Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 11, No. 2, 2026
www.scholink.org/ojs/index.php/se

Original Paper

Spatiotemporal Characteristics and Driving Factors of Drought in the Pearl River Basin Based on Temperature Vegetation Dryness Index

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Received: February 01, 2026 Accepted: March 22, 2026 Online Published: April 2, 2026

doi:10.22158/se.v12n1p171 URL: http://dx.doi.org/10.22158/se.v12n1p171

Abstract

Using the temperature vegetation dryness index (TVDI), Sen's slope estimation, and the Mann-Kendall test, this study analyzed the spatiotemporal characteristics and trends of drought in the Pearl River Basin from 2001 to 2023, and examined the influences of temperature and precipitation on TVDI. The results indicated that the average TVDI over the study period was 0.6607, with a standard deviation of 0.0186, reflecting a general state of moderate drought and a significant downward trend in drought severity. On average, the proportions of areas with no drought, light drought, moderate drought, severe drought, and extreme drought were 1.09%, 11.36%, 78.85%, 8.33%, and 0.37%, respectively. Over the past 23 years, drought severity has generally increased from north to south. Extreme drought was concentrated in the southern Leizhou Peninsula (Guangdong), while severe drought mainly occurred in the Leizhou Peninsula, the Pearl River Estuary, and parts of eastern Guangdong (Jieyang, Chaozhou, Huizhou), as well as Nanning, Baise, and Qinzhou in Guangxi province. Gejiu City in Yunnan also experienced frequently severe droughts. In contrast, lower TVDI values were primarily found in southeastern Guizhou, northeastern Guangxi, and northwestern Guangdong. Drought severity in the eastern Pearl River Basin exhibited a worsening trend, whereas conditions in the west tended to improve. Approximately 70% of the basin showed a gradual decline in drought intensity. At a 0.05 significance level, significant drying was noteworthy in the Pearl River Delta, eastern Leizhou

Peninsula, northern Guangdong, Jieyang (Chaozhou), and eastern Yunnan. In contrast, significant drought alleviation occurred in Qinzhou, Fangchenggang, and Baise (Guangxi), the border region of Yunnan–Guangxi–Guizhou, as well as Yangjiang, Maoming, eastern Meizhou, Shanwei, and Huizhou in Guangdong province. Regionally, TVDI was significantly and negatively correlated with air temperature, suggesting that rising temperatures contributed to drought alleviation. Overall, both temperature and precipitation showed negative effects on drought severity. TVDI was negatively correlated with precipitation across all land use types, and the strongest correlation was identified in grasslands. Except for forest land, TVDI in other land use types exhibited weak correlations with air temperature.

Keywords

TVDI, Sen's slope estimation, Mann-Kendall test, Partial correlation analysis

The increasing frequency of extreme climate events has exerted profound influences on human societies (EASTERLING, MEEHL, PARMESAN et al., 2000; Gan et al., 2010). Among them, drought represents a particularly severe natural disaster due to its wide geographical extent and prolonged duration (Han et al., 2014; He, Baiyun, & Zhang, 2015). In particular, under the influences of global warming and human production and activities, frequent and long-term droughts have severely damaged ecosystem services, directly or indirectly caused a series of ecological, environmental, and economic challenges, such as water resource shortage, land degradation, desertification and crop reduction (Cheng et al., 2022; Jiang et al., 2010), and seriously restricted the sustainable development of society.

Temperature vegetation dryness index (TVDI) is a drought monitoring method that integrates thermal infrared and optical remote sensing, possessing advantages of simple calculation and high adaptability (Cheng et al., 2022). Domestic and foreign scholars have remarkably concentrated on drought research through TVDI. For instance, Jiang et al. (2010) conducted a quantitative study on the TVDI index using field observation data from Heilongjiang province. Their findings confirmed a negative correlation between TVDI and soil moisture across different growth stages of dryland crops, indicating that TVDI effectively reflects soil moisture conditions in the study area. Wei (2018) verified the accuracy of TVDI by using the monthly soil moisture data obtained from meteorological stations, proving that TVDI could monitor drought conditions in the Pearl River Basin, followed by analyzing the spatial characteristics of drought in the Pearl River Basin from 2008 to 2012. Gao et al. (2018) used TVDI to conduct regression analysis and verification of soil moisture content. Their results revealed that TVDI values obtained from remote sensing image inversion showed a significant correlation with field-measured soil moisture, confirming the reliability of soil moisture estimates in the inversion region. Utilizing MODIS data products and the TVDI model, Wen (2014) assessed two major drought events in Sichuan Province (China), involving the summer drought of 2006 and the winter drought of 2009-2010. The analysis revealed that the 2009-2010 drought was primarily concentrated in the Pearl River Basin, with up to 70% of the area affected at its peak. Consequently, as a spatially coupled method integrating land surface temperature and vegetation index, TVDI has proven to be both effective and feasible in capturing drought characteristics.

