

Analysis of Spatiotemporal Drought Distribution Characteristics in Dali Prefecture Based on the CI Index

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How to cite this paper: Zi, H. C., & Xi, W. J. (2025). Analysis of Spatiotemporal Drought Distribution Characteristics in Dali Prefecture Based on the CI Index. *Journal of Geoscience and Environment Protection*, 13, 30-44.

<https://doi.org/10.4236/gep.2025.1311003>

Received: September 28, 2025

Accepted: November 9, 2025

Published: November 12, 2025

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Abstract

Drought is one of the primary meteorological disasters affecting Dali Prefecture. This study employs the Integrated Meteorological Drought Index (IMDI) to systematically analyze the spatiotemporal evolution characteristics of meteorological drought in Dali Prefecture from 2002 to 2023. Using linear trend analysis, spatial interpolation, and meteorological statistical methods, the key findings are as follows: interannual drought frequency fluctuated between 5.3% and 34.2%, with a mean of 24.3%; the 2019 extreme drought event showed significant correlation with concurrent Indian Ocean sea surface temperature anomalies; spatially, drought frequency exhibited a north-high-south-low pattern, ranging from 23.1% in the south to 29.8% in the north, with northern counties (e.g., Jiachuan, Heqing) recording the maximum frequency (29.8%) resulting from the föhn effect on the leeward slope of the Nushan Mountains and high agricultural water consumption; annual drought duration increased significantly at 1.9 days/decade; seasonally, droughts intensified in spring (+0.62 days/decade) and winter (+1.5 days/decade) but weakened in summer (−0.8 days/decade) and autumn (−0.4 days/decade), a pattern potentially linked to East Asian monsoon weakening causing reduced winter-spring moisture transport; for drought severity, light drought dominated (annual mean: 42.5 days, 58% of total drought days) followed by progressively shorter durations of moderate, severe, and extreme drought, while combined severe/extreme drought duration increased at 0.7 days/decade, consistent with regional warming and increased evapotranspiration. This study elucidates the spatiotemporal drought patterns and climatic drivers in Dali Prefecture, providing a scientific basis for drought resilience planning and optimized water resource allocation in this plateau marginal region.

Keywords

Dali Prefecture, Composite Index of Meteorological Drought (CI), Drought Days, Drought Frequency, Spatial Distribution

1. Introduction

Dali Prefecture, characterized by a typical monsoon climate, faces drought as a critical climatic risk constraining its development (Yu et al., 2018). Against the backdrop of global climate change and accelerated regional urbanization (Ren et al., 2024), the frequency and intensity of drought events have exhibited a pronounced increasing trend (Yin et al., 2024). These events exert multifaceted impacts on residents' living environments, industrial operations, and ecological balance. Notably, agricultural systems are particularly sensitive to drought stress, where climatic anomalies trigger crop water deficits (Shi et al., 2024). This often disrupts planting structures and causes yield fluctuations, directly undermining regional food supply stability and farmers' livelihood security. Such climatic pressure not only reduces land carrying capacity but also impedes the advancement of rural revitalization strategies. Furthermore, drought exacerbates regional water conflicts, leading to domestic water shortages and industrial production reductions (Xing et al., 2023), and even destabilizes ecosystems. Thus, a thorough investigation of the spatiotemporal distribution and evolving patterns of drought holds significant scientific and practical value for formulating drought response strategies and policies (Wang et al., 2023).

Within the field of global climate change research, the development of drought assessment models has gained significant academic attention (Cao & Lu, 2021). Multiple quantitative indicator systems have emerged across various dimensions, such as the water-balance-based SPEI (Standardized Precipitation Evapotranspiration Index), the Palmer Index accounting for land surface processes, the Z-index reflecting precipitation anomalies, and the Standardized Precipitation Sequence Method (Zhang et al., 2018). By parameterizing the spatiotemporal distribution of climatic elements, these assessment tools are integrated into drought early-warning systems and agricultural risk management frameworks, thereby providing quantitative support for formulating regional adaptation strategies. Different drought indices exhibit distinct advantages and limitations, each suited to specific regions and drought types. For example, the Standardized Precipitation Index (SPI), requiring only precipitation data for straightforward calculation, is ideal for regions lacking other meteorological observations. In contrast, the Comprehensive Meteorological Drought Index (CI) incorporates precipitation, evaporation, and other factors to provide a more holistic representation of drought conditions (Su & Sun, 2017; Zhao et al., 2012; Zhang et al., 2011).

