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The drought monitoring cased on TVDI model: A case study of Luxi, Yunnan Province, Southwestern China

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Abstract

Drought is a very complex natural disaster caused by regional water budget or imbalance between supply and demand. Due to the unique geographical environment and climate characteristics, Yunnan plateau always break the drought disasters. Monitoring is the key to simulating, warning, pretecting and reducting the disaster. In this study, the Ts-NDVI feature of Luxi County was established by the data of normalized vegetation index (NDVI) and temperature of land surface (Ts) based on the Landsat 8. Meanwhile, based on the resluts of space feature, temperature vegetation drought index (TVDI) calculated as an index parameter. Furtheremore, combined with the information of meteorology and the DEM data of land using types, the drought conditions were verified. The results show that: (1) As a widely recognized drought index, the TVDI is highly feasible to monitor the drought situation in Luxi County; (2) The results of Ts-NDVI and TVDI are shown by using remote sensing image data in the study area in 2013 and 2018. Using Landsat 8 remote sensing image data in 2013 and 2018 to calculate and construct Ts-NDVI feature and TVDI, the results show that the study can be divided into five drought grades: wet, normal, light drought, drought and heavy drought; (3) As time goes on, the drought has been reduced from 2013 to 2018; The proportion of severe drought declined during the study period, especially in the central and northern areas of the county. Except for the continuing severe drought in the southern region, the rest of the region has been alleviated. Normal and light drought increased greatly, mostly in the northern region, and wet areas mostly in the central region.

Keywords

Temperature of land surface (Ts); Temperature vegetation drought index (TVDI); normalized vegetation index (NDVI); Ts-NDVI feature.

1. Introduction

Drought is one of the most serious climate disasters which affected the human society and caused the dramatic economic losses with the characteristics of high frequency, long duration and wide spread. With the development of sensing monitoring methods, drought monitoring had required real-time, large-scale, dynamic and objective. Now, crop water supply index method, temperature and vegetation drought index method, thermal inertia method and vegetation status index method have emerged. Sandholt had proposed TVDI model based on the relationship between vegetation index

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and surface temperature and has been widely used in China[1,2]. Now, it has become the main models of drought remote sensing monitoring.

Yunnan Province which is located in the southwestern of China and belongs to the low latitude plateau monsoon climate area has caused frequent natural disasters affected by instability of the southwest and Southeast monsoon. Especially drought, accounting for 43.1% of the meteorological disasters in Yunnan Province. The precipitation in the dry season is only 16.1% of the annual precipitation, and the frequency of annual drought is 50%~60%. In recent years, the trend of further intensification has been observed.

In order to reflect the scope and extent of drought occurrence in time and accurately, predict the future development trend of the region, and take active and effective prevention measures in the future. This paper intends to use Landsat8 data to retrieve the temperature and TVDI date of Luxi to analyze the spatial and temporal distribution and change of drought in the region from 2013 to 2018.

2. Study Method

2.1 Research area

Luxi (24°15′-24°26′ N, 103°30′-104°04′ E) is located in the southeast of Yunnan Province, besided the south of Nanpanjiang River with the highest altitude of 2459.3 m and the lowest altitude of 821m (Figure 1). The topography of the area is complex, and there are five climatic types vertically distributed in the south subtropical zone, the middle subtropical zone, the north subtropical zone, the south temperate zone and the middle temperate zone. The three-dimensional climatic types of the subtropical zone and the temperate zone coexist. The average annual temperature is 15.2 ℃, the average annual sunshine is 2122 hrs, the average annual rainfall is 979 mm, and the frost-free period is 272.7 days. Winter (dry season) is mainly controlled by westerly circulation, with less cloudiness, sufficient sunshine, less rainfall, and high wind speed. It is often affected by polar cold air mass and southeastern regression airflow. Summer (rainy season) is mainly controlled by the southwest wet airflow from the Bay of Bengal in the Indian Ocean. There is abundant water vapor, which forms a large amount of rainfall and has a large annual temperature difference.