The Pearl River Basin covers a vast area in southern and southwestern China, and it is characterized by complex geographical and environmental factors, including diverse landforms, hydroclimatic conditions, vegetation coverage, and soil type. Influenced by the monsoon climate, the basin is associated with highly uneven spatial and temporal precipitation patterns (Chen, 2020). In recent years, drought events have become more frequent and increasingly serious, with persistent dryness occurring during the autumn, winter, and spring of 2020-2021 (Qian & Lu, 2022). This has led to significant freshwater shortages in key regions such as the Pearl River Delta, Dongjiang River, and Hanjiang River, severely impacting industrial and agricultural production, the livelihoods of urban and rural populations, and the ecological environment (Du et al., 2022). Therefore, it is urgent to monitor and predict the occurrence and development of drought, and to implement scientifically informed countermeasures based on the characteristics of regional drought. Although numerous studies have employed the TVDI to investigate drought spatiotemporal dynamics in various regions, research concentrating on the Pearl River Basin, particularly over short time series, remains limited. In this study, Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) were derived from MOD11A2 and MOD13A1 remote sensing datasets, respectively, and TVDI was calculated using the LST-NDVI feature space. The spatiotemporal distribution and trends of TVDI in the Pearl River Basin from 2001 to 2023 were analyzed using Theil–Sen median slope estimation and the Mann–Kendall significance test. Furthermore, the relationship between TVDI and changes in temperature and precipitation was examined through correlation analysis, aiming to provide theoretical support for ecological and environmental protection and sustainable development in the Pearl River Basin.

1. Materials and methods

1.1 Overview of the Study Area

Located between 102°14 '-115°53' E and 21°31 '-26°49' N (Fig. 1), the Pearl River Basin covers a total area of 44.68×10^4 km^2, spanning six provinces in China, including Yunnan, Guangxi, Guizhou, Guangdong, Hunan, and Jiangxi. The basin covers four sub-basins: Dongjiang River, Xijiang River, Beijiang River, and Pearl River Delta. The research area was geographically defined by the Wuling Mountains to the north, the South China Sea to the south, the Yunnan–Guizhou Plateau to the west, and the alluvial plains of the Pearl River Delta to the southeast. The topography sloped from the elevated northwest to the lower southeast. The western part of the basin was dominated by the Yunnan–Guizhou Plateau, while the eastern portion featured the Pearl River Delta plain. The central region consisted of a complex mix of hills and basins, characterized by dense river networks, diverse soil types, and high vegetation coverage (Dai, 2005; Wang, Jiang, & Nie, 2022). Most of the regions were located in the subtropical monsoon climate zone, where the average annual temperature ranged from 14 to 22 °C and the average annual drop ranged from 660 to 2200 mm. Under the combined action of the monsoon climate and terrain, the precipitation gradually decreased (Wang et al., n.d.) from the east to the west, exhibiting remarkable seasonal variability, regional disparities, and interannual fluctuations. The summer monsoon arrives early, resulting in an extended flood season lasting from April to October, while winter precipitation remains minimal.