Numerous scholars have investigated drought characteristics and climate change patterns across China using diverse meteorological drought indices (Lu et al.,

2009). For instance, Yang Chunyan et al. applied statistical methods to analyze spatiotemporal drought distribution in Southwest China, revealing significant regional disparities and an intensifying trend over the past five decades (Yang et al., 2021). Wu Xiulan et al. utilized the Standardized Precipitation Index (SPI) to examine drought features in Xinjiang, uncovering interdecadal drought variability and a south-to-north decreasing spatial gradient (Wu et al., 2022). Li Xiaohan et al. studied spatiotemporal drought disaster distribution in Beijing, documenting increased drought events over 30 years with notably higher spring drought frequency (Li et al., 2021). Feng Shiyuan et al. employed the Standardized Precipitation Evapotranspiration Index (SPEI) to assess drought patterns in Northwest China, highlighting elevated winter-spring drought frequency that poses threats to wheat production (Feng et al., 2021). Wu Yixuan et al. investigated spring maize seasonal drought characteristics based on the Crop Water Deficit Index (CWDI), providing a scientific basis for agricultural drought mitigation (Wu et al., 2021).

Yunnan Province exhibits uneven precipitation distribution, significant inter-annual variability, distinct dry seasons, and frequent drought occurrences (Xu, 2023). Precipitation during May to October accounts for over 85% of the annual total (Wang, 2017), whereas the dry season (November to the following April) receives minimal rainfall. This pronounced spatiotemporal imbalance constitutes the primary driver of drought. Furthermore, situated on a low-latitude plateau, the region experiences intense solar radiation and high evaporation rates that exacerbate drought initiation and progression (Xie et al., 2016).

As the core region of the Western Yunnan Plateau, Dali Bai Autonomous Prefecture ranks 12th in administrative area size among Yunnan's prefecture-level divisions (Zhang, 2009). Under the influence of the plateau monsoon system, it exhibits a distinct alternating dry-wet season climate. Intra-annual precipitation disparities induce recurrent water stress, establishing this area as a representative research zone for droughts in Southwest China. Studies by Qi Junqing et al. on Yunnan's drought characteristics reveal seasonal patterns with marked regional variations driven by synergistic topographic and climatic influences (Qi et al., 2019). Within Dali Prefecture, complex terrain—where orographic orientations interact with prevailing airflows—generates uneven spatial precipitation distribution, resulting in spatially heterogeneous drought manifestations (Zhou et al., 2018).

In recent years, Dali Prefecture has experienced frequent drought disasters, with particularly severe occurrences during winter and spring seasons (He et al., 2016). During the extreme 2013 drought in western Yunnan, the regional average precipitation from June to August (main flood season) plummeted to 5.7 mm—representing a 92% reduction relative to the climatic baseline (Zhang et al., 2020). This event triggered regional hydrological imbalances: 728 small-to-medium rivers experienced flow interruption, 352 water storage projects approached functional zero capacity, and 3105 groundwater extraction facilities exhibited impaired yield efficiency. Agriculturally, 4258 villages reported impacts across

213,400 hectares of croplands—comprising 61,900 hectares with growth retardation, 73,500 hectares manifesting physiological impairment, and 77,000 hectares undergoing crop ecosystem collapse—necessitating emergency water provision for 631,000 residents and 182,400 livestock. The 2019-2020 drought exhibited extended duration, expanded spatial extent, and inflicted multisectoral losses (Ren et al., 2014), severely disrupting regional production systems and livelihood security.

Against the backdrop of intensifying global climate change, drought patterns have grown increasingly complex (Lyu et al., 2013). Long et al.'s (2012) study on spatiotemporal drought distribution in Yunnan Province demonstrated heightened drought frequency and intensity, with significantly elevated probability of extreme drought occurrence (Long et al., 2012). Dali Prefecture likely exhibits analogous drought trends. This study employs the Compound Index (CI) to analyze drought characteristics (e.g., frequency and Drought Duration) across Dali Prefecture during 2002-2023, aiming to elucidate spatiotemporal evolution patterns of drought and establish scientific foundations for meteorological drought prediction and disaster risk reduction strategies in the region.