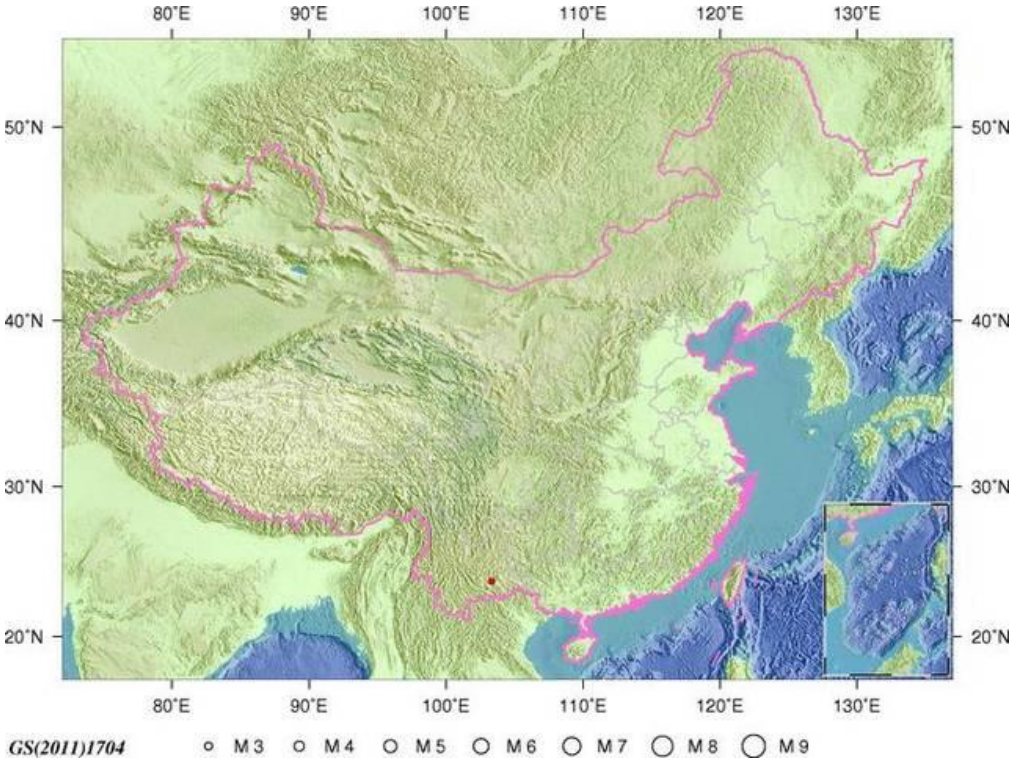

Fig. 1 Location of Luxi

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2.2 Data sources

Landsat 8 OLI remote sensing images were selected for two scenes, all of which lasted from April to June. The map projection was UTM projection and the Earth ellipsoid was WGS-84 (Table 1).

Table 1 Data Source of Luxi County

Data	Ribbon	Cloudiness
2013/5/22	129	0.96
2013/6/14	130	0.39
2018/5/03	130	1.64
2018/5/28	129	0.13

The Sensor type is Landsat 8 OLI, and sources is USGS, and the resolving is 30m.

2.3 Research area

2.3.1 Normalized vegetation index (NDVI)

Normalized vegetation index (NDVI) is a remote sensing parameter used to monitor vegetation growth and vegetation spatial coverage. The larger the NDVI value, the better the vegetation condition. In the Formula 1, NIR is the reflection value in near infrared band and R is the reflection value in red band.

$$NDVI = (NIR-R) / (NIR+R) \quad (1)$$

2.3.2 Inversion of surface temperature

There are mainly three kinds of inversion algorithms of surface temperature in the world: atmospheric correction method (also known as radiation transfer equation), single channel algorithm and split window algorithm. This paper uses Landsat 8 TIRS to retrieve surface temperature based on atmospheric correction method. The expression of thermal infrared radiation brightness is (radiation transfer equation):

$$L\lambda = [\varepsilon B(TS) + (1-\varepsilon)L\downarrow]\tau + L\uparrow \quad (2)$$

where ε is the surface specific emissivity, TS is the real surface temperature (K), B (TS) is the blackbody thermal radiance, and τ is the atmospheric transmittance in the thermal infrared band. The radiation brightness B (TS) of the blackbody with temperature T in the thermal infrared band is as follows:

$$B(TS) = [L\lambda - L\uparrow - \tau(1-\varepsilon)L\downarrow]/\tau\varepsilon \quad (3)$$