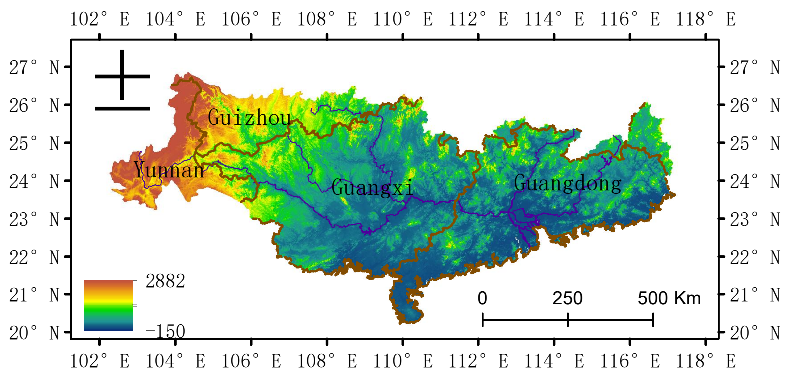

Figure 1. Distribution Map of the Pearl River Basin in the Study Area

1.2 Data Source and Processing

(1) Remote sensing data: The standard products of MODIS remote sensing data are MOD11A2 (land surface temperature) and MOD13A1 (vegetation index), among which MOD11A2 is an 8-day synthetic product data with a spatial resolution of 1 km. The dataset spanned from 2001 to 2023, covering 23 years. MOD11A2 provides 8-day composite LST data at a spatial resolution of 1 km, totaling 46 images per year and 2,116 images overall. MOD13A1 includes 16-day composite NDVI data with a spatial resolution of 500 m, totaling 23 images per year and 1,058 images in total. MODIS images were preprocessed using MRT and ENVI software, including projection, radiometric correction, mosaicking, and clipping. In ENVI, the 8-day LST data were aggregated into monthly LST values using the mean synthesis method, while the 16-day NDVI data were composited into monthly NDVI values using the maximum value composite method. In ENVI software, the 8-day LST data were composited into monthly LST data using the mean synthesis method, while the 16-day NDVI data were aggregated into monthly NDVI values using the maximum value composite method. To ensure consistency between datasets, all layers were resampled to a spatial resolution of 1 km using ArcGIS, thereby aligning the spatial resolution of the LST and vegetation index products.

(2) Elevation data: Digital Elevation Model (DEM) data were downloaded from the Geospatial Data Cloud (http://www.gscloud.cn). The ASTGTM-DEM product, with an original spatial resolution of 30 m, was resampled to 1 km to match the resolution of the remote sensing data and used for topographic correction of the LST data.

(3) Temperature and precipitation data: The data were obtained from datasets shared by researcher Peng Shouzhang on the platform of the National Tibetan Plateau Data Center (Peng, 2019; Peng, 2020), with a spatial resolution of 0.0083333 (approximately 1 km).

1.3 Research Methods

1.3.1 The TVDI was calculated using Equation (1).

Among them:

$$\begin{cases} T_s(VI)_{min}=a_1+b_1NDVI & (2) \\ T_s(VI)_{max}=a_2+b_2NDVI & (3) \end{cases}$$

where T represents the surface temperature; represents the minimum land surface temperature corresponding to NDVI, that is, the wet-edge fitting equation; represents the maximum land surface temperature corresponding to NDVI, that is, the dry edge fitting equation. The coefficients a_1, b_1, a_2, and b_2 are the slopes and intercepts of the respective linear fittings.

The value range of TVDI is between 0 and 1. A higher TVDI value indicates more severe soil drought. The drought classification thresholds are summarized as follows:

- 0 ≤ TVDI < 0.46: No drought
- 0.46 ≤ TVDI < 0.57: Light drought
- 0.57 ≤ TVDI < 0.76: Moderate drought
- 0.76 ≤ TVDI < 0.86: Severe drought
- TVDI ≥ 0.86: Extreme drought

1.3.2 Sen's Slope Estimation Method and Mann-Kendall Test

Sen's slope estimation method is a non-parametric method for trend analysis that is robust against outliers and measurement errors, making it well-suited for long-term time series data (https://doi.org/10.5281/zenodo.3114194).

The slope is calculated as::

$$\beta=\text{mean}\left(\frac{x_j-x_i}{j-i}\right), \quad (4)$$

where and are values in the time series; β greater than 0 indicates that the time series presents an upward trend; less than 0 indicates that the time series shows a downward trend.

Mann-Kendall test is a non-parametric method used to assess the statistical significance of trends in time series data. It does not require the data to be normally distributed and is resistant to missing values and outliers (Wang et al., 2022). The test statistic S and the standardized statistic Z are calculated as follows:

$$Z=\begin{cases} \frac{S}{\sqrt{vas(S)}} & (S>0) \\ 0 & (S=0) \\ \frac{S+1}{\sqrt{vas(S)}} & (S<0) \end{cases} \quad (5)$$

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(x_j-x_i) \quad (6)$$

$$\sin(\theta)=\begin{cases}1 & (\theta>0)\\ 0 & (\theta=0)\\ 1 & (\theta<0)\end{cases} \tag{7}$$

For large sample sizes (n ≥ 8), the distribution of *S* approaches normal with:

$$E(s)=0 \tag{8}$$

$$Var(s)=\frac{n(n-1)(2n+5)}{18} \tag{9}$$

At a given significance level α, if $|Z|>Z_{1-\alpha/2}$, the null hypothesis of no trend is rejected, indicating a significant trend change in the time series data. $Z_{1-\alpha/2}$ represents the critical value from the standard normal distribution corresponding to the confidence level α. Specifically, when the absolute value of *Z* exceeds 1.65, 1.96, and 2.58, the trend is considered statistically significant at 90%, 95%, and 99% confidence levels, respectively.