2. Materials and Methods

2.1. Data Sources

Daily precipitation and temperature observation data for 2002-2023 were acquired from 12 national meteorological stations in Dali Prefecture. The dataset was sourced from the China Meteorological Administration National Meteorological Science Data Sharing Service Platform China Surface Climate Data Daily Value Dataset (V3.0; DSS-V3.0), specifically providing annual, monthly, and daily mean precipitation records (unit: 0.1 mm) for Dali Prefecture meteorological stations during 2003-2023. The stations include Dali, Jianchuan, Heqing, Yongping, Yangbi, Xiangyun, Midu, Weishan, Nanjian, Yunlong, Binchuan, and Eryuan, comprehensively covering the primary regions of Dali Prefecture to effectively represent the spatial distribution of drought conditions. All meteorological data originate from the National Meteorological Information Centre and have undergone rigorous quality control and homogeneity testing to ensure accuracy and continuity.

2.2. Research Methodology

2.2.1. Integrated Meteorological Drought Index (CI)

Integrated Meteorological Drought Index (CI) is a drought assessment indicator that integrates multiple factors including precipitation and evaporation, effectively characterizing the overall drought conditions. This index is calculated in accordance with the national standard Classification of Meteorological Drought (GB/T 20481-2006) using the following mathematical expression:

$$CI = aZ_{30} + bZ_{90} + cM_{30} \quad (1)$$

In this equation, M_{30} denotes the monthly-scale relative moisture index. The weighting coefficients a , b , and c are calibrated through historical drought scenario inversion: Coefficient a is determined as the ratio of the mean SPI_{30} value in samples experiencing mild drought or higher severity to the historical minimum SPI_{30} ($SPI_{30_min} = -2.31$), empirically assigned 0.4. Coefficient b is derived from the linear equivalence relationship between the minimum SPI_{30} and SPI_{90} values ($SPI_{90_min} = -1.98$), with an empirical coefficient of 0.4. Coefficient c is obtained via normalization of M_{30} based on its drought-period sensitivity using the historical extreme value ($M_{30_min} = -0.83$), assigning an empirical parameter value of 0.8.

In the computation of the CI index, the standardized variables Z_{30} and Z_{90} facilitate cross-temporal and cross-regional comparability of precipitation anomalies. The incorporation of M_{30} indirectly integrates temperature effects on drought through evapotranspiration quantification, thereby characterizing the water supply-demand balance. Consequently, the CI index achieves a comprehensive representation of drought conditions, exhibiting particular effectiveness in characterizing agricultural drought.

The daily Composite Drought Index (CI) is derived through Equation (1-1) based on rolling computation of antecedent mean temperature and precipitation. Drought severity classification criteria are defined in **Table 1** (Zhao et al., 2012).

Table 1. Classification of comprehensive meteorological drought severity.

Level	Category	CI Value Range	Drought Impact Description
1	No Drought	$-0.6 < CI$	Precipitation at or above average; no surface drought observed, absence of drought indicators.
2	Mild Drought	$-1.2 < CI \leq -0.6$	Precipitation below average; surface air dryness observed; soil moisture mildly insufficient.
3	Moderate Drought	$-1.8 < CI \leq -1.2$	Sustained precipitation deficit; soil surface desiccation; inadequate soil moisture; visible daytime wilting of plant leaves.
4	Severe Drought	$-2.4 < CI \leq -1.8$	Critical soil moisture deficit: cracked soil layers and dried horizons; plant withering, leaf scorching, fruit drop; severely impacts crops/ecology; adversely affects industrial production and drinking water supply.
5	Exceptional Drought	$CI \leq -2.4$	Prolonged critical soil moisture deficit: vegetation perishes; devastating impacts on agriculture/ecology; significantly disrupts industrial operations and human/livestock water security.