TS can be obtained by the function of Planck's formula, which is as follows:

$$TS = K_2/\ln(K_1/ B(TS)+ 1) \quad (4)$$

where for TM, K_1 = 607.76 W / (m2 * m * sr), K_2 = 1260.56K; For ETM+, K_1 = 666.09 W / (m2*m*sr), K_2 = 1282.71K; For TIRS Band10, K_1 = 774.89 W / (m2*m*sr), K_2 = 1321.08K. In this paper, K_1=774.89 W / (m2*m*sr), K_2=1321.08K. Temperature Vegetation Dryness Index

2.3.3 Temperature Vegetation Dryness Index (TVDI)

Temperature Vegetation Drought index (TVDI) is a method of retrieving surface soil moisture in vegetation coverage area based on optical and thermal infrared remote sensing channel data. The slope between them was negatively correlated with crop moisture index. Therefore, temperature was proposed. The concept of Vegetation Drought index. TVDI is calculated by vegetation index and surface temperature. Based on the relationship between vegetation index and surface temperature, a temperature vegetation drought index is proposed:

$$TVDI= (Ts-Tsmin) / (Tsmax-Tsmin) \quad (5)$$

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where Tsmin = a + b * NDVI wet edge equation; Tsmax = c + d * NDVI dry edge equation; TVDI range is [0,1]. The higher TVDI, the lower soil moisture, the smaller TVDI, the higher soil moisture. According to the definition of TVDI, when TVDI is 0, the soil moisture is close to the normal wet soil. When TVDI is equal to 1, the soil moisture is close to the withering water content. The closer TVDI is to 1, indicating that the soil is dry and water-deficient.

3. Result

The vegetation coverage of Luxi County increased significantly from north to south, especially from 2013 to 2018 (Figure 2). This may be due to the global warming in recent years, the increase of extreme weather events, and the intensification of El Nino phenomenon. Under this abnormal climate change, the plateau topography in Yunnan has blocked the airflow by mountains, and the extremely low air moisture content has prevented the monsoon from landing to form rainfall. At the same time, the polykarst landform in Yunnan Province, Luxi, has a world-famous karst cave, Alu ancient cave, with complex geological structure, low utilization rate of water resources and obvious infiltration.

It is difficult for surface vegetation to play a role in water conservation. The high value in 2018 indicates that the vegetation coverage is obviously higher than that in 2013. Combining with the land use classification map of Luxi County, it can be seen that most of the vegetation coverage increases significantly belong to cultivated land and bare land, which indicates that with the increase of precipitation, vegetation and crops begin to grow (Figure 3).

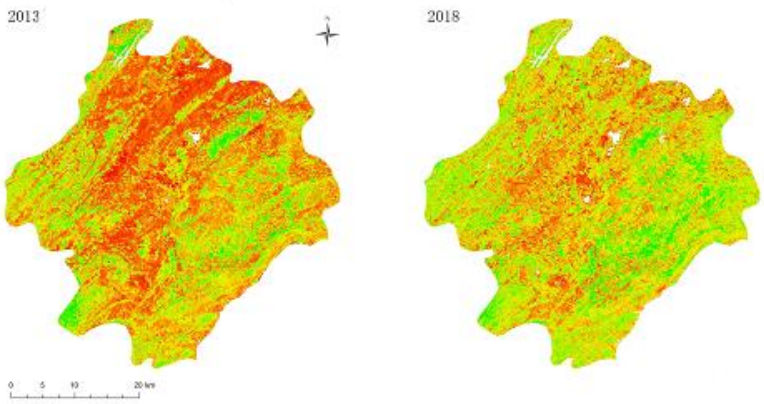

Fig. 2 The map of Normalized Vegetation Index of Luxi in 2013 and 2018 (Red represents 1 of the NVDI value and Green represents 0)

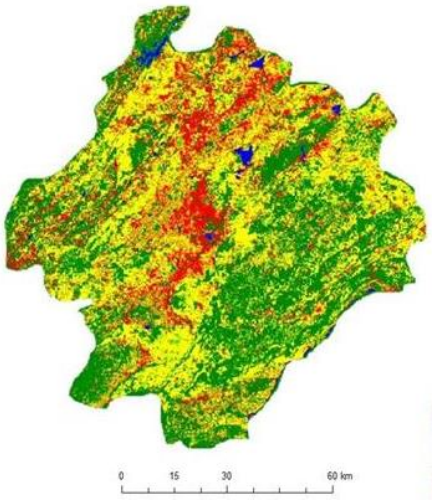

Fig. 3 Classification map of land use types of Luxi (Red represents construction land; Bule represents cloud area; Yellow represents field and Green represents the forest)

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According to Fig. 5, it can be found that the temperature in the central part of the county town, the north and the northeast of the county decreased significantly from 13 to 18 years, which is consistent with NDVI data. Because of the increase of vegetation coverage, the surface temperature decreased.

Agricultural drought generally considers that the soil moisture content of 0-20 cm is less than 40% of field capacity, less than 50% is moderate drought, less than 60% is light drought, 60%-80% is normal, and more than 80% is wet [11]. According to the classification of drought grade [12-14], combined with the factors of climate and season in the study area, Luxi County is classified into five categories: wet (0-0.2), normal (0.2-0.4), light drought (0.4-0.6), drought (0.6-0.8), heavy drought (0.8-1), as shown in Table 2.

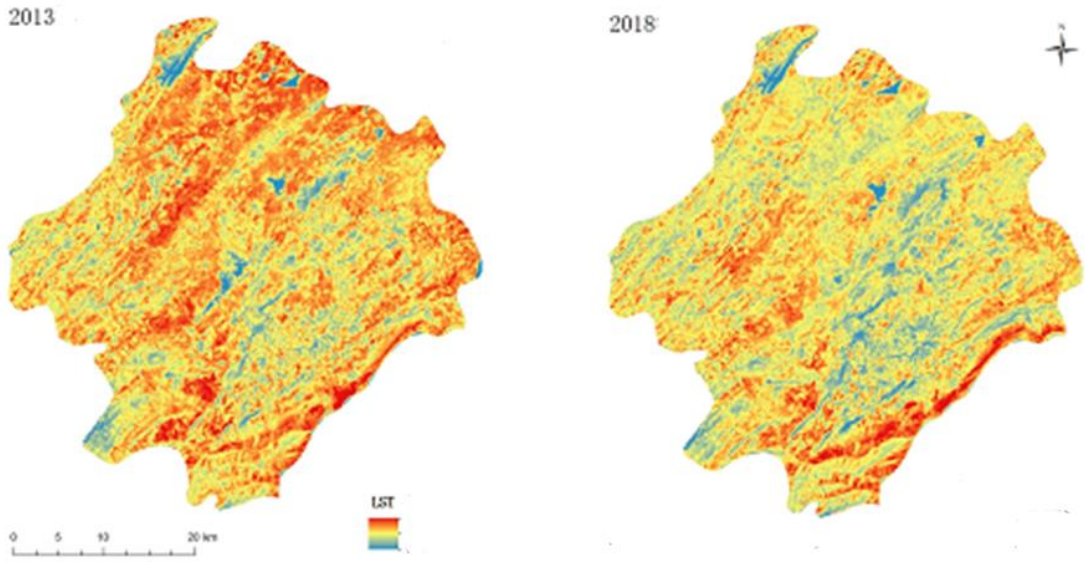

Fig. 4 Surface temperature map of Luxi in 2013 and 201

As can be seen from Figure 5, there was a large area of drought in Luxi, the southern part was the most serious and the northern and central parts were all seriously drought. Until 2018, the drought situation improved significantly, and only the eastern part of the county was still in a severe drought state, especially the drought situation in the central and eastern parts was basically wet. The proportion of severe drought decreased from 5.04% in 2013 to 2.6%. The wet state increased slightly from 1.15% to 2.34%, and the normal and light drought state increased from 8.1% to 25.9%, 35.3% to 50.5%, respectively. It has been proved that the drought situation in Luxi County has improved significantly from 2013 to 2018.