1.3.3 Partial Correlation Analysis

The partial correlation coefficient is calculated using the simple correlation coefficient and examines the relationship between two variables while controlling for the effect of a third variable (). The simple correlation coefficient is calculated as follows:

$$R_{xy}=\frac{\sum_{i=1}^{n}[(x_i-\bar{x})(y_i-\bar{y})]}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \tag{10}$$

where and $\bar{y}$ represent the mean values of x and y over the n-year period, which is calculated as follows:

$$\bar{x}=\frac{1}{n}\sum_{i=1}^{n}x_i \quad ; \quad \bar{y}=\frac{1}{n}\sum_{i=1}^{n}y_i \tag{11}$$

The calculation formula for partial correlation coefficients is derived from the simple correlation coefficient:

$$R_{xy,z}=\frac{R_{xy}-R_{xz}R_{yz}}{\sqrt{(1-R_{xz}^2)}\sqrt{(1-R_{yz}^2)}} \tag{12}$$

Specifically, $R_{xy,z}$ denotes the partial correlation coefficient between dependent variable and independent variable after holding independent variable constant. If $R_{xy,z}>0$, it indicates a positive correlation; if $R_{xy,z}<0$, it signifies a negative correlation. A larger absolute value of the partial correlation coefficient reflects a stronger correlation between the variables.

The statistical significance of the partial correlation coefficient is tested using the t-test through the following formula:

$$t=\frac{R_{xy,z}}{\sqrt{1-R_{xy,z}^2}}\sqrt{n-m-1} \tag{13}$$

where n represents the study duration (time series: 2001-2023, n=23), and m denotes the number of independent variables. A threshold of α=0.05 indicates a statistically significant correlation, while α=0.01 denotes an extremely statistically significant correlation.

2. Results and Discussion

2.1 Characteristics of Interannual drought Variation in the Pearl River Basin

The average TVDI in the Pearl River Basin during 2001-2023 was 0.6607, and the average TVDI in previous years ranged from 0.6176 (2020) to 0.6929 (2004), with a standard deviation of 0.0186, indicating great inter-annual variation. The years 2004, 2008, 2011, and 2022 were characterized by severe drought events, and 2004 was the most severe year. In contrast, 2010, 2014, 2016, and 2022 experienced light drought conditions, and 2019 recorded the mildest drought. Over the past 23 years, the Pearl River Basin has generally experienced moderate drought, and no basin-wide severe or extreme drought occurred. Over the past 23 years, TVDI exhibited a significantly downward trend (α=0.05), and the annual decline rate was $0.0013 \cdot a^{-1}$ (Figure 2a), indicating that the overall drought situation in the Pearl River Basin exhibited a significantly downward trend over the past 23 years, especially from 2012 to 2021, and the drought situation was relatively light.

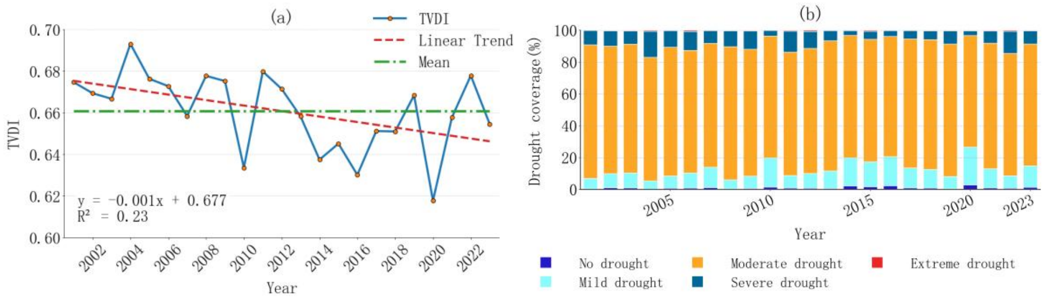

Figure 2. Inter-annual Changes of TVDI in the Pearl River Basin during 2001-2023 (a: Annual mean TVDI, b: Area Proportion of Drought Grade)

From 2001 to 2023, the average proportions of area affected by no drought, light drought, moderate drought, severe drought, and extreme drought were 1.09%, 11.36%, 78.85%, 8.33%, and 0.37%, respectively, and moderate drought constituted the largest share, while extreme drought accounted for the smallest (Figure 2b). The proportion of drought-free area ranged from 0.26% in 2004 to 2.91% in 2020 and exhibited an overall increasing trend, although this trend was not statistically significant. Light drought areas ranged from 5.21% (2004) to 23.66% (2020), and this elevation was statistically significant (α = 0.05). The proportion of moderate drought varied between 70.19% (2020) and 83.92% (2001), exhibiting a general downward trend that was not statistically significant. Severe drought area proportions ranged from 2.93% (2014) to 16.31% (2004), also showing a non-significant decreasing trend. The extent of extreme drought ranged from 0.11% (2001) to 0.76% (2006), displaying a weak, non-significant increasing trend. Overall, the average drought severity in the Pearl River Basin demonstrated a significant decline over the 23-year period, primarily due to the reduction in moderate and severe drought, while the proportion of light drought significantly increased. The emerging upward trend in extreme drought, although was not statistically significant, warrants close attention.

