Postprint: Remote Sensing Monitoring of Drought Severity Grades in Northern Tibet Based on MODIS TVDI and Fuzzy Mathematical Methods

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Abstract

To achieve dynamic and continuous monitoring of spring and summer drought conditions across the northern Tibetan region, a remote sensing-based drought classification standard was established using the Temperature Vegetation Dryness Index (TVDI) and fuzzy mathematics methods, with the study period spanning 1980–2017. MODIS product data were first utilized to calculate TVDI. Based on meteorological drought grade monitoring results, a drought grade classification standard based on MODIS TVDI was then established using fuzzy mathematics methods, and the monitoring results were validated for accuracy. Finally, the spatiotemporal variation characteristics of drought conditions in northern Tibet in recent years were analyzed. The main conclusions are as follows: 1. The Temperature Vegetation Dryness Index TVDIN and TVDIE, calculated based on the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) respectively, both achieved significant correlation with measured soil moisture content at 20 cm depth at the 0.05 level, with TVDIE exhibiting a higher coefficient of determination. 2. Based on TVDIE, drought conditions were classified into five grades: no drought, light drought, moderate drought, severe drought, and extreme drought. The drought grades obtained for northern Tibet according to this standard were generally consistent with meteorological drought grade monitoring results. 3. In recent years, drought conditions in northern Tibet have been generally not severe and have shown an overall alleviating trend. Among these years, 2009 was the most severe, with the area experiencing moderate drought or higher reaching 24% of the region. Within the year, drought conditions were most severe in June. Regarding the spatial distribution characteristics of drought conditions, the southwestern and central parts of the study area experienced relatively severe drought, while the northern and southeastern parts were relatively milder. The research find-

ings can provide data support for drought monitoring in northern Tibet, and the method for classifying remote sensing-based drought grades can serve as a reference for drought studies in other regions.

Full Text

MODIS TVDI-Based Drought Monitoring in North Tibet Using Fuzzy Mathematics

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Abstract:

A dynamic and continuous monitoring of spring and summer drought in north Tibet during the period of 1980–2017 was carried out. The Temperature Vegetation Drought Index (TVDI), fuzzy mathematics, and monitored results of meteorological drought level were used to develop the classification standard of remote sensing drought, and the accuracy of monitored results was verified. The spatiotemporal variation of drought in north Tibet in recent years was analyzed. The main conclusions are as follows: (1) TVDI and TVDI calculated based on the normalized vegetation index (NDVI) and enhanced vegetation index (EVI) were significantly correlated with the soil moisture content at 20 cm depth at the 0.05 significance level, with TVDI showing a higher determination coefficient; (2) Based on TVDI , drought could be divided into five levels including no drought, slight drought, moderate drought, heavy drought, and severe drought, which was consistent with the monitored results of meteorological drought level; (3) Drought in the study area was not very serious in recent years, and the holistic drought situation was somewhat alleviative. The drought was the most serious in 2009, with the area proportion of moderate and above drought reaching as high as 24%. Monthly, the drought was most serious in June. In terms of spatial distribution, drought in the southwest and central parts of the study area was relatively serious, while it was relatively slight in the north and southeast. The research results could be referred to in monitoring drought in north Tibet.

Keywords: temperature vegetation drought index; fuzzy mathematics; drought level; MODIS; north Tibet

1 Data and Methods

1.1 Study Area

The study area is located in north Tibet, with geographical coordinates of 78°23 40 -95°10 46 E, 29°40 40 -35°42 55 N [FIGURE 1]. The average elevation exceeds 4500 m, with annual precipitation ranging from 247.3 to 513.6 mm. The climate is characterized by cold and arid conditions, with sparse vegetation cover. According to meteorological data, the primary land cover types include high-cold desert steppe, high-cold steppe, high-cold meadow steppe, and high-cold meadow.

1.2 Data Sources

MODIS data from 2002–2018 were used, specifically the MOD13A2 (NDVI and EVI) and MOD11A2 (Land Surface Temperature, LST) products, with spatial resolutions of 1 km and temporal resolutions of 16 days and 8 days, respectively. Data processing was conducted using NASA's MODIS Reprojection Tool (MRT) for format conversion, reprojection, and mosaicking. The Savitzky-Golay filter [17] was applied for noise reduction. Meteorological drought data from 2010-2017 were obtained from the Tibet Autonomous Region Climate Center, including drought levels classified according to the national standard "Meteorological Drought Grade" (GB/T 20481−2006).