Table 2 Classification of drought grades

TDVI	Drought grades	2013	2018
0 ＜TVDI＜0.2	Moist	1.2%	2.3%
0.2 ＜TVDI＜0.4	Normal	8.1%	26.0%
0.4 ＜TVDI＜0.6	Light drought	35.3%	50.5%
0.6＜TVDI＜0.8	Drought	47.8%	18.7%
0.8 ＜TVDI＜1	Severe drought	5.1%	2.6%

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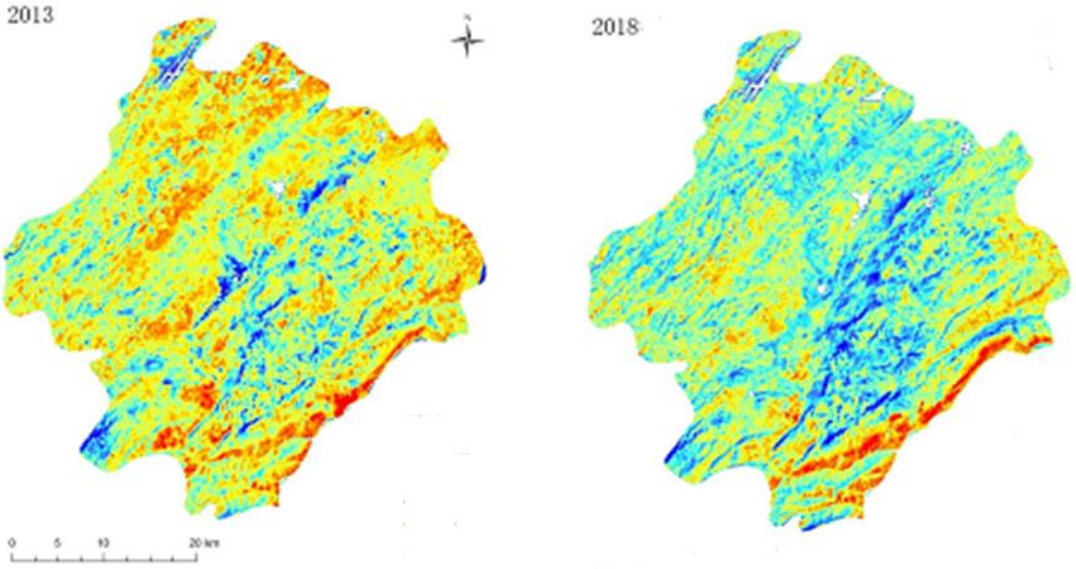

Fig. 5 TDVI map of of Luxi in 2013 and 2018 (Red represents severe drought; Bule represents moist; Yellow represents drought; Cyan represents light drought and Green represents the normal)

4. Conclusion

According to the above analysis results, as a widely recognized drought index, Temperature Vegetation Drought Index (TVDI) effectively avoids the shortcomings caused by a single layer when monitoring drought. Due to the limitation of the distribution density and labor cost of the ground station, the traditional site monitoring method is difficult to reflect the drought condition of the accurate large-scale continuous space in real time. The monitoring speed is slow, and the single point data is difficult to represent large areas. This model is very feasible to monitor the drought situation in Luxi. The characteristic space is calculated by using Landsat8 remote sensing image data in 2013 and 2018.

The results of temperature and Vegetation Drought index showed that the study area was divided into five drought grades: wet, normal, light, drought and heavy drought. In terms of time, with the passage of time, the drought eased from 2013 to 2018; in terms of space, the proportion of heavy drought in the study period decreased, especially in the central and northern areas of the county. Except for the continuing severe drought in the southern region, the rest of the region has been alleviated. Normal and light drought increased greatly, mostly in the northern region, and wet areas mostly in the central region.

TVDI model inverted by remote sensing can well characterize the change of soil moisture and has strong drought response ability. Based on the data collected in 2013 and 2018, the drought situation in Luxi County of Yunnan Province in recent years has been obtained, which can provide basic data for active and effective drought prevention and drought relief measures and production and life in the future, so that drought relief work can be more targeted.

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