regression model $Y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n$ for mathematical modeling; (3) Using the error formula for error analysis between the prediction model and the actual model.

3. RESEARCH METHODOLOGY

3.1. Selection of Influencing Factors

Forest combustible moisture content is a key factor affecting whether a forest is on fire or not, and whether it can spread in forest fire after fire, and the change of forest combustible moisture content is affected by many factors. The influencing factors for predicting the water content of forest combustible matter mainly include topographic factor, meteorological factor, and stand factor [23]. Terrain factor belongs to the stable influence factor, and four terrain factors, namely slope, slope position, slope direction and elevation, were mainly selected in this study. Different terrain factors will affect the water content of the same combustible material to some extent [23-24]. The following briefly explains the way in which topographic factors affect the water content of combustible materials. (i) Slope: steeper slopes result in faster water loss when it rains. Soil moisture content is lower, creating a dry environment that burns easily when it encounters an ignition source. It is easy to form a windward slope, the vegetation is affected by the loss of their own body water. Slope position: Slope position affects the distribution of vegetation, and also affects the loss of water from the forest floor. (iii) Slope direction: The direction of the slope affects the amount of time the vegetation receives sunlight, with some vegetation locations receiving no sunlight and others receiving sunlight. The duration of exposure to sunlight leads to differences in the water content of forest combustibles. (iv) Elevation: Differences in elevation affect precipitation and temperature, which affects the conditions in which vegetation can survive. Higher elevations have lower temperatures, slower rates of volatilization and loss of moisture from combustibles, and higher water content of combustibles.

Meteorological factors are semi-stable influence factors, and three meteorological factors, wind speed, wind direction and humidity, were mainly selected for this study. Different influence conditions will affect the water content of the same tree species. The following explanation is the effect of meteorological factors on the water content of combustible materials [23]. (1) Wind speed: the speed of wind will affect the volatilization and loss of moisture in forest combustibles, and a high wind speed will result in fast water loss and easy drying of combustibles. (2) Wind direction: different wind direction will affect the forest combustible moisture content is different, the windward side of the combustible water volatilization and loss than the leeward side of the fast. (3) Humidity: different humidity will affect the environment of the forest, humidity in the region of wet forest, combustible water content is high, low humidity forest is drier, combustible water content is lower.

3.2. Data Analysis and Modeling

Through the experimental data and sampling data to get each species of live branches, live leaves, dead branches, dead leaves of the water content, each species of 60 groups of data, select 45 groups to establish a prediction model, 15 groups of data for model testing, 5 species of a total of 300 groups of data, because the data is more than listed here.

Using spss software to analyze the water content of combustible materials and influence factors, because the data analysis of pure text cannot be analyzed, so for the numerical value of a substitution. Slope position is replaced by low, medium and high (1 for low slope, 2 for medium slope, 3 for high slope); slope direction is expressed in degrees (different degrees represent different directions, 8 directions and 360 °); wind direction is replaced by 8 directions (1 for east, 2 for south, 3 for west, 4 for north, 5 for south-east, 6 for north-east, 7 for south-west, 8 for north-west); wind direction is replaced by 8 directions (1 for east, 2 for south, 3 for west, 4 for north, 5 for south-east, 6 for north-east, 7 for south-west, 8 for north-west). For south-west, 8 for north-west); the crown width of trees was split into crown height and crown width. Take the influence factor as the independent variable and the combustible water content as the dependent variable, and number the influence factor X_1 as slope, X_2 as slope direction, X_3 as slope position, X_4 as elevation, X_5 as wind speed, X_6 as wind direction, X_7 as humidity, X_8 as ground diameter, X_9 as crown height, X_{10} as crown width, X_{11} as tree height, X_{12} as degree of depression, and X_{13} as tree species; and number water content Y_1 as water content of live branches, Y_2 as water content of live leaves, and Y_2 as water content of living leaves, and Y_1 as water content of live branches. Y_1 is water content of living branches, Y_2 is water content of living leaves, Y_3 is water content of dead branches, and Y_4 is water content of dead leaves.

3.2.1. Correlation analysis

Principle of regression analysis: regression analysis refers to the use of data statistics principles, mathematical processing of a large number of statistical data, and to determine the correlation between the dependent variable and certain independent variables, to establish a better correlation regression equation (function expression), and extrapolated for predicting future changes in the dependent variable of the analytical method [17]. According to the number of dependent and independent variables are divided into: univariate regression analysis and multiple regression analysis; according to the functional expression of the dependent and independent variables are divided into: linear regression analysis and nonlinear regression analysis [17].