1.3 Methods

1.3.1 TVDI Calculation TVDI is calculated based on the feature space formed by vegetation index and land surface temperature. The formula is:

$$TVDI = \frac{LST - LST_{min}}{LST_{max} - LST_{min}}$$

where LST_{min} and LST_{max} represent the minimum and maximum land surface temperatures corresponding to a given vegetation index, defining the wet and dry edges, respectively.

Both NDVI-LST and EVI-LST feature spaces were constructed. For validation, soil moisture content at 20 cm depth was used as the ground truth data. The correlation between TVDI and soil moisture was analyzed for the period 2002-2014. Drought levels were classified into five categories: no drought, slight drought, moderate drought, heavy drought, and severe drought.

The correlation matrix between TVDI and soil moisture is represented as:

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m0} & \cdots & r_{mn} \end{pmatrix}$$

where r_{mn} represents the correlation coefficient between TVDI and soil moisture at point (u_m, v_n).

The TVDI matrix is calculated as:

$$B = X \times R$$

where B represents the TVDI drought monitoring matrix, and X is the weight matrix of influencing factors.

1.3.2 Fuzzy Mathematics Classification Fuzzy mathematics was applied to establish membership functions for drought classification. Based on the national standard "Meteorological Drought Grade" (GB/T 20481−2006), the drought classification standard was developed with TVDI values corresponding to different drought levels. The 20 cm soil moisture content was used as the validation standard, with TVDI values showing significant correlation with soil moisture conditions.

The membership function for drought classification is defined as:

$$\mu(x) = \begin{cases} 0 & \text{if } x \leq a \\ \frac{x-a}{b-a} & \text{if } a < x < b \\ 1 & \text{if } x \geq b \end{cases}$$

where a and b are threshold values for different drought levels.

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2 Results

2.1 TVDI Feature Space and Drought Monitoring

The NDVI-LST and EVI-LST feature spaces for 2017 are shown in [FIGURE 2]. The characteristic triangular distribution indicates: (1) The dry edge shows a significant negative correlation between vegetation index and temperature; (2) The wet edge remains relatively stable across different vegetation conditions; (3) NDVI ranges from 0 to 0.8, while EVI ranges from 0 to 0.6; (4) EVI demonstrates better sensitivity than NDVI in high vegetation cover areas; (5) During March-May, LST and EVI show stable relationships, while June-August exhibit more complex patterns corresponding to different drought levels.

The drought classification set is defined as:

$V = \{\text{No drought, Slight drought, Moderate drought, Heavy drought, Severe drought}\}$

Based on TVDI , the classification standard was established with thresholds at 0.37, 0.55, 0.69, 0.83, and 1.0.

2.2 Validation and Accuracy Assessment

Validation using 20 cm soil moisture data from 2015–2016 showed that TVDI had higher accuracy than TVDI . The coefficient of determination reached 0.85–0.89, with overall classification accuracy exceeding 95% for drought levels. The confusion matrix analysis indicated that the fuzzy mathematics approach improved classification precision by 16.32% and 12.51% for moderate and severe drought categories, respectively.

2.3 Spatiotemporal Variation of Drought

From 2002–2017, the frequency of moderate and above drought levels showed significant interannual variation [FIGURE 7]. The year 2009 experienced the most severe drought, with moderate and above drought covering 40.8% of the region during June–August [FIGURE 8]. The drought severity followed the order: 2009 > 2010 > 2013 > 2015 > 2017.

Spatially, drought was more severe in the southwest and central regions, while the northern and southeastern areas experienced relatively milder conditions. The seasonal analysis revealed that June was the most drought-prone month, coinciding with the peak growing season and higher water demand.

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3 Discussion and Conclusion

(1) Both TVDI and TVDI showed significant correlation with 20 cm soil moisture content, with TVDI demonstrating superior performance. The fuzzy mathematics classification method effectively improved drought monitoring accuracy.

(2) The established drought classification standard based on TVDI is consistent with meteorological drought monitoring results, providing a reliable method for operational drought monitoring in north Tibet.

(3) Recent drought conditions in north Tibet have been relatively moderate, with 2009 being an exceptional year of severe drought. The spatial pattern shows higher drought risk in southwestern and central regions, which should be prioritized for drought mitigation efforts.

The research results provide a scientific basis for drought monitoring and early warning systems in the high-altitude, cold regions of Tibet.

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Note: Figure translations are in progress. See original paper for figures.