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SPATIOTEMPORAL VARIATION OF DROUGHT AND ITS CORRELATION WITH PLANT SPECIES OF YUNNAN PROVINCE, CHINA

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Abstract

Drought is the main natural disaster in Yunnan Province, China. In the present paper monthly precipitation observation data from Yunnan Province durign the period of 1966 - 2015 were used. From the data, the selected percentage of precipitation anomalies was used as drought index. By applying the ArcGIS inverse distance interpolation method and Mann Kendall non parametric trend test method the spatiotemporal variation characteristics of drought in Yunnan province were analyzed. Results show that the drought in Yunnan Province has a slightly upward trend. In spring and winter, there is a tendency to become wet but in summer and autumn, the tendency is shown by dry condition. It was observed that the studied area is prone to a severe drought in winter, and there will be more droughts in the east part, the northwest part, and the southwest part of Yunnan province when it is autumn. In other periods, severe doughts usually attack the middle part of Yunnan province, which can be proved by the characteristics of vegetation distribution.

Introduction

Drought is a most common natural disaster in many countries and regions of the world. About 70% of natural disasters in China are of meteorological origin, and 50% of those are caused due to drought (Bao *et al.* 2011, Chen *et al.* 2011, Hen *et al.* 2011). Natural disasters like dryness or drought prevail in the environment because of human existence and social development. Khan *et al.* (2006) used SPI to research the historical drought conditions of Darling basin in Australia. Kasei *et al.* (2010) used SPI to study temporal and spatial variation characteristics of drought distribution within a span of 1961 - 2005 of West AfricanVolta river basin. Kasei *et al.* (2010) have also assessed the regional drought intensity of the same area. Sergio and Vicente-Serrano (2010) studied the temporal and spatial characteristics of the drought in the Iberian Peninsula, and found that the regional and spatial distribution of drought is very complex.

To study the temporal and spatial variation of precipitation, Mann-Kendall trend analysis method was used (Wang 2012, 2014, Wang *et al*. 2013). Liu *et al.* (2011) and Zhang *et al.* (2012) studied the spatiotemporal variations of drought using wavelet transform. Han and Chen (2011) calculated the integrated meteorological drought index (Ic) from the daily average temperature and precipitation data from 1973 - 2012 in Henan Province. The drought-time distribution and trend of drought in Henan Province were analyzed by statistical frequency, intensity and number of days (Han and Chen 2011). Duan and Huang (2014) used the precipitation percentage anomaly as the drought evaluation index, and used the Kriging interpolation method of ArcGIS to generate the drought frequency map for analyzing the spatial and temporal distribution of drought in Yunnan Province. In the present study GIS spatial interpolation and Mann-Kendall nonparametric test and other technical means and Correlation analysis method were used to study the spatiotemporal correlation of spatial and temporal variations of drought and vegetation species changes in Yunnan and to provide scientific basis and technical support for drought warning.

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Yunnan is located in the southwest border of China, between 97°31 ' and 106°11' E, and 21°8 'and 29°15' N. The province has seven types of temperature and climate zone, resulting in a complex natural geographical environment. Although the total amount of water resources in Yunnan Province is rich, but the uneven distribution of time and space made it prone to get drought. Drought has caused great damage to agricultural production and social economy. So the prevention and relief of it has received extensive social attention (Long *et al.* 2012, Ren *et al.* 2014, Gao *et al.* 2015). The 29 primary meteorological stations in this study have certain regional representation, which basically reflect the different climatic characteristics of Yunnan Province (Fig. 1).