Correlation analysis of independent variables and dependent variables, according to the results of the analysis to screen out the influence factors with small influence values, in the establishment of the model to remove the factors with small correlation, to improve the accuracy of the establishment of the model. A correlation value greater than 0 indicates a positive linear correlation between the variables, and a correlation value less than 0 indicates a negative linear correlation between the variables. The independent variables X_1 are slope, X_2 are slope direction, X_3 are slope position, X_4 are elevation, X_5 are wind speed, X_6 are wind direction, X_7 are humidity, X_8 are ground diameter, X_9 are crown height, X_{10} are crown width, X_{11} are tree height, X_{12} are degree of depression, and X_{13} are tree species; and the independent variables Y_1 are water content in live branches, Y_2 are water content in live leaves, Y_3 are water content in dead branches, and Y_4 are water content in dead leaves. The correlations between the influence factors and water content were analyzed in Tables 1 to 5 below:

Table 1. Correlation analysis between impact factors and water content of hooded oak

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1-0.66	-0.45	-0.36	0.36	-0.53	0.38	0.53	0.21	-0.28	0.35	0.31
Y_2-0.63	-0.51	-0.28	0.27	-0.59	0.29	0.56	0.23	-0.36	0.34	0.29
Y_3-0.58	-0.47	-033	0.31	-0.60	-0.26	0.62	0.32	-0.31	0.39	0.35
Y_4-0.71	-0.49	-0.21	0.29	-0.63	-0.28	0.58	0.19	-0.28	0.36	0.34
Note: The impact factor tree species (X_{13}) has a correlation of 0 and is not listed in the table.										

Table 2. Correlation analysis between impact factors and water content of Quercusglauca

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Y_1-0.53	-0.45	-0.38	0.29	-0.60	-0.36	0.55	0.26	-0.23	-0.29	-0.31	0.39	0.12
Y_2-0.76	-0.56	-0.28	0.34	-0.68	-0.29	0.53	0.29	-0.19	-0.31	-0.35	0.32	0.19
Y_3-0.65	-0.42	-0.31	0.27	-0.58	-0.35	0.42	0.23	-0.26	-0.33	-0.39	0.25	0.09
Y_4-0.67	-0.47	-0.27	0.24	-0.59	-0.36	0.48	0.24	-0.24	-0.26	-0.28	0.34	0.10

Table 3. Correlation between the influence factors and water content of Yunnanprunus

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Y_1-0.59	-0.46	-0.33	0.23	-0.55	-0.30	0.48	-0.28	0.33	-0.21	-0.29	0.29	0.12
Y_2-0.62	-0.49	-0.25	0.28	-0.51	-0.23	0.49	-0.19	0.14	-0.20	-0.33	0.31	0.33
Y_3-0.57	-0.47	-0.26	0.26	-0.54	-0.36	0.48	-0.17	0.20	-0.14	-0.31	0.36	0.27
Y_4-0.56	-0.46	-0.28	0.28	-0.53	-0.29	0.42	-0.18	0.34	-0.18	-0.30	0.39	0.31

Table 4. Correlation analysis between impact factors and water content ofMetasequoiasp.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Y_1-0.56	-0.47	-0.37	0.24	-0.50	-0.37	0.49	0.25	0.23	-0.28	-0.36	0.31	0.24
Y_2-0.69	-0.49	-0.39	0.33	-0.52	-0.32	0.51	0.24	0.21	-0.22	-0.37	0.33	0.14
Y_3-0.54	-0.53	-0.31	0.30	-0.56	-0.31	0.57	0.21	0.24	-0.19	-0.37	0.36	0.13
Y_4-0.58	-0.47	-0.38	0.32	-0.53	-0.37	0.47	0.23	0.20	-0.37	-0.36	0.34	0.27

Table 5. Correlation analysis between impact factors and water content of silver wattle

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Y_1-0.55	-0.48	-0.38	0.29	-0.51	-0.37	0.62	0.27	0.23	-0.28	-0.31	0.25	0.16
Y_2-0.56	-0.47	-0.32	0.34	-0.48	-0.34	0.61	0.28	0.19	-0.26	-0.22	0.33	0.23
Y_3-0.52	-0.51	-0.31	0.32	-0.47	-0.38	0.59	0.24	0.30	-0.25	-0.28	0.38	0.14
Y_4-0.57	-0.52	-0.36	0.37	-0.52	-0.29	0.61	0.31	0.25	-0.31	-0.36	0.32	0.19

When selecting the influencing factors, the absolute value of correlation is higher than 0.4 for modeling. According to Table 1, only the slope (X_1), slope direction (X_2), wind speed (X_5) and humidity (X_7) have correlation values higher than 0.4 among the 13 factors, and the correlation values of the other remaining 9 factors are less than 0.4. Therefore, only four factors, namely, slope (X_1), slope direction (X_2), wind speed (X_5) and humidity (X_7), are selected for modeling.

3.2.2. Modeling

The water content of forest combustibles is affected by combustibles themselves and environmental factors and other aspects of the integrated impact, and there is a certain causal link between them [14]. Therefore, the relationship between many influencing factors and the water content of combustibles should be analyzed comprehensively, and from the analysis results, four influencing factors, namely, X_1 slope, X_2 slope direction, X_5 wind speed and X_7 humidity, were selected, and a prediction model of the water content of combustibles in live branches, live leaves, dead branches and dead leaves of five tree species was established by using multiple linear regression method.

3.2.3. Model validation

Substituting the constructed 20-group prediction model into the 15 groups of data of each tree species not involved in modeling, the predicted water content of live branches, live leaves, dead branches and dead leaves of five tree species were calculated, compared with the actual water content, and the error rate was calculated by using the formula. The calculation formula is as follows:

$$\text{Error}(\%) = \frac{\text{Actual moisture content} - \text{Predicted moisture content}}{\text{Actual water content}} \times 100\%$$

(1) The maximum error of the cape-do oak live branch model is 11.52%, and the average error is 4.37%; the maximum error of the cape-do oak live leaf model is 16.29%, and the average error is 6.72%; the maximum error of the cape-do oak withered branch model is 34.5%, and the average error is 11.07%; the maximum error of the cape-do oak withered leaf model is 20.02%, and the average error is 11.02%.

(2) The maximum error of the live oak model was 18.5%, and the average error was 9.54%; the maximum error of the live oak model was 9.58%, and the average error was 3.36%; the maximum error of the dead oak model was 23.47%, and the average error was 7.58%; the maximum error of the dead oak model was 22.24%, and the average error was 9.37%.

(3) The maximum error of Yunnan poplar live branch model was 16.47%, and the average error was 6.24%; the maximum error of Yunnan poplar live leaf model was 18.07%, and the average error was 8.15%; the maximum error of Yunnan poplar dead branch model was 32.19%, and the average error was 11.81%; and the maximum error of Yunnan poplar dead leaf model was 29.96%, and the average error was 10.47%.

(4) The maximum error of the live branch model of Yew tree was 12.58%, and the average error was 5.34%; the maximum error of the live leaf model of Yew tree was 16.29%, and the average error was 8.49%; the maximum error of the dead branch model of Yew tree was 17.44%, and the average error was 7.69%; the maximum error of the dead leaf model of Yew tree was 15.62%, and the average error was 9.27%.

(5) The maximum error of the silverthorn live branch model is 10.27%, and the average error is 3.92%; the maximum error of the silverthorn live leaf model is 23.2%, and the average error is 5.60%; the maximum error of the silverthorn dead branch model is 14.69%, and the average error is 5.56%; and the maximum error of the silverthorn dead leaf model is 20.02%, and the average error is 6.43%.

By appealing to the maximum error and average error, it can be concluded that the established water content prediction model has an error with the actual value, which is caused by the following reasons: (1) rainfall during sampling, water absorption of combustible materials leads to the error of water content; (2) windy during wind speed measurement, which leads to the measurement of the wind speed bias; (3) deviation in the position of the placement during the measurement of the slope leads to the inaccuracy of the slope factor. (4) The electronic balance range is not precise enough, which affects the accuracy of the data.

4. CONCLUSION ANALYSIS

The water content of forest combustible material is a key factor affecting the ignition and spread of forests, and is the main reference factor for forest fire prediction and forecasting. Using multiple linear regression method, we analyzed the important factors affecting the water content of combustible material selected slope, slope direction, wind speed, humidity, and constructed 20 combustible material water content prediction models of live branches, live leaves, dead branches and dead leaves of five tree species. It can be seen that there is an error between the established water content prediction model and the actual value, and the detailed data can be seen in the model test, and the reasons for the error can also be seen from the error analysis.

Forest fires have a great impact on forest resources and the living environment. Different regions have different topography and climate, and the climate inside the forest is also different, which makes it difficult to prevent and control forest fires under these complex factors. In this paper, although only 20 sample plots with a total of 60 sets of data were selected to study the water content prediction model of five common species of Dianthus species, namely, Quercus capitata, Quercus glauca, Yunnan poplar, Yunnan oleander, and silverthorn. However, the obtained prediction model can be used to estimate the water content of the same tree species in other areas of central Yunnan. The predicted water content can be used to classify the forest danger level and provide a basis for classifying the combustibility of combustible materials. Therefore, it is very useful to develop a prediction model for water content, which can be used to predict the water content of combustible materials and provide help and reference for forest fire prevention and management.

5. SUMMARY

Predicting the moisture content of combustibles in Diane is critical to fire risk assessment. Low moisture content means that combustible materials are more flammable, increasing the likelihood of fires; high moisture content reduces fire risk. Accurate moisture content prediction can help to take targeted fire prevention measures, such as timely clearing of dead grasses and enhanced monitoring, to reduce the probability of fire and protect people's lives and properties.

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