2.2 Spatial Distribution of Drought in the Pearl River Basin

Over the past 23 years, the average TVDI in the Pearl River Basin exhibited a spatial gradient, increasing from north to south (Figure 3). In the northern region, the average TVDI was as low as 0.288, while it reached 0.944 in the southern Leizhou Peninsula, indicating a general intensification of drought conditions from north to south. Extreme drought was primarily concentrated in the southern Leizhou Peninsula of Guangdong Province. Severe drought was mainly distributed across the Leizhou Peninsula, the Pearl River Estuary, and the eastern Guangdong cities of Jieyang, Chaozhou, and Huizhou, as well as Nanning, Baise, and Qinzhou in Guangxi Province. Additionally, Gejiu City in Yunnan Province experienced frequent severe drought events. The areas with low average TVDI values were mainly distributed in southeast Guizhou, northeast Guangxi, and northwest Guangdong. The standard deviation of TVDI in the Pearl River Basin was between 0.090 and 0.8322, with the highest interannual variability found in the central and northern Guangxi Province and the Pearl River Delta of Guangdong Province, indicating remarkable year-to-year fluctuations in drought severity in these regions.

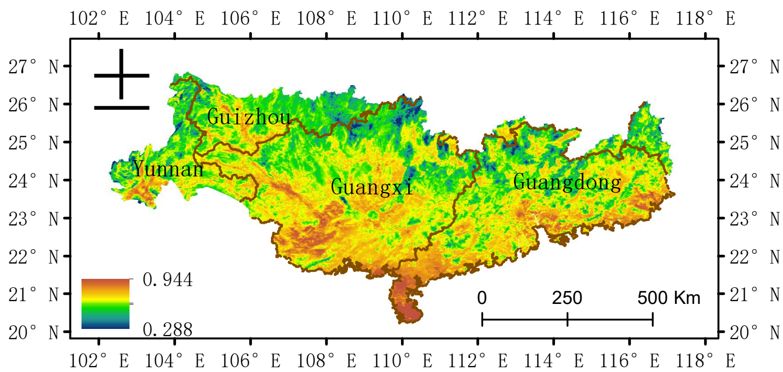

Figure 3. Spatial Distribution of Annual TVDI in the Pearl River Basin from 2001 to 2023

3. Changing trend of drought in the Pearl River Basin

Notably, drought conditions in the Pearl River Basin exhibited spatial heterogeneity, with a worsening trend in the eastern region and a weakening trend in the western region (Figure 4a). Notably, southeastern Yunnan, located at the river's source, also showed a significant intensification of drought. The area experiencing the most remarkable increase in drought severity, as indicated by the highest rate of increase in the TVDI, was the Pearl River Delta in Guangdong province, where the TVDI increased at a rate of 0.0121 a^{-1}. Regions with a TVDI increase rate exceeding 0.005 a^{-1} accounted for approximately 0.16% of the basin (about 720 km^2), which mainly concentrated in Foshan, Zhongshan, Dongguan, and Shenzhen, and located on both sides of the Pearl River Estuary. Areas with a moderate increase of TVDI (0.003–0.005 a^{-1}) included 0.85% of the basin, predominantly in northwestern Guangdong, northern Guangxi, and southeastern Yunnan. Regions with a slight increase of TVDI (0–0.003 a^{-1}) represented 16.41% of the total area. Conversely, the most significant reductions in TVDI, indicating improved drought conditions, were found in the Yunnan-Guangxi border region and the central and southern parts of Guangxi, including Nanning and Qinzhou, where the rate of decline exceeded 0.006 a^{-1} and reached a maximum of 0.008 a^{-1}. The largest proportion of the basin (68.23%) exhibited a mild decline in TVDI (0–0.003 a^{-1}), suggesting that nearly 70% of the region has experienced a slow alleviation of drought in recent years.