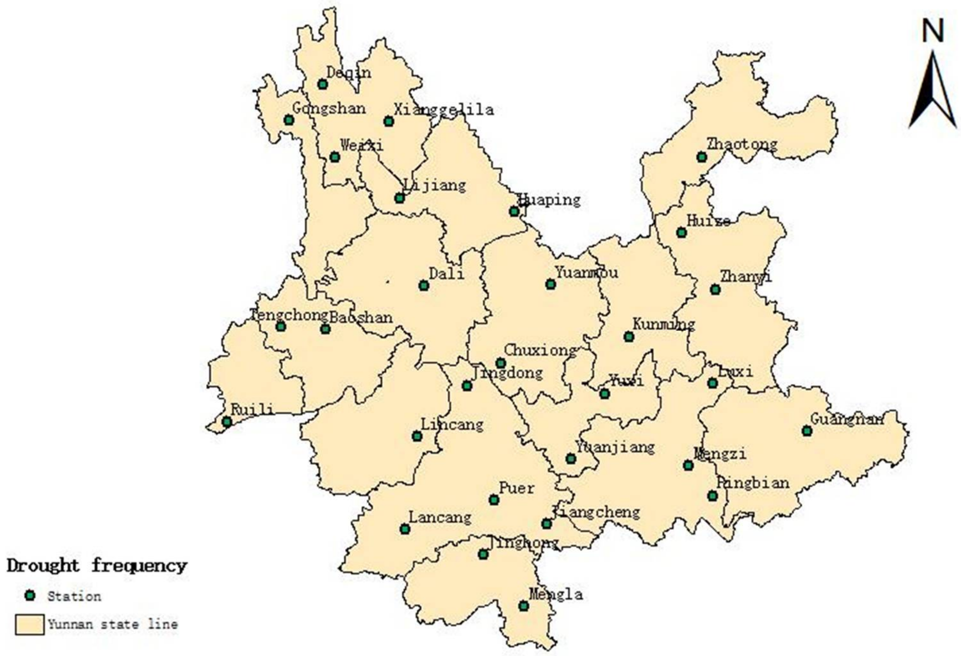


Fig. 1. Site distribution in Yunnan province.

Materials and Methods

Precipitation anomaly percentages can be a direct reflection of drought conditions due to insufficient rainfall and are often used for drought event detection and assessment. This is the simplest and most widely used drought characteristic analysis method in the five single index of drought detection. The precipitation anomaly percentage expressed as: measured precipitation value minus the same period the average precipitation value, and then divided by the same period the average rainfall, using the following formula.

$$D_p = \frac{p - \bar{p}}{\bar{p}} \times 100\% \qquad (1)$$

D_p is the percentage of anomaly precipitation (%), p is the precipitation of a certain period (mm), precipitation anomaly percentage is the standardization of precipitation, which can be a direct reflection of a period of drought in meteorology. Droughts and floods are reflected in the percentage of precipitation anomalies (Table 1).

Table 1. The precipitation anomaly percentage drought hierarchies.

Drought rating	Monthly scale	Quarter scale	Annual scale
Slight drought	$-60 < D_P \le -40$	$-50 < D_P \le -25$	$-30 < D_P \le -15$
Moderate drought	$-80 < D_P \le -60$	$-70 < D_P \le -50$	$-40 < D_P \le -30$
Serous drought	$-95 < D_P \le -80$	$-80 < D_P \le -70$	$-45 < D_P \le -40$
Extreme drought	$D_P \le -95$	$D_P \le -80$	$D_P \le -45$

Mann-Kendall non-parametric test can effectively distinguish a process of a change in the natural fluctuations and a clear trend (Zhang *et al.* 2013). As the hydrometeorological data follows non-normal distribution, Mann-Kendall non-parametric test method has good adaptability. The Mann-Kendall nonparametric test is usually used for the detection of precipitation trends. Here are the principles.

$$\tau = \frac{4f}{N(N-1)} - 1 \qquad (2)$$

$$\sigma_r^2 = \frac{2(2N=5)}{9N(N-1)} \qquad (3)$$

$$M = \frac{\tau}{\sigma_r} \qquad (4)$$

M is the rank correlation coefficient; f for the dual observations; N for the sequence length; σ_r for the standard deviation. $\alpha = 0.05$ Take the significant level, if $|M| > 1.96$ the trend changes significantly. When $M > 0$ the upward trend, and $M < 0$ said a downward trend.

Drought frequency is the probability that the spot will have drought during the year. It can be calculated like this:

$$D = n / N \times 100\% \qquad (5)$$

In this formula, D is the frequency of drought, n is the number of years of drought, N is the total number of years.

