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Application of Remote Sensing Data-based Detection of Forest Vegetation Water Content in Forest Fire Prevention

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Abstract:

Forest fires occurring on Earth cause huge losses every year and their frequency is on the rise. In order to reduce the occurrence of forest fires, there have been a number of new technologies that have emerged to predict and dynamically monitor forest fires based on remote sensing technology. In this paper, the Normalised difference infrared index (NDII) value of the study area is based on remote sensing satellite image data to detect and estimate the water content of the vegetation in the forest area to predict the occurrence of forest fires, so as to strengthen the precautionary measures for forest fires and reduce the probability of forest fires. The results showed that vegetation water content was significantly negatively correlated with the risk of forest fires, and when the vegetation NDII value was lower than -0.8486, it indicated that the water content of the vegetation area had dropped to a very low level, and it would be highly combustible and the probability of fire would be very high. For the study area, the water content of the vegetation tends to be even lower especially during the hot and dry seasons, making the overall increase in the forest fire risk level. This paper further validates that the water content of vegetation is one of the key indicators in forest fire risk assessment. This study provides more prevention indicators for forest fire prevention facilities and improves the prevention system.

Keywords: Forest fires; Aerospace remote sensing data; Vegetation water content.

1. Introduction

Forests, as an important resource of the Earth's ecology, have a major function in regulating the circulation of air and water resources in nature and are an indispensable part of climate change. At the same time, forests are the basis for providing the environment and materials on which human beings and living creatures depend for their survival, and are known as the 'cradle of life', with an irreplaceable role in long-term social and natural development[1].

However, in recent years, the frequency and intensity of forest fires have shown an upward trend, especially under drought or hot weather conditions, where the fire risk becomes more and more severe. According to incomplete statistics, in 2024, there were 295 forest and grassland fires throughout China, and this not only consumes a large number of human resources but also damages huge economic resources. Therefore, how to effectively monitor and predict the occurrence of forest fires has also become an important research topic in protecting forest resources and preventing natural disasters. Traditional forest fire monitoring often relies on manual inspection or ground sampling, there is a slow response, limited coverage and other shortcomings, and there is a part of the region, the staff fire prevention awareness is poor, the fire prevention foundation and the system are not perfect, which makes the fire prevention difficult [2]. However, with the development of science and technology, there are new types of forest fire monitoring means. In January 2025, Li Xuguang proposed the use of infrared thermal imaging, multi-spectral remote sensing, and other means to detect forest fires [3].In February 2025, Cao Kongfei proposed the use of drones and artificial intelligence technology to detect the occurrence of forest fires in real time and apply it to forest fire suppression[4].

The emergence of these new technologies undoubtedly provides more efficient and accurate solutions for forest fire prevention[5]. However, in forest fire prevention, most of the technologies focus on the detection of forest fires, and there is no prominent and significant means in the prediction and early warning of forest fires. Therefore, this study is based on optical remote sensing (ORS), which is a non-contact observation method based on the reflection and absorption properties of electromagnetic waves and is capable of obtaining ground information from the air in real time for a wide range of areas in terms of reflected or radiated information [6]. And by analyzing the spectral characteristics of forest vegetation, especially the water content of vegetation, it can provide important clues for fire risk assessment. The moisture content of vegetation is an important indicator of the flammability of vegetation fires, and vegetation with lower moisture content is more likely to burn and the probability of fires increases as a result [7]. Therefore, the monitoring of the moisture content of forest vegetation based on optical remote sensing technology can predict the occurrence of forest fires to a certain extent, and provide relevant data support for the fire risk early warning system.

Against the above research background, this study aims to assess the moisture content of forest vegetation through spectral analysis of remote sensing technology and to further establish a comprehensive assessment model for the probability of forest fires. Through this model, early warning of forest fires can be realised, providing brand-new technical support for fire prevention, thus reducing the risk of forest fires to a greater extent and reducing the disasters and losses caused by forest fires.

2. Data and methodology

2.1 Overview of the study area

The study area selected for this paper is located in the forest area of Xichang City, Liangshan Prefecture, Sichuan Province, with the geographical location shown in Fig. 1. There was a forest fire in this area on 30 March 2020, with an overfire area of about 1,000 ha and 80 ha of burnt forest. The fire site was near LPG storage and distribution stations, petrol stations, schools and cultural relics units (e.g., Guangfu Temple, Museum of Slave Societies) in the Qionghai Lushan scenic area. The forest fire in the rescue process due to sudden changes in the wind direction of the fire, a steep increase in wind, flying fire breaks the road, and self-help failure, resulting in 19 people involved in the fire fighting sacrificed, 3 people were injured. It resulted in a total area of 3047.7805 hectares of various types of land overfires, a combined area of 791.6 hectares of affected forest, and a direct economic loss of 97,312,000 yuan.

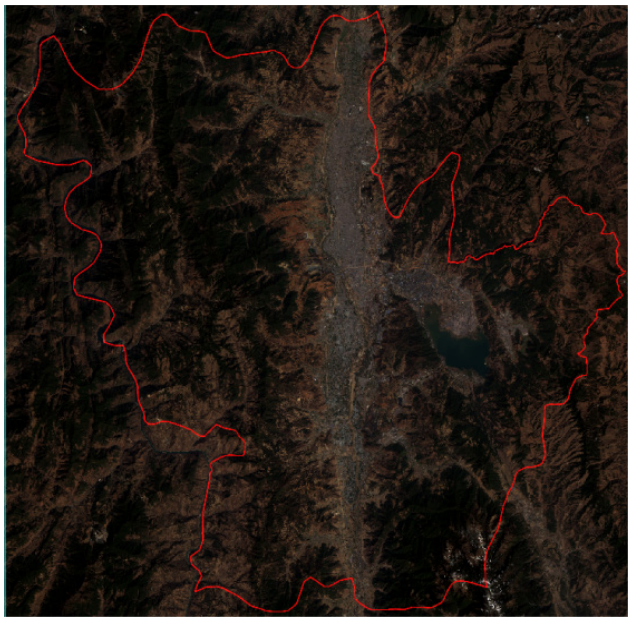

Fig. 1 Map of Xichang City, Liangshan Prefecture, Sichuan Province

The vegetation in the area is dominated by Yunnan pine forest areas with high turpentine content and high com-

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bustibility. The region belongs to the subtropical monsoon climate zone, dry and hot river valley climate, dry season (January-June) high temperature and little rain, the total annual rainfall is maintained at an average of about 800-1000mm, the average annual temperature is 17.2 degrees Celsius, belongs to the dry climate, the effect of incendiary winds is significant, prone to lightning fires, and by the influence of combustibility of the factors, the region is very prone to man-made accidental fires [8, 9]. Therefore, it is particularly important to improve the fire prevention system in this area.

2.2 Data acquisition

2.2.1 Satellite imagery data

Landsat 8 satellite data, currently the most commonly used in the series, was developed by the National Aeronautics and Space Administration (NASA) in cooperation with the United States Geological Survey (USGS), launched successfully on 11 February 2013 and is currently operating well. It has an altitude of 705 kilometers, an orbital inclination of 98.2 degrees, a revisit period of 16 days, and carries both the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI consists of eight bands with a spatial resolution of 30 m and one panchromatic band with a resolution of 15 m and an imaging width of 185x185 km ; the TIRS consists of two separate thermal infrared bands with a resolution of 100 m. The OLI is a spatial imaging system with a spatial resolution of 30 m and a resolution of 15 m.

In this experiment, the image data of Landsat8 of the study area in the March 2020 phase, the image data of lansat8 in the March 2018 phase, and the image data of lansat8 in March 2016 phase were acquired through the official website of Geospatial Data Cloud, and the data were analyzed and processed in the following experiments. The corresponding vegetation water content was also evaluated by calculating the parameters. The data of March 2020 in the data is just before the Xichang forest fire on 30 March 2020, and this set of data will be strongly correlated with the occurrence of forest fires.

2.3 Data processing

2.3.1 Satellite image data processing

The software tools used in this experiment for satellite image data pre-processing are ENVI5.6 and ArcGIS software.

In the experiment, the data downloaded from the Geospatial Data Cloud website were imported into the ENVI software, and the three sets of overall image data of different periods were pre-processed by Radiometric Calibration and atmospheric correction modules in the ENVI software, and the processed satellite images were cropped by ArcGIS software through the map of Xichang City downloaded from the AliCloud data visualization platform datavision website. The processed satellite images were cropped from the map of Xichang City downloaded from the website of ArcGIS software.

After processing, the Normalised Difference Vegetation Index (NDVI) value of the image is calculated using the ENVI software band math tool according to the formula. The NDVI calculation formula is

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{red}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{red}}} \quad (1)$$

Finally, the calculated NDVI values were combined with the ArcMap module of ArcGIS software to extract the vegetation in Xichang City and produce the vegetation extraction map of Xichang City.

2.3.2 Study regional vegetation data processing

According to the vegetation extraction map of Xichang City, suitable and uniformly distributed vegetation was identified as the roi interval of interest for the experiment, and finally, the NDVI and Normalised difference infrared index (NDII) values of the images were calculated and extracted by using the band math tool in the ENVI software again, and the calculation formulae are as follows.

$$\mathrm{NDII} = \frac{\rho_{\mathrm{NIR}} - \rho_{SWIR_1}}{\rho_{\mathrm{NIR}} + \rho_{SWIR_1}} \quad (2)$$

3. Experimental result

3.1 Satellite image data results

The results obtained after the preprocessing of three groups of image data at different times by ENVI software are shown in Fig. 2. Observing the three groups of pre-processed images in 2016, 2018 and 2020, it can be judged that there is no great change in the forest area of Xichang City in this experimental study area, which is usable data and will not interfere with the experiment.

(a) Image from March 2020

(b) Image from March 2018

(c) Image from March 2016

Fig. 2 Pre-processed image

After calculating the NDVI values in the image data, the results of the vegetation extraction map for Xichang City are shown in Fig. 3. From the results of vegetation extraction in the figure, it can be seen that the vegetation distribution is more uniform in the northwest region and southeast region of Xichang City, while other regions are unevenly distributed due to the influence of human development factors, in order to the accuracy of the experimental data, the experiments will be selected as a uniform distribution of vegetation in the area of interest ROI region of the experiments in Fig. 3 blue area. Considering that the forest area in the southeast region is very close to the area of the forest fire on 30 March 2020 in Xichang City, which is closer to the experimental expectation, the final roi area of interest is determined as in Fig. 3.

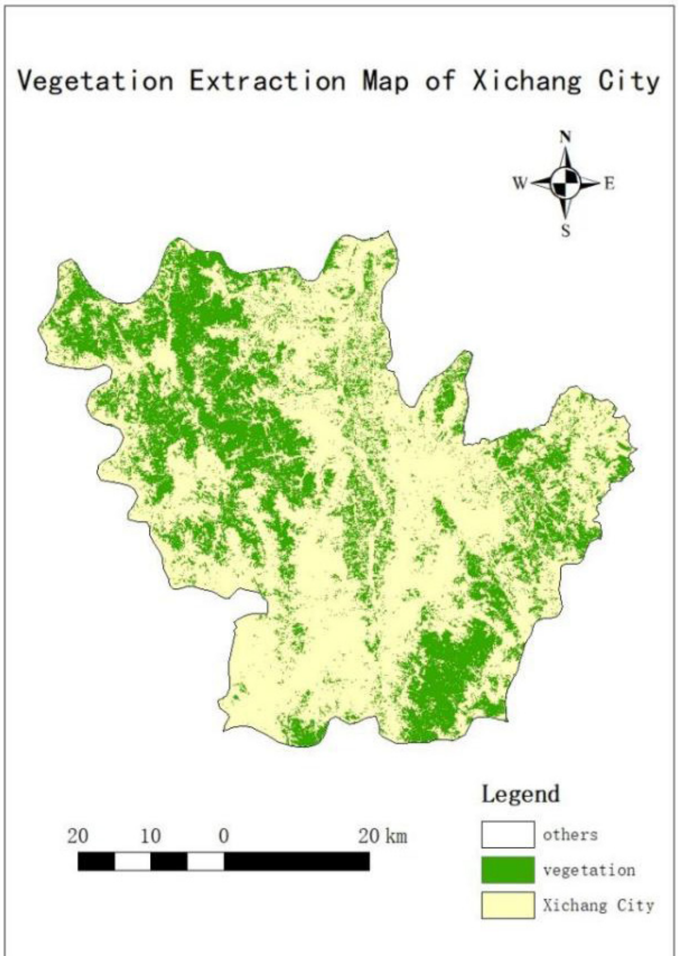

Fig. 3 Vegetation extraction map of Xichang city

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3.2 Vegetation area data results

3.2.1 NDVI values analysis

The results of the NDVI and NDII values of the vegetation areas in Xichang City for the three data sets of March 2020, March 2018, and March 2016 obtained in the experiment are shown in Table 1, Table 2, and Table 3 through the formulae. The obtained data contain the mean, maximum, and minimum values of NDII and NDVI values in the roi interval of interest, as well as the variance of the calculated data.

Table 1. NDVI and NDII values of vegetation areas in Xichang city in 2020

	minimum	maximum	mean	variance
NDVI	-0.0877	0.6828	0.4593	0.1124
NDII	-0.8486	-0.4783	-0.7770	0.0606

Table 2. NDVI and NDII values of vegetation areas in Xichang city in 2018

	minimum	maximum	mean	variance
NDVI	-0.1599	0.6535	0.4517	0.1019
NDII	0.4861	0.8600	0.7814	0.0487

Table 3. NDVI and NDII values of vegetation areas in Xichang city in 2016

	minimum	maximum	mean	variance
NDVI	-0.1028	0.3181	0.1752	0.0570
NDII	0.0323	0.4927	0.2917	0.0684

Observation of the data results, the table data in 2016, 2018 and 2020 NDVI value data size are in the -1 ~ 1 normal range, and the three groups of data NDVI value mean value is similar, respectively, 0.4593, 0.4517 and 0.1752, the difference is not more than 0.3, which indicates that the experiment for the Xichang City forest area of interest ROI area. This indicates that the vegetation in the forest area of interest in Xichang City did not change significantly from March 2016 to March 2020, and this result excludes the possibility of errors brought about by changes in geographic environmental factors, ensuring the accuracy of the experimental data and the stability of the experimental results.

3.2.2 Moisture content analysis and flammability assessment

Since NDII has a strong positive correlation with vegetation water content and is the preferred index for moisture monitoring, vegetation water content can be assessed based on the NDII values of local vegetation to determine the flammability of local vegetation and the probability of forest fires when they occur.

By comparing the NDII values of the three groups of data in Tables 1-3, it can be found that the average NDII value in March 2020 is -0.7770, which is much smaller than the average NDII value of 0.7814 in March 2018 and 0.2917 in March 2016. This experimental result indicates that the average water content of forest vegetation and other combustible materials in the experimental area in March 2020 is much lower than the average moisture content of forest vegetation and other combustible materials in March 2016 and March 2018, which coincides with the actual situation of forest fires in Xichang City on 30 March 2020, and this result also proves that the reduction of the average moisture content has a strong correlation with the probability of forest fires.