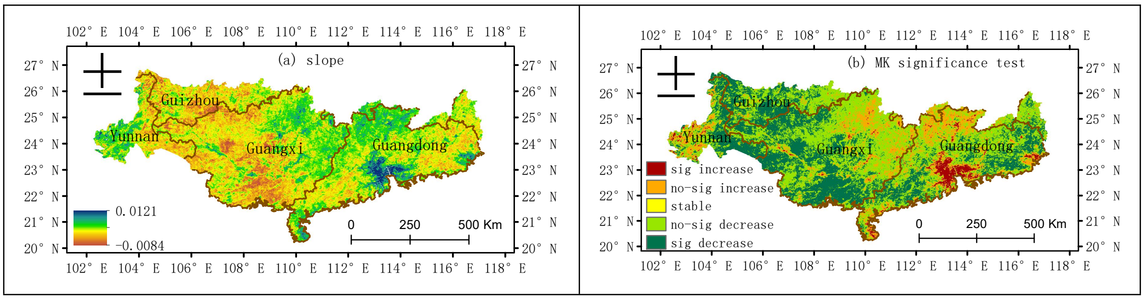

Figure 4. Spatial trends in TVDI across the Pearl River Basin from 2001 to 2023: (a) Sen's slope estimates of TVDI variation rate; (b) Results of the Mann–Kendall test

At the significance level of $\alpha = 95\%$, the area where TVDI increased significantly accounted for 3.12%, which was mainly distributed in the Pearl River Delta of Guangdong (Figure 4b), the eastern part of Leizhou Peninsula, Jieyang of Chaozhou, the northern part of Guangdong, and the eastern part of Yunnan. The area with significant decrease of TVDI accounted for 33.79%, which was mainly distributed in Qinzhou, Fangchenggang and Baise in Guangxi, the junction of Yunnan, Guangxi and Guizhou provinces, as well as several locations in Guangdong, including Yangjiang, Maoming, eastern Meizhou, Shanwei, and Huizhou. Areas exhibiting no significant increase or decrease in TVDI comprised 14.80% and 33.79% of the basin, respectively, and were primarily concentrated in the northern portion of the Pearl River Basin. Areas with no significant change in TVDI were minimal, accounting for only 0.30% of the total area.

4. Response of Drought to Climate Change in the Pearl River Basin

Precipitation in the Pearl River Basin gradually increased from northwest to southeast, while air temperature increased from north to south. The average annual precipitation in the Pearl River Basin ranged from 1186.4 to 1763.6 mm, and exhibited a statistically significant upward trend during 2001–2023. Under controlled temperature conditions, TVDI in 84.1% of the Pearl River Basin was negatively correlated with precipitation (Fig. 5a). Significant negative correlations ($\alpha \leq 0.05$) were identified in the Dongjiang River Basin, Hanjiang River Basin, and the upper and lower reaches of the Xijiang River Basin, with partial correlation coefficients ranging from -0.50 to -0.81.

The annual average temperature ranged from 19.1 ℃ to 20.6 ℃, and the annual average temperature showed a significant rising trend ($p<0.05$) during 2001-2023, with an elevating rate of 0.034 ℃/a. There was a significantly negative correlation between the average annual temperature and the average TVDI, and the correlation coefficient reached -0.415 ($p<0.05$), indicating that under the background of global warming, the rising temperature made the drought situation in the river basin tend to ease. Under the condition of controlled precipitation, the partial correlation between TVDI and air temperature in the Pearl River Basin was mainly negative (Fig. 5b), accounting for 78.5%. Statistically significant negative correlations were mainly concentrated in the central and eastern parts of the Xijiang River

Basin, and partial correlation coefficients ranged from -0.45 to -0.78. In contrast, significantly positive correlations between air temperature and TVDI were identified in specific areas, including the Yunnan–Guangxi junction in the upper reaches of the Xijiang River Basin and the Pearl River Delta, where partial correlation coefficients ranged from 0.51 to 0.82.

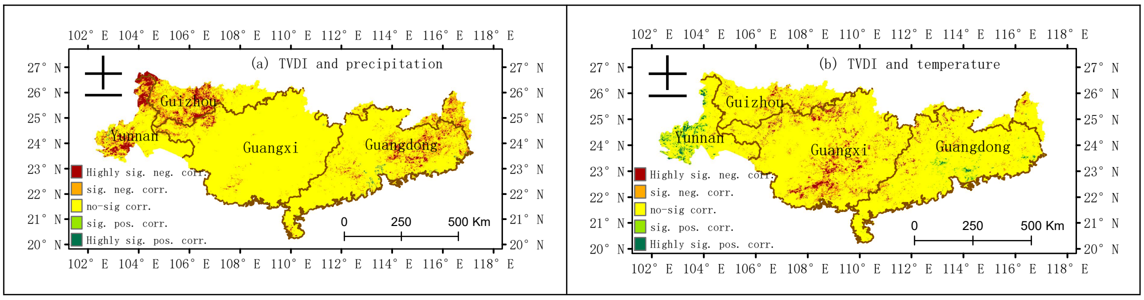

Figure 5. Significant Correlations between TVDI and Precipitation (a) and Temperature (b) in the Pearl River Basin during 2001-2023

According to the correlation analysis across different land use types (Fig. 6), TVDI was negatively correlated with precipitation across all categories. Among them, grassland exhibited the strongest negative correlation, with a coefficient of -0.41. Except for forest land, the correlation between TVDI and air temperature was generally weak across other land use types. In forested areas, TVDI exhibited moderately negative correlations with both precipitation and air temperature, and average correlation coefficients were -0.21 and -0.20, respectively. For cropland, TVDI was significantly negatively correlated with precipitation (average r = -0.21), while the correlation with air temperature was weak and not statistically significant (average r = -0.09). Impervious surfaces were the least affected by climatic variables, and an average correlation coefficient was –0.11 between TVDI and precipitation, accompanying by a weakly positive correlation with air temperature (average r = 0.12).

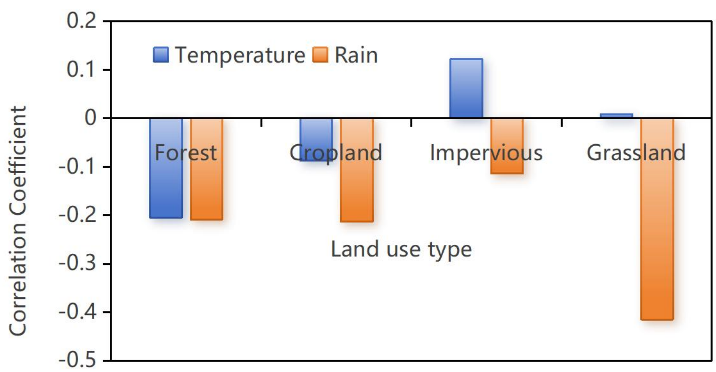

Figure 6. Correlation between Meteorological Factors and TVDI for Different Land Types

4. Conclusions

According the findings of this study, the following conclusions can be drawn:

(1)The average TVDI in the Pearl River Basin during 2001-2023 was 0.6607, with a standard deviation of 0.0186. On the whole, the Pearl River Basin exhibited moderate drought, and there was no severe and extreme drought in the whole river. In recent 23 years, TVDI showed a significant downward trend with an annual decline rate of $0.0013 \cdot a^{-1}$, especially during 2012 to 2021 when the drought was light.

(2) From 2001 to 2023, the average area percentages of no drought, light drought, medium drought, medium drought, and extreme drought were 1.09%, 11.36%, 78.85%, 8.33%, and 0.37%, respectively. The proportion of drought-free area exhibited an increasing trend, while the proportion of light drought area showed a significant increasing trend. The proportion of areas experiencing moderate and severe drought has shown a decreasing trend, whereas the proportion of areas affected by extreme drought has exhibited a slight increasing trend, indicating the need for vigilance regarding the rising risk of extreme drought.

(3)Over the past 23 years, the drought situation in the Pearl River Basin has gradually increased from north to south. Extreme drought has primarily occurred in the southern part of the Leizhou Peninsula in Guangdong Province. Severe drought has been concentrated in the Leizhou Peninsula, the Pearl River Estuary, and in cities, such as Jieyang, Chaozhou, and Huizhou in eastern Guangdong, as well as Nanning, Baise, and Qinzhou in Guangxi. Additionally, Gejiu in Yunnan Province has frequently experienced severe drought. Areas with low average TVDI values were mainly distributed in southeast Guizhou, northeast Guangxi, and northwest Guangdong.

(4) The drought in the eastern part of the Pearl River Basin exhibited a worsening trend, while the drought in the western part demonstrated a weakening trend. However, drought in southeastern Yunnan, the source region of the Pearl River Basin, was also worsened. The most significant increase in TVDI was identified in the Pearl River Delta in Guangdong province. Overall, nearly 70% of the basin has experienced a slow decreasing trend in drought severity.

(5) At the significance level of $\alpha = 95\%$, significant increases in drought were notable the Pearl River Delta, the eastern part of Leizhou Peninsula, Jieyang in Chaozhou, the northern part of Guangdong, and the eastern part of Yunnan. Conversely, drought conditions significantly eased in Qinzhou, Fangchenggang, and Baise in Guangxi; the border areas of Yunnan, Guangxi, and Guizhou provinces; and in Yangjiang, Maoming, eastern Meizhou, Shanwei, and Huizhou in Guangdong.

(6) At the regional scale, a significantly negative correlation was found between air temperature and TVDI. Consequently, both temperature and precipitation contributed negatively to drought severity, and temperature had a relatively stronger influence.

(7) TVDI was negatively correlated with precipitation across all land use types. The strongest correlation was found in grasslands, with a correlation coefficient of -0.41. Except for forest land, TVDI in other land use types exhibited weak correlations with air temperature. In forested areas, TVDI was moderately negatively correlated with both precipitation and temperature.

Funding

This research was funded by Shaoguan Science and Technology Program (Grant No. 250916198034397); Technology Research Project of Guangdong Meteorological Service (GRMC2023M45).

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References

Chen, Z. S. (n.d.). Empirical diagnosis of temporal and spatial variation of drought in the Pearl River Basin. *Journal of Sun Yat-sen University (Natural Science Edition)*, *59*(4), 33-42.

Cheng, X. Q., Zhou, Z. Y., Li, W. P. et al. (2022). Drought monitoring and its influencing factors in Central Asia based on MODIS data. *Transactions of the Chinese Society of Agricultural Engineering*, *3*(10), 128-137.

Dai, X. L. (2005). Analysis of hydrological characteristics and their evolution trend in the source area of the Pearl River. *Renmin Pearl River*, *26*(6), 17-20.

Du, Q. S., Huang, H., Wu, X. H. et al. (2022). Analysis of drought situation and countermeasures in the Pearl River Basin in Winter 2021 and Spring 2022 in Guangdong Province. *China Flood Control and Drought Relief*, *32*(12), 89-92.

EASTERLING, D. R., MEEHL, G. A., PARMESAN, C. et al. (2000). Climate extremes: Observations, modeling, and impacts. *Science*, 289, 2068-2074.

Gan, L., Liu, R., Ji, Q. et al. (n.d.). Spatial and temporal evolution of extreme precipitation events in Sichuan Province. *Journal of Mountain Science*, *39*(1), 10-24.

Gao, P. X., Zhang, W. P., Liang, S. et al. (2018). Inversion of dry and wet soil based on temperature vegetation drought index (TVDI). *Journal of Irrigation and Drainage*, *37*(10), 123-128.

Han, L. Y., Zhang, Q., Yao, Y. B. et al. (2014). Regularity and causes of drought disasters in Southwest China in recent 60 years. *Acta Geographica Sinica*, *69*(5), 632-639.

He, J. C., Gang, B. Y., & Zhang, Y. J. (2015). Soil drought characteristics based on MODIS data. *Arid Land Geography*, *38*(4), 735-742.

https://cstr.cn/18406.11.Meteoro.tpdc.270961

https://doi.org/10.11888/Meteoro.tpdc.270961

https://doi.org/10.5281/zenodo.3114194.

Jiang, L. Q., Wang, P., Jiang, L. X. et al. (n.d.). Application of temperature vegetation drought index (TVDI) to agricultural drought monitoring. *Chinese Agricultural Science Bulletin*, *37*(29), 132-139.

Meng, D., Li, X.J., Gong, H. L. et al. (2015). Variation of NDVI and driving forces of climatic factors in Beijing-Tianjin-Hebei region. *Journal of Geo-Information Science*, *17*(8), 1001-1007.

Peng, S. (2019). *1-km monthly mean temperature dataset for china (1901-2023)*. National Tibetan Plateau Data Center.

Peng, S. (2020). *1-km monthly precipitation dataset for China (1901-2023)*. National Tibetan Plateau / Third Pole Environment Data Center.

Qian, Y., & Lu, K. M. (n.d.). Analysis and thinking of drought situation in the Pearl River Basin in 2021. *China Flood Control and Drought Relief*, *32*(6), 27-30.

Wang, Q., Zhang, T. B., Yi, G. H. et al. (2017). Spatiotemporal variation of vegetation NPP and its driving factors in Hengduan Mountain region during 2004-2014. *Acta Ecologica Sinica*, *37*(9), 3084-3095.

Wang, R. Q., Jiang, X. H., & Nie, T. (2022). Spatial and temporal variations and driving forces of NDVI in the Pearl River Basin based on geodetectors. *People's Pearl River*, *43*(7), 61-73.

Wang, X. D., Zhang, B., Ma, B. et al. (n.d.). Temporal and spatial evolution of drought in Northeast China in recent 58 years based on daily value SPEI. *Plateau Meteorology*, *41*(3), 721-732.

Wang, Y. X., Shi, P., Zeng, L. L. et al. (2011). Analysis of normalized vegetation index and interannual change of precipitation in the Pearl River Basin from 1982 to 1999. *Journal of Tropical Oceanography*, *30*(4), 44-50.

Wei, R. Q. (2018). *Study on spatiotemporal variation evaluation of drought vulnerability in Panxi region*. Chengdu: Chengdu University of Technology.

Wen, B. (2014). *Spatial and temporal distribution of drought in Sichuan Province*. Chengdu: Sichuan Normal University.

Zhang, Z. Z., & Kang, H. J. (2023). Spatio-temporal changes and driving forces of land use/cover in Wuwei City from 2000 to 2020. *Science Technology and Engineering*, *23*(20), 8579-8587.