2.2.2. Drought Frequency

Drought frequency serves as a critical indicator for assessing regional drought conditions, reflecting the probability of drought occurrence. This study employs the 20-year daily Composite Meteorological Drought Index (CI) data from Dali Prefecture to calculate drought frequency using Equation (2):

$$P = n/N \times 100\% \quad (2)$$

In Equation (2): n denotes the number of days with $CI \leq -0.6$ during the 20-year period, N represents the total number of days over the 20 years. Linear trend analysis

was employed to quantify the interannual trends and rates of change in drought frequency, thereby elucidating its temporal evolution characteristics. Kriging interpolation was applied to process station-based drought frequency data, generating spatial distribution maps to visualize regional disparities in drought frequency and facilitate a comprehensive analysis of its spatial distribution patterns.

3. Analysis of Spatiotemporal Variation Characteristics of Drought in Dali Prefecture

3.1. Characteristics of Drought Frequency in Dali Prefecture

3.1.1. Temporal Variation of Drought Frequency in Dali Prefecture

Based on the analysis of meteorological data from 2001 to 2023 (Figure 1), the probability of drought occurrence in the study area fluctuated between 5.3% (2015) and 38.7% (2007), with a twenty-year average of 0.14%. Linear regression indicates a gradual increasing trend in drought frequency, showing a decadal-scale increase rate of 25.77%. Distinct phased evolutionary characteristics are observed: during 2007-2012, the drought index exhibited a standard deviation of 8.2, representing a stable fluctuation phase; from 2013 to 2019, the standard deviation increased to 14.7, marking a transition to a relatively active stage; post-2015, drought frequency has shown accelerated growth, with a cumulative increase of 70.9% over five years. This intensification may be linked to regional precipitation pattern variations and atmospheric circulation adjustments.

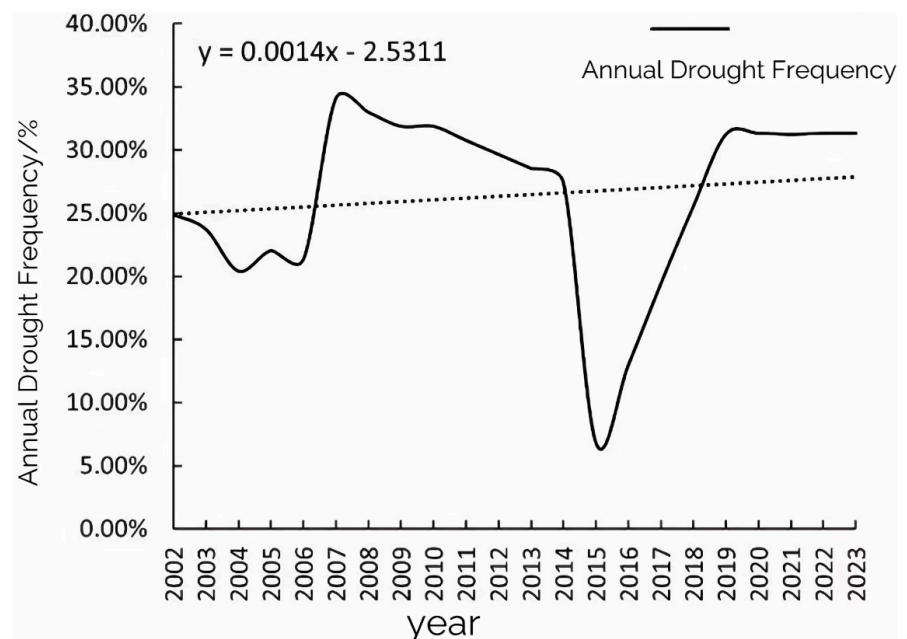


Figure 1. Interannual variation of drought frequency in Dali prefecture (2002-2023).

Over the past two decades, precipitation in Dali Prefecture has exhibited an overall fluctuating upward trend. However, the increasingly uneven seasonal distribution—characterized by increased rainfall during the rainy season and decreased rainfall in the dry season—has intensified seasonal droughts. These inter-

decadal variations in drought frequency are associated with altered precipitation patterns under global climate change.

3.1.2. Spatial Distribution of Drought Frequency in Dali Prefecture

Analysis of the annual average drought frequency at 12 meteorological stations in Dali Prefecture during 2002 – 2023 indicates a spatial distribution ranging from 23.1% to 29.8%, with Jianchuan Station in the northern region recording the highest frequency and Yangbi Station in the south exhibiting the lowest. **Figure 2** confirms that drought frequencies in southern Dali Prefecture are consistently lower than in the northern areas.

