Study on the Relationship among Forest Fire Temperature and Precipitation and Its Spatial-temporal Variability in China

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Abstract

Objective The aim was to discuss the relationship between forest fire and meteorological elements (precipitation and temperature) in each region of China. Method Firstly, the average precipitation and temperature in forest area of each province in fire season were obtained based on meteorological data, forest distribution data, seasonal and monthly data of forest fire in China. Secondly, the relationship among forest fire area, precipitation and temperature was discussed through temporal and correlation analysis. Result The changes of precipitation and temperature with time could reflect the annual variation of fire area well. Forest fire area went up with the decrease of precipitation and increase of temperature, and visa versa. Meanwhile, there existed differences in the relationship in various regions over time. Correlation analyses revealed that there was positive correlation between forest fire area and temperature, especially in Northwest China (R = 0.367, P < 0.01), Southwest China (R = 0.327, P < 0.05), South China (R = 0.333, P < 0.05), East China (R = 0.516, P < 0.01) and Xinjiang (R = 0.447, P < 0.05) with obviously positive correlation. At the same time, the correlation between forest fire area and precipitation was significantly positive in Northwest China (R = 0.482, P < 0.01) while it was significantly negative in South China (R = -0.323, P = 0.03) but there was no significant correlation in other regions. Conclusion Relationships between forest fire and meteorological elements (precipitation and temperature) revealed in the study would be useful for fire prevention and early warning in China.

Key words Forest fire; Precipitation; Temperature; Spatial-temporal variability

Weather is one of important parts of fire environment composed of weather topography and fuel. Meteorologists and forest scientists suggested that some meteorological elements had great effects on the occurrence of fire. Under specific conditions, weather has greater impact on fire compared with topography and fuel so it is dominant in fire environment. Many studies showed that there was good correlation between meteorological elements and forest fire. The changes of meteorological elements with time can explain the seasonal and annual variation of fire frequency and area well. It is easy to obtain meteorological data so meteorological data has been mainly used to assess fire danger which could provide references for the rapid establishment of decision by government departments. As the complex ecological system affected by weather topography and fuel, fire has great spatial-temporal variability. Fire and its relationship with weather will vary with space and time. Therefore, studying the relationship between meteorological elements and fire in various regions has important guiding meaning for fire prevention and early-warming in regional forest. As global warming, the frequency and intensity of forest fire will go up and analyzing the relationship between meteorological elements and fire can help draw up the countermeasures to respond to climate change in future.

China is one of countries with serious forest fire in the world. From 1950 to 2000, the total frequency of forest fire in China reached 693,966 times and the total area of forest fire was up to 3,864.00 hm² with annual frequency of 13,607 times. The frequency of forest fire per 0.1 million hm² forest was ten times and the area of forest fire every year was 0.7576 hm² which accounted for about 0.6% of total area of forest so the average area of each fire was 55.70 hm². As a main natural disaster in forest, forest fire can not only destroy forest ecosystem but also bring great loss to people’s lives and property. Thus, studying the relationship among forest fire, temperature and precipitation plus its spatial-temporal variability have a great significance to the prevention and mitigation of forest fire in China. At present, there are many relevant studies in different regions of China, but it is deficient in the relationship between meteorological elements and forest fire on the national scale.

In the study, the relationship among forest fire, temperature and precipitation in various regions would be discussed by using spatial interpolation and geographic information system (GIS) technology. Firstly, data of meteorological elements (temperature and precipitation) in forest area in each province of China from 1980 to 2000 were obtained by means of space technology; afterwards, China was divided into eight regions according to fire season and regional characteristics. Data from 1980 to 2000 were analyzed then the correlation among fire area, temperature and precipitation in each region was analyzed and finally the main conclusions and outlook for future study were expounded.

Material and Methods

Fire data

Data of forest fire including the frequency and area of forest fire in each province of China from 1980 to 2000 were from China’s Forest Yearbook and Forest Information Compilation. Data from 1980 to 2000 were analyzed and it was because that the observation and statistics of forest fire from...
1980 to 2000 were stable and data had good continuity so that the extreme value caused by human statistics could be eliminated mostly and data series were more consistent with actual situation.

Meteorological data

Meteorological data mainly contained daily maximum temperature, daily minimum temperature and daily precipitation. Daily meteorological data were collected from 476 stations then the distribution of meteorological elements on the surface was obtained through spatial interpolation. Spatial interpolation adopted an improved interpolation model by Thornton et al. which could use data from many stations to conduct space interpolation for daily meteorological parameters and simplified treatment was carried out due to a small number and uneven distribution of meteorological stations plus complex and diverse climate in China.