The minimum NDII value in March 2020 also reached a very low value of -0.8486, indicating that the vegetation at this location has the lowest water content and is most likely to be one of the possible ignition points for the 30 March 2020 forest fire in Xichang.

By analysing the experimental results, it can be judged that the water content of the vegetation in Xichang City in March 2020 is much smaller than that in March 2018 as well as in March 2016, and that the vegetation is highly combustible, with a high probability of forest fires.

4. Discussion

According to the experimental data, the mean values of

NDVI in the vegetation area of Xichang City in March 2016, 2018 and 2020 were 0.1752, 0.4517 and 0.4593, respectively. Although there were inter-annual fluctuations in the values from 2016 to 2018, the combination of Xichang City's weather factors caused by the abnormal changes in the change of the values and the difference between the values is not more than 0.3, and at the same time, the three sets of data are consistent with the NDVI theoretical value range (-1~1), and the data as a whole and the variance did not show significant anomalies. This result shows the stability of vegetation cover in the experimental study area, and the low volatility of the NDVI data without systematic shift indicates that no large-scale degradation of vegetation cover or land use change has occurred in the study area, which verifies that the influence of geographic changes in the study area on the experimental results is negligible, and is in line with the description of the stability of broadleaf evergreen forest cover in the southwestern region in the 'Report on China's Forest Resources'.

The mean value of NDII in the study area in March 2020 was -0.7770, which showed a significant negative shift from 2016 (0.2917) and 2018 (0.7814). Since NDII is linearly and positively correlated with vegetation water content, this indicates that the regional vegetation water content in March 2020 dropped to the lowest value in the three-year observation period, which is about 35 to 48 per cent lower than the previous two years, suggesting a very high risk of combustibility.

In addition, this paper is based on the maximum value, minimum value and average value of NDII value of the study area in March 2020 as three different thresholds to be able to establish a three-level warning system[10]. This paper concludes that when the NDII value is lower than the maximum value of NDII in the vegetation area of Xichang City in March 2020 -0.478, there is a certain probability of forest fire occurrence, and a three-level forest fire warning can be carried out; when the NDII value is lower than the average value of NDII in the vegetation area of Xichang City in March 2020 -0.7770, a two-level forest fire warning can be carried out; when the NDII value is lower than the When the NDII value is lower than the minimum value of NDII in the vegetation area of Xichang City in March 2020 -0.8486, the probability of forest fire is very high, and the first-grade forest fire warning is carried out. According to the three different forest fire warning thresholds, a forest fire warning model can be established.

5. Conclusion

Through this study, the vegetation in the forest area of Xichang City, Liangshan Prefecture, Sichuan Province was monitored and analysed in relation to this study. The results showed that vegetation water content was significantly and negatively correlated with the risk of forest fires, and the probability of fires would be very high when the vegetation water content to NDII value was lower than -0.8486. For the study area, especially in the hot and dry seasons, the water content of vegetation tends to be lower, which makes the forest fire risk level increase as a whole, which undoubtedly proves that the water content of vegetation is one of the key indicators in the assessment of forest fire risk.

Overall, vegetation water content, as an important indicator for forest fire prevention and detection, has a broad application prospect in enhancing human's aspect of forest fire prevention . However, there are some obvious limitations in this study, for example, the data source used in this experiment is Landsat8 satellite, as a space remote sensing satellite, the impact data provided by this satellite has a certain time lag, and it is not possible to do real-time monitoring, and it is not possible to provide even data feedback, which will undoubtedly make the detection and early warning system does have a certain timeliness.

This paper puts forward some ideas for this problem. In the future, it may be possible to replace the data source from aerospace satellites with time lag to airborne remote sensing with immediacy, and portable drones to carry optical remote sensing to observe specific areas, which can solve the defects of data provided by aerospace remote sensing satellites that do not have immediacy. In addition, the performance and functions of remote sensing should be continuously optimised and enhanced on a larger spatial and temporal scale to continuously improve the forest fire risk assessment system.

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