Spatial interpolation is a raster image computed from a limited number of sample data points and is used to predict the value of the attribute outside of the sample data in an area. Inverse distance weighting method: a local estimation weighted average interpolation method, the distance and the size of the weight is inversely proportional to:

The calculation formula for inverse distance weight interpolation method:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \qquad (6)$$

Where $\hat{Z}(s_o)$ is the predicted value in s_o and N is the number of samples around the forecast point, λ_i is the weight of each sample, which is inversely proportional to the distance between the sample point and the predicted point; $Z(s_i)$ is the measured value obtained atb S_i.

Results and Discussion

Based on monthly precipitation data of 29 first-class meteorological stations in Yunnan Province, we have used the annual precipitation data from 1966 - 2015 were used. The insert chart function in excel to display annual precipitation data in the form of a line chart was used. Using Excel tool to fit the trend curve, the precipitation of Yunnan Province showed, a downward trend (Fig. 2). And then Mann-Kendall trend test was used to examine it. The Mann-Kendall function is constructed in MATLAB software, and then the annual precipitation is treated as standard column vector into MATLAB. Then Mann-Kendall trend test of annual precipitation was obtained in Yunnan Province, in which Slope Estimate = -0.22919, M statistic = -1.2128, here M is less than 0, so it is a downward trend. But <1.96 did not pass the significant test, which means drought trend in Yunnan Province for the insignificant upward trend. From the drought frequency distribution map of Yunnan Province (Fig. 3), it can be seen that some areas of the province fall under higher frequency distribution of drought frequency. These are Deqin, Shangri-La, Huaping, Dali, Chuxiong, Yuanmou, Kunming, Huize, Zhanyi, Guangnan, and Mengla. Their frequencies of drought were found to mainly range from 18-22%. Drought-prone areas are mainly distributed in the central, southern, eastern, and parts of northwestern-Yunnan.

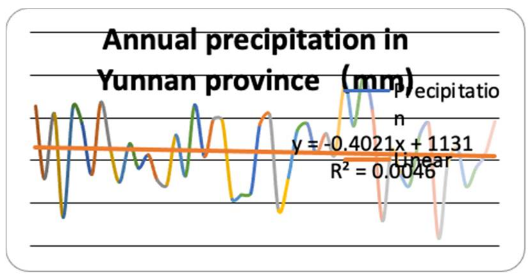


Fig. 2. Annual precipitation in Yunnan province.

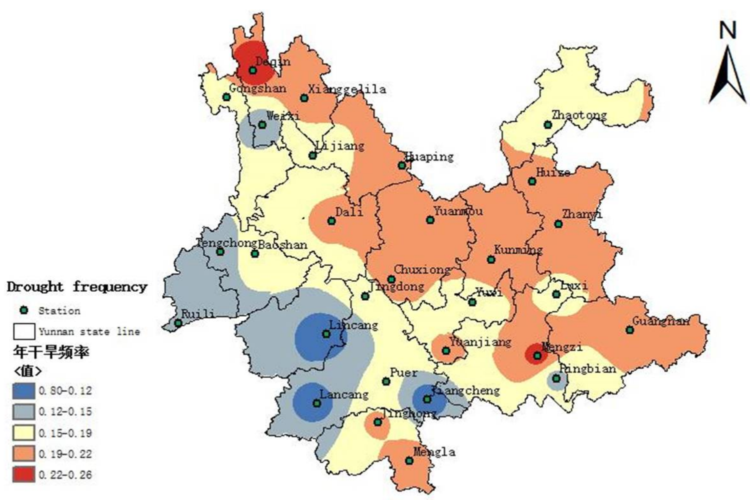


Fig. 3. Drought frequency distribution in Yunnan province.

In the present study meteorological division method to divide the seasons were used. By the frequency of seasonal drought in Yunnan Province (Fig. 4), one can draw a conclusion that the frequency of drought in spring (March - May) was 29%, and that for summer (June - August) was 10%.

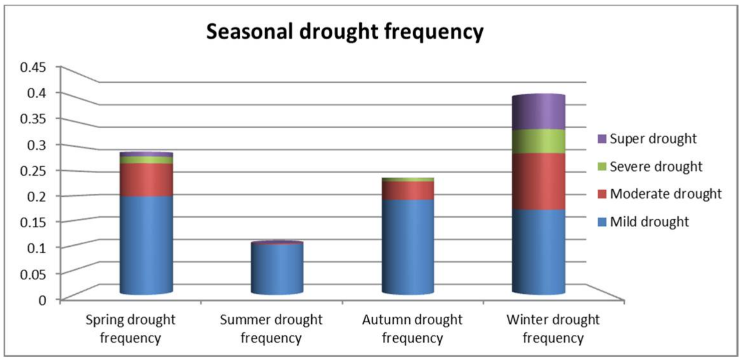
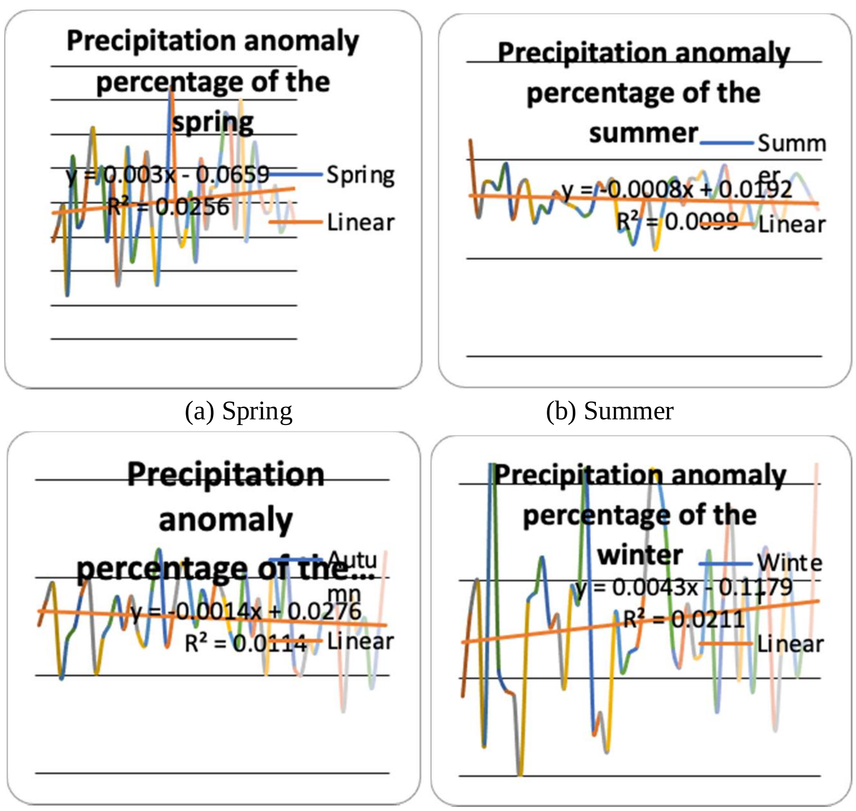


Fig. 4. Seasonal drought frequency.

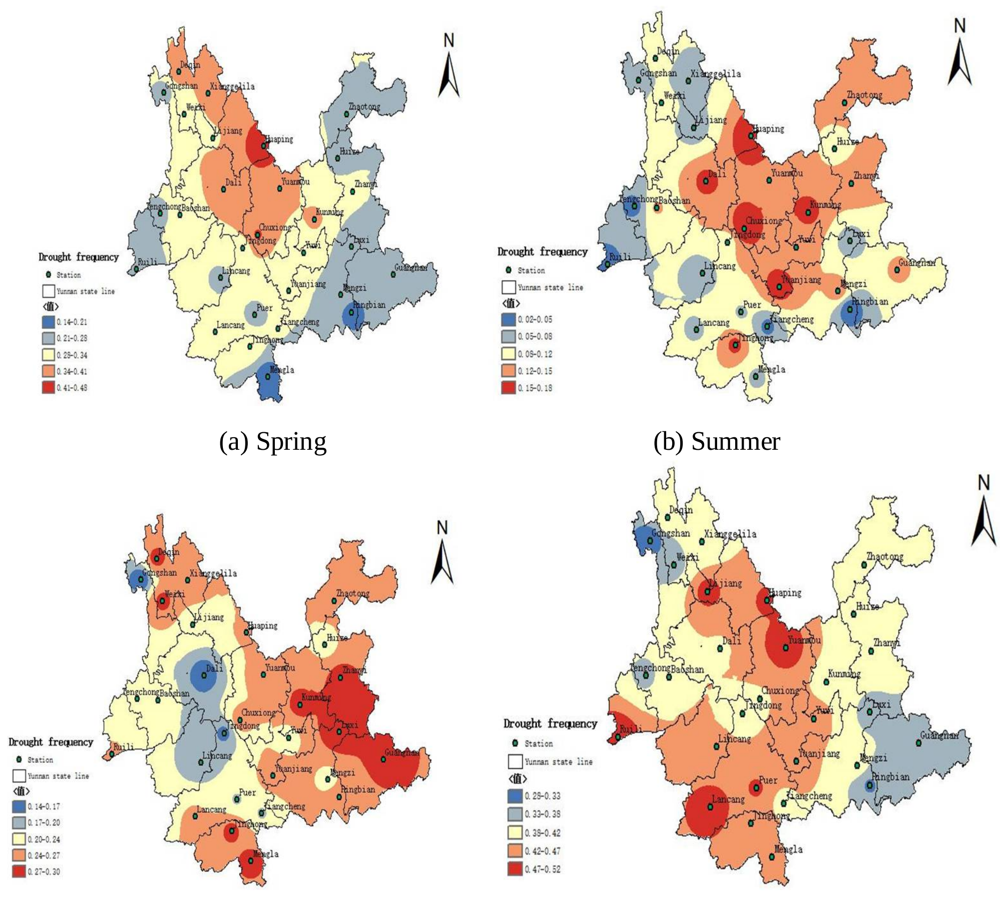


(a) Spring (b) Summer

(c) Autumn (d) Winter

Fig. 5. Precipitation anomaly percentage of four seasons.

In autumn (September - August) it was 24%, and in winter (December - February) it was 41%. The frequency of drought in the four seasons was from winter to spring, and autumn to summer. Using the Excel table tool to fit the trend percentage of precipitation anomalies in four seasons (Fig.5), and then using Mann-Kendall trend test to check the precipitation anomaly percentage in Yunnan Province, it was found that the trend of precipitation anomalies in all the four seasons did not fit. There was no significant upward trend in the percentage of precipitation anomalies in spring and winter, and there were no significant declining trends in summer and autumn. The results showed that the drought in spring and winter in Yunnan had a decreasing trend, and the drought in summer and autumn tended to increase.



(a) Spring (b) Summer

(c) Autumn (d) Winter

Fig. 6. Four seasons drought frequency.

The frequency of drought in spring in Yunnan Province shows that the places which have high frequency of drought in spring are Deqin (Fig. 6a), Shangri-La, Huaping, Dali, Yuanmou, Chuxiong, and Kunming, and the drought frequency is between 34 and 48%. Drought in spring is easy to happen in Yunnan and Northwest of Yunnan. The frequency of drought in summer in Yunnan Province shows that the frequency of drought is higher in Huaping, Dali, Yuanmou, Chuxiong, Kunming, Yuanjiang, Zhanyi, and Zhaotong (Fig.6b), which ranges mainly 12-18%. In summer, drought is easy to happen in the middle of Yunnan and the northeast part. The high frequency of drought places in autumn is Zhanyi, Kunming, Luxi, Guangnan, Deqin, Weixi, Jinghong, and Mengla (Fig.6c). In these areas, the drought frequency ranged mainly 27-30%. Drought in autumn is likely to occur in eastern-, and northwestern-Yunnan and parts of southwestern Yunnan. The frequency of drought in winter in Yunnan Province shows that it is higher in Lijiang, Huaping, Yuanmou, Ruili, Lancang, and Pu'er (Fig.6d). Druing this season, the drought frequency ranged mainly between 47 and 52%. Drought in winter is easy to occur in the southwest of Yunnan, Yunnan, and parts of Northwest Yunnan.

The changes of frequency of drought in Yunnan Province were obvious during a year (Fig.7). In June, July, and August it was less than 2%, and was the lowest in the whole year. The drought frequencies were 36, 24, 28, and 34% in January, February, March, and November, respectively. It was 42% in December, and from November to March in the following year, the frequency of drought was > 20%, making them drought-prone month in a year. In addition, December has the highest frequency of drought during a year. The results showed that the frequency of drought was the lowest in June, July and August, and the highest frequency of drought occurred from November to March.

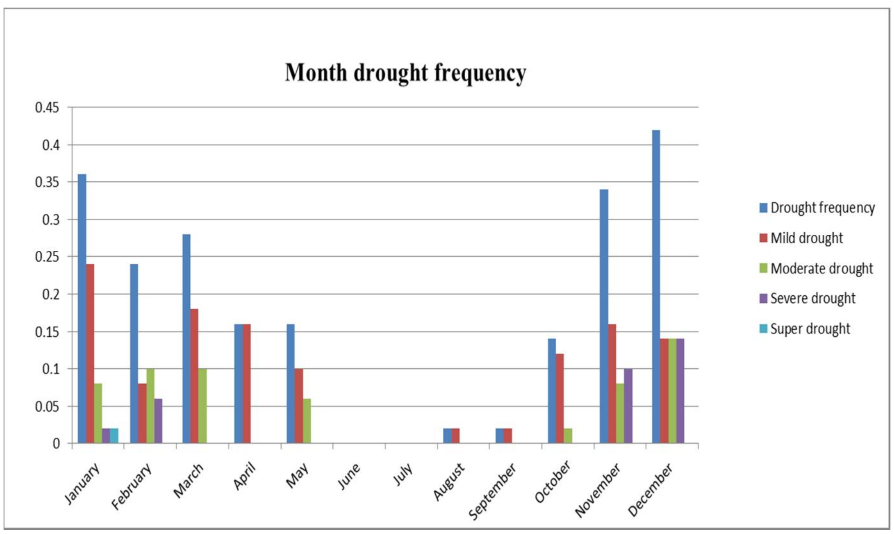
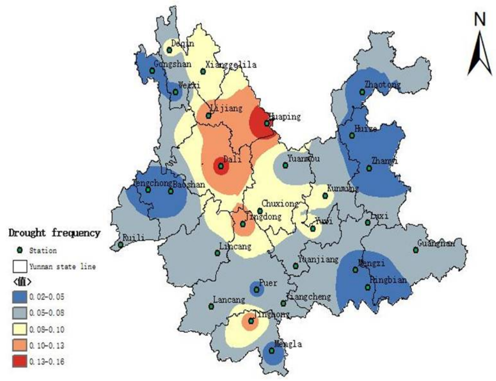
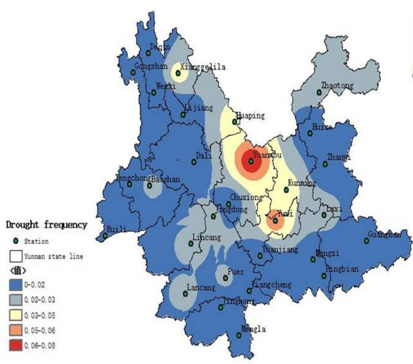


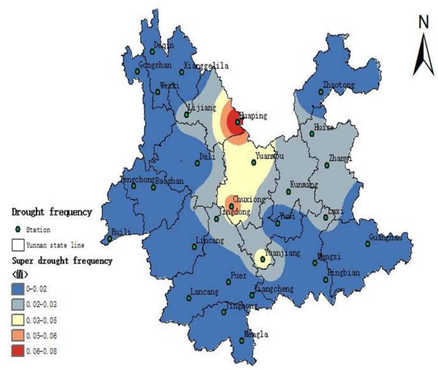
Fig. 7. Month drought frequency.

The places which have high frequency of drought in Yunnan are Kunming, Yuxi, Chuxiong, Jingdong, Huaping, Lijiang, and Jinghong, where the value fluctuated mainly between 8 and 16%. Moderate-drought-prone areas are mainly distributed in central Yunnan and northwestern Yunnan (Fig.8a). The frequency of severe drought in Yunnan Province is high in Yuanmou, Yuxi, Kunming, Huaping, and Shangri-la, where the values fell mainly between 3 and 8%. The areas with severe drought are mainly distributed in the middle of Yunnan (Fig.8b). The frequency of high-level drought is high in Lijiang, Huaping, Yuanmou, Chuxiong, Jingdong, Yuanjiang, Kunming, Huize, and Zhanyi Luxi, among which drought frequency was between 2 and 4%. The high-level drought-prone areas are mainly located in Yunnan, eastern Yunnan and parts of northwestern Yunnan (Fig.8c).



(a) Drought frequency





(b) Severe drought frequency (c) Super drought frequency

Fig. 8. Drought rating map.

The way by which various vegetation is formed reflects intrinsic relationships to its habitat. The environment determines what type of vegetation would grow there but meanwhile can also threaten its growth. During the long process of natural selection and survival competition, when the environment changes within the threshold of vegetation, it can adapt different strategies to tackle environmental challenges. This is achieved by evolving different body form, or by differentiating its niches, but for some plant species, environmental change can exceed their survival threshold. When this happens, they will go extinction and disappear from that area. From the point of result, that plants can live in a given area reflects the fact that they must be adapted to the ecological conditions. From a long-term perspective, their existence and growth in this area are results of natural selection. In a shorter-term perspective, it is a result of threat, the environment imposes to these plant species. Consequently, by studying the vegetation distribution, one could infer what the ecological condition would look like, and the vegetation type along with the life form for a certain species. And it could also enable researchers to make an intelligent guess about the climatic condition of the vegetation distribution. Since areas afflicted by drought often face problems about long-term lack of water, by studying the climatic condition there, the correctness of spatial and temporal variations of drought can be verified. After mass sampling, and calculating related coefficients, study has shown that there is a correlation between drought character and vegetation type.

Correlation analysis is a statistical analysis method that examines the linear relationship between two variables. Popularly speaking, it is an analysis that measures the closeness of correlation between two or more correlated variable elements. Correlation elements need to have a certain connection or probability before correlation analysis can be carried out, such as precipitation and plant types in this article, precipitation affects plant growth and types. Using correlation analysis method, the value range of correlation coefficient is [-1,1], 0～0.09 is no correlation, 0.1～0.03 is weak correlation, 0.3～0.5 is medium correlation, and 0.5～1.0 is strong correlation. Due to the undulating terrain and complex topography of Yunnan Province, different small environments are often created within a small span due to altitude differences, resulting in the vertical zonal distribution of vegetation, in completely different vegetation distribution characteristics. However, on a large horizontal scale, the vegetation distribution characteristics have a certain correlation with the spatial and temporal distribution characteristics of drought.

In summary, the drought in Yunnan, China showed no significant upward trend, but getting wet in spring and winter, and dryness in summer and autumn, it occurred more frequently in spring and winter, and the frequency of drought in summer was the lowest. The frequency trend of drought in four seasons follows winter > spring > autumn > summer. Moderate to severe drought happens in winter. The monthly drought rate was the highest in December, the lowest frequency occurred in June, July, and August, and the most drought-prone months were from November to the next March.

Drought-prone areas are mainly distributed in central-, southern-, eastern-, and parts of northwestern-Yunnan. The drought-prone areas in the spring are in central- and northwest of Yunnan, and the drought-prone areas in summer are in central- and northeastern-Yunnan. While those in autumn are eastern-, northwestern- and southwestern Yunnan and in winter are in central-, southwestern-, and parts of northwestern Yunnan. The central part of Yunnan was moderate-drought-prone and mainly distributed in central- and parts of northwestern Yunnan. On the other hand, the areas with severe drought are mainly distributed in the middle-, and the extreme -drought-prone areas are mainly located in Yunnan, eastern Yunnan and parts of northwestern Yunnan.

The present study further indicates that the quantitative study on the effect of temporal and spatial drought pattern on vegetation distribution helps to predict the trend of drought change, thereby enable to know the changing pattern of plant distribution under long-term limitation in water sources. This model can be applied to areas whose drought effect is reinforced by global warming, and it can have its other applications in ecosystem, production, and livelihood.

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