Data processing

The distribution of forest is closely related to climatic characteristics so there are great differences in climatic characteristics between forest area and other areas with vegetation. Meanwhile the exact location of each fire couldn't be obtained so it was supposed that fire would happen in any region of forest. Data of meteorological elements used in the analysis on the relationship between meteorological elements and fire were the average values of meteorological elements in forest area of each province. Firstly taking the distribution map of forest as mask then the distribution of meteorological elements in forest area was acquired from nationwide meteorological raster data by using the grid processing module of GIS software Arc/Info. Data of forest distribution were from a land use map developed by Liu Jiyuan et al. Afterwards the average values of meteorological elements in certain period in forest area of each province were obtained by the command module Zonalmean of Arc/Info Grid.

In order to reflect the annual variation of meteorological elements and their relationship with fire variation better data of meteorological elements and fire in each province from 1980 to 2000 were normalized. That is to say the original values minus the multi-year average of data series was divided by the standard deviation and its formula is as follows:

\[
E(t)_{\text{normal}} = \frac{E(t) - E(t)_{\text{multi-ave}}}{E(t)_{\text{multi-SD}}} 
\]

(1)

\[
E(t)_{\text{multi-SD}} = \sqrt{\frac{1}{T} \sum_{i=1}^{T} (E(t) - E(t)_{\text{multi-ave}})^2} 
\]

(2)

Where \( E(t) \) is multi-year average; \( E(t)_{\text{multi-SD}} \) is standard deviation.

Results and Analyses

Spatial distribution zone of forest fire season and regional features of weather in China

Forest fire happens all the year round in China. For Northeast China it occurred frequently in spring and autumn; in South China it mainly appeared in winter and spring; Xinjiang often suffered fire in summer. In spring forest fire moved from south to north while it moved from north to south in autumn.

Referring to the division of main large regions in China the distribution of fire month in Xinjiang was obviously different from that of other provinces in Northwest China. Fire happened from April to October in Xinjiang but fire season in other provinces of Northwest China was from January to April plus November and December. In addition there was great difference between Inner Mongolia and other provinces in North China. That is to say fire season was February March June October and November in Inner Mongolia while it was from January to March and from November to December in North China. In other distribution zone the distribution of fire season was consistent basically among various provinces in the same region. These differences mainly appeared in fire prevention period with lower fire prevention strength. Therefore the summary of fire season in large area had little effect on each province. Thus in order to reflect the correlation between meteorological elements (temperature and precipitation) and fire elements (fire frequency and area) in fire season better Inner Mongolia and Xinjiang were as two single regions so China was divided into eight regions (Fig. 1). The distribution of fire season in each region could be found in Table 1.

Fig. 1 Spatial distribution zone of forest fire season in China

In addition the multi-year average precipitation and temperature of forest areas in each province of China from 1980 to 2000 were analyzed in the paper. As shown in Fig. 2 the characteristics of meteorological elements were similar in various provinces in the same region. Compared with monthly average precipitation and temperature in each region from 1980 to 2000 fire in most regions (such as Northwest China, Southwest China, South China, East China, North China and Northeast China) occurred in the months with less rainfall. Fire in Inner Mongolia happened in spring and autumn with less rainfall plus June with more rainfall. It is because that lightning activity is frequent in June and it is easy to cause lightning fire. In Xinjiang fire appeared frequently in summer with higher temperature. It can clearly be seen that temperature played important roles in the distribution of forest fire within a year in Xinjiang.

Relationship between meteorological elements (temperature and precipitation) and area of forest fire and its spatial-temporal variability

In order to further discuss the relationship between meteorological elements and annual variation of forest fire in each region the annual variation of normalized meteorological data and fire data from 1980 to 2000 were analyzed. The changes of relationship among normalized average precipitation temperature and fire area with time in each region could be found in Fig. 3. Besides temperature and precipitation data were the monthly average values of temperature and accumulated value.

Table 1 Monthly distribution of forest fire season in various regions

<table>
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<tr>
<th>Region</th>
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* and * refer to fire season and non-fire season respectively.

![Fig. 2](image-url) **Multi-year average precipitation and temperature in forest area in each province**

For the sake of studying the quantitative relationship of annual variation among temperature, precipitation and fire area better, the correlation of average temperature precipitation and fire area in forest area of various regions was analyzed. Fig. 4 revealed that the area of forest fire had good positive correlation with temperature in most regions such as Northwest China (R = 0.367, P = 0.01), Southwest China (R = 0.327, P = 0.02), South China (R = 0.33, P = 0.02), East China (R = 0.516, P < 0.01) and Xinjiang (R = 0.447, P = 0.042) with significantly positive correlation. There was obviously positive correlation (R = 0.482, P < 0.01) between precipitation and fire area in Northwest China while negative correlation (R = -0.323, P = 0.03) could be found in South China and there was no significant correlation in other regions.

The results above showed that the meteorological elements related to fire area and correlation coefficient were different in various regions. However, there was positive correlation between precipitation and fire area in Northwest China. It is generally assumed that it is easy to cause large area of fire under less rainfall and dry combustible material. However, fire area was positively correlated to temperature and precipitation in Northwest China. At the same time, there was obviously positive correlation between temperature and precipitation (R = 0.634, P < 0.01). As shown in Fig. 2, multi-year average precipitation was less in fire season in Northwest China. Therefore, in fire season in Northwest China, precipitation went up as the increase of temperature. However, due to less rainfall in Northwest region, the changes of fuel moisture caused by rainfall (which could reduce the frequency of fire in principle) were weakened obviously by the increase of surface evaporation resulting from temperature increase (which can increase the frequency of fire) so there was positive correlation between precipitation (or temperature) and fire area in Northwest China. Based on the results above, it was suggested that temperature had more obvious effects on the annual variation of fire area compared with precipitation in Northwest China.
a: Northwest China; b: Southwest China; c: South China; d: East China; e: North China; f: Northeast China; g: Xinjiang; h: Inner Mongolia.

Fig. 3 Variation of temperature, precipitation and fire area in different regions during 1980–2000

“+” and “-” mean significant correlation and insignificant correlation respectively.

In a word, the changes of precipitation and temperature can reflect the annual variation of fire area well. Precipitation variation can affect water content in combustible material and further influence the combustibility of material. Thus, there was good synchronous relationship between the variation of precipitation and fire area. Meanwhile, the variation of temperature can affect the evaporation of water in fuel and surface temperature of fuel and further influence the combustibility and burning point of fuel. Temperature reduction with the increase of precipitation and temperature increase with the decrease of temperature also have good synchronous relationship with the variation of fire area. Meanwhile, the results also revealed that there was certain difference in the synchronous relationship in various regions over time. This synchronous relationship was consistent with the results of fire season monthly average temperature and precipitation in each province of China. In Xinjiang, there was good synchronous relationship between fire area and temperature in most years. However, there was good conformity between fire area and precipitation in other regions.

In addition, there was no obvious correlation among fire area, temperature and precipitation in North China, Northeast China and Inner Mongolia. From Fig. 3e, Fig. 3f and Fig. 3h, fire area in the three regions varied slightly after 1987 and it was often negative. It was because that the measures of fire prevention was strengthened nationwide after the large forest fire in Heilongjiang in 1987. Therefore, human factors are crucial to the formation of regional fire in the three regions.

Conclusions and Discussions

Based on the data of temperature and precipitation in forest area of each province in China from 1980 to 2000, the spatial-temporal variability and correlation of temperature, precipitation and fire area were analyzed in the paper. The results showed that the variation of temperature and precipitation in fire season could reflect the annual variation of fire area well, but the relationship was different in various regions. From correlation analysis, there was obvious correlation between temperature and fire area in most regions while there was certain correlation between precipitation and fire area.
ea in a few regions. Besides, with the constant enhancement of human disturbance, human activity replacing natural factors dominated the situation of fire in North China, Northeast China and Inner Mongolia.

There still exist some limitations in the study, namely lacking detailed information about fire location. Fire environment is composed of fuel topography and weather, so the occurrence of fire is related to fuel terrain features and its distribution. It was assumed that fire happened in all forest areas. The characteristics of weather accompanying fire might be weakened.

The relationship between forest fire and meteorological elements plus its spatial-temporal variability in China were discussed by means of statistical method. Fire is caused by natural factors and human factors. Without considering human factors, it was difficult to accurately obtain the effects of meteorological factors on the annual variation of fire. Regional fire model integrating natural ecological process and human factors will be an effective tool to assess the effects of meteorological factors on the dynamic variation of fire in future.

References


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