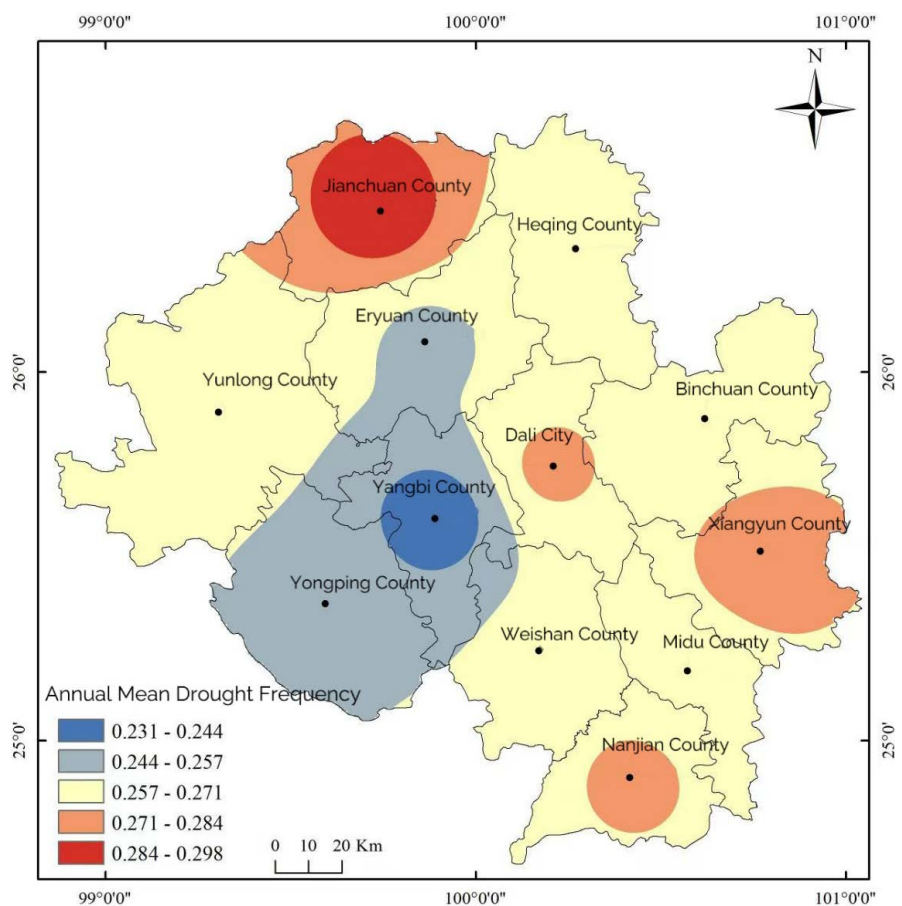


Figure 2. Spatial distribution of annual average drought frequency in Dali prefecture.

Based on the analysis, the spatial distribution pattern of drought frequency in Dali Prefecture—characterized by higher occurrence in the northern areas than in the southern regions—exhibits significant correlation with topographic-climatic characteristics and agricultural irrigation infrastructure. The southern region receives abundant precipitation influenced by the Gaoligong Mountains and Nujiang River, whereas the northern areas experience reduced rainfall due to higher elevation with predominantly hilly terrain. Compounded by underdeveloped farmland irrigation facilities, this results in diminished drought resilience in the north, thereby exacerbating drought severity.

3.2. Interannual Variation of Drought Days in Dali Prefecture

3.2.1. Interannual Variation of Annual Drought Days in Dali Prefecture

During 2002-2023, the annual average drought days in Dali Prefecture exhibited interannual fluctuations ranging from 23.6 to 172.8 days, with a mean of 88.9 days. The maximum value (172.8 days) occurred in 2007, while the minimum (23.6 days) was recorded in 2015. Over this period, drought days increased at a rate of 1.9 days per decade. Global warming has enhanced atmospheric water-holding capacity and increased evaporation, thereby driving the upward trend in drought occurrence. Temporally, drought days demonstrate uneven intra-annual distribution, concentrating primarily during the dry season (November–April) and July–August. Scarce winter-spring precipitation, combined with intermittent breaks in monsoon rainfall and elevated evaporation during July–August, predisposes the region to short-term drought events.

3.2.2. Interannual Variation of Seasonal Drought Days in Dali Prefecture

During 2002-2023, spring drought duration in Dali Prefecture ranged from 6 to 71.3 days, with a multi-year mean of 13.5 days. The maximum occurred in 2010 (71.3 days) and the minimum in 2015 (6 days). Temporal analysis (**Figure 3**) indicates a gradual increasing trend in spring drought duration during the study period, averaging 0.62 days per decade. Enhanced South China Sea monsoon activity during spring elevates moisture transport, yielding favorable thermo-hygrometric conditions that reduce drought probability. However, post-2005 spring drought duration exhibits amplified interannual fluctuations, potentially associated with pre-monsoon atmospheric circulation instability. Notably, frequent March–April droughts coincide with the critical hydric demand phase of major-season crops, where soil moisture deficits commonly cause reduced seedling emergence and agricultural losses.

Observed summer drought duration varied from 0.8 to 82.6 days (seasonal mean: 31.2 days), peaking in 2002 (33.5 days) and reaching its minimum in 2015 (6 days). Trend analysis (**Figure 3**) reveals a declining tendency over the past two decades at 0.85 days per quinquennium. Following the flood season, northward progression and westward extension of the Western Pacific Subtropical High (WPSH) significantly modulate regional climate. During August–September, persistent WPSH dominance generates continuous solar exposure, excessive radiation flux, accelerated soil moisture depletion, and intensified evapotranspiration. Despite increased precipitation under global warming, substantial interannual variability persists—exemplified by a 26-day extreme drought in 2019—highlighting regional heterogeneity in climate response patterns.

Autumn drought duration (2002-2023) demonstrates pronounced interannual variability (range: 2.8 days [2013] to 91.4 days [2007]; mean: 33.8 days, SD = 18.7), indicating event irregularity. The 2007 extreme drought (91.4 days) coincided with 52% precipitation deficit, driven by anomalously westward-extending WPSH obstructing moisture advection. Conversely, 2013 recorded only 12.5 drought days amid 37% precipitation surplus from prolonged rainy episodes. A significant

decreasing trend prevails at 1.42 days per quinquennium ($p < 0.05$), potentially linked to delayed East Asian summer monsoon retreat and reinforced autumn southwestern warm-humid airflow. Spatially, northern dry-hot valleys (e.g., Binchuan) average 45 – 50 days, constituting a high-value nucleus, while southern highlands (e.g., Weishan) experience 20% – 25% fewer drought days due to orographic enhancement.

Winter drought duration fluctuated between 0 and 46.2 days (mean: 10.4 days), exhibiting distinct decadal phases: 2002-2012 averaged 8.3 days, rising 51.8% to 12.6 days during 2013-2023. The 2020 peak (36.3 days) corresponded with $+1.8^{\circ}\text{C}$ thermal anomalies and 65% precipitation deficiency, possibly associated with negative-phase Arctic Oscillation redirecting cold-air trajectories eastward. Conversely, 2015 recorded merely 2.5 drought days due to active southern branch troughs inducing anomalous rainfall. Winter drought duration has increased significantly at 1.63 days per quinquennium ($p < 0.01$) over 2002-2023, attributed to intensified Siberian High pressure system and weakened Qinghai-Xizang Plateau thermal forcing, which reinforce winter monsoon southward penetration. During meridional expansion of the continental high, subsiding westerlies at the anticyclonic periphery sustain 2.1 mm/day evaporation despite low thermohygric indices, establishing a persistently moisture-depleting environment.

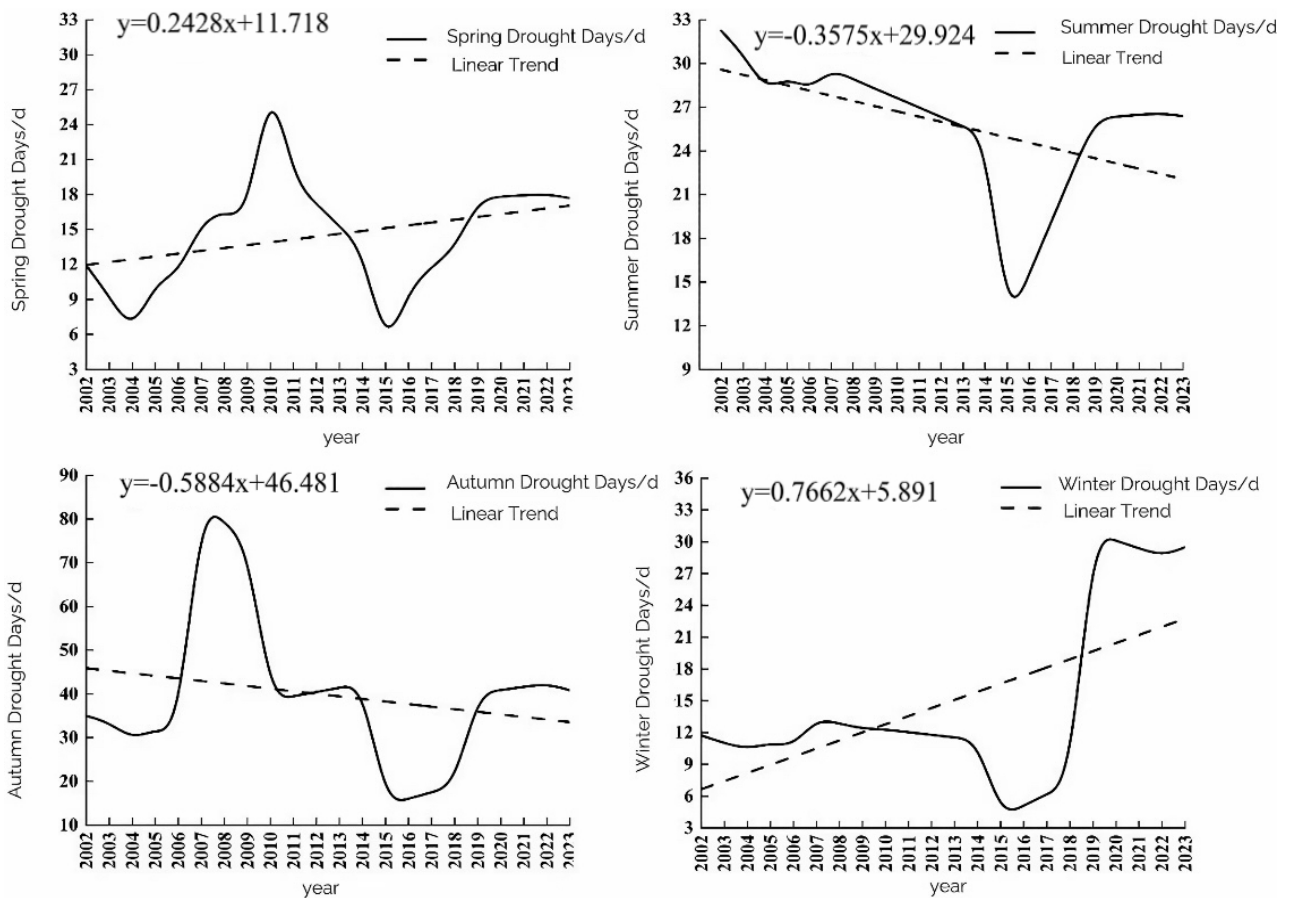


Figure 3. Interannual variation of seasonal drought days in Dali prefecture (2002-2023).

3.3. Spatial Distribution of Multi-Grade Drought Days in Dali Prefecture

Situated within 24° - 27°N and 99° - 101°E, Dali Prefecture exhibits a terrain configuration characterized by a north-south latitudinal span of approximately 3 degrees and pronounced east-west elongation. Despite occupying a unified climatic zone, complex topography induces significant local climatic differentiation. Observational data (Figure 4) demonstrate pronounced spatial heterogeneity in drought distribution: the northern Gaoligong Mountains experience weakened local circulation due to terrain uplift, resulting in higher precipitation; the eastern

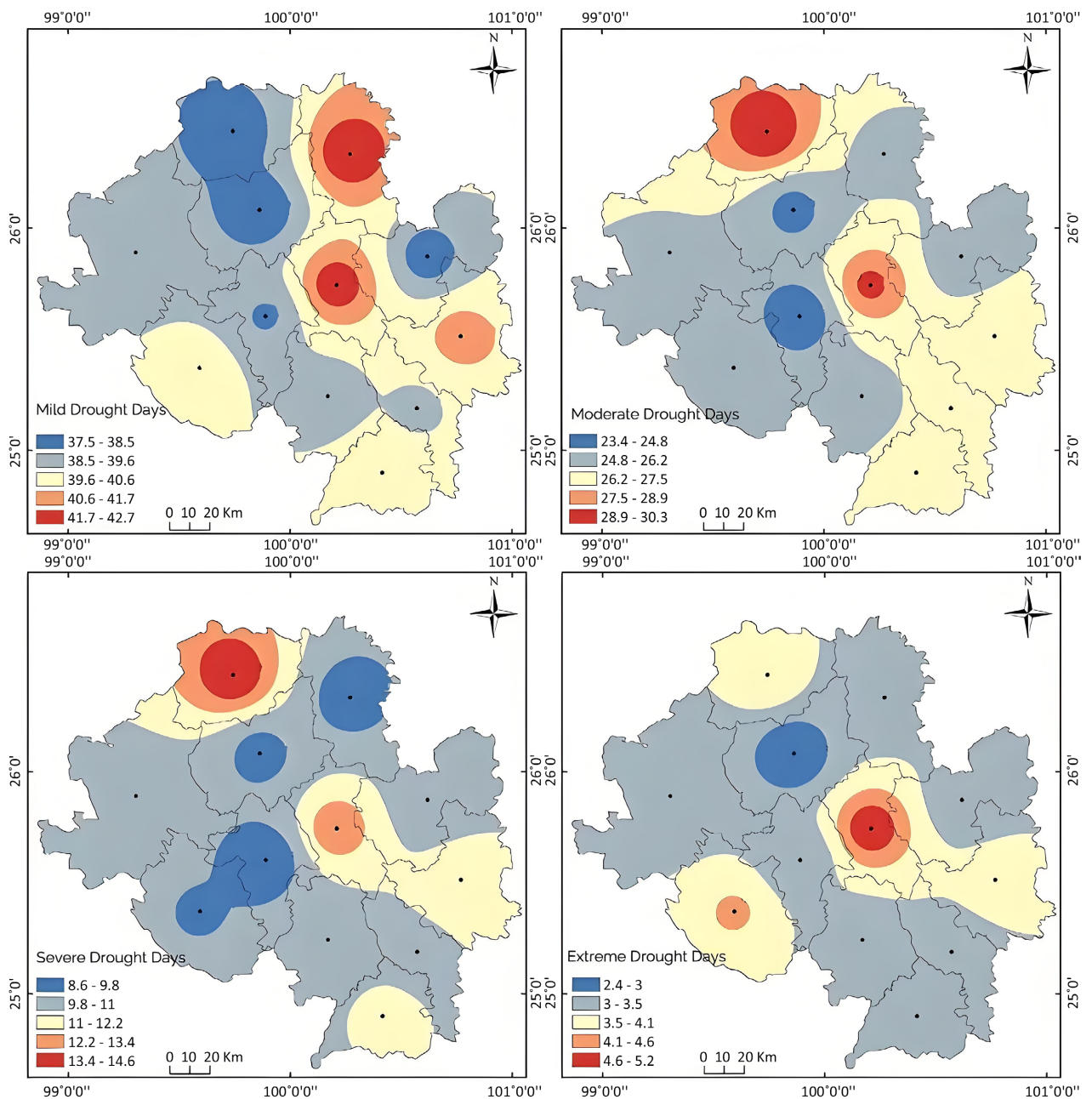


Figure 4. Spatial distribution of drought days at different severity levels in Dali prefecture.

foothills of the Cangshan Mountains benefit from enhanced vapor condensation conditions through topographic blocking; the western Yunnan-Guizhou Plateau transition zone exhibits elevated atmospheric aridity driven by terrain uplift and foehn effects; while the windward slopes of the southern Jade Dragon Snow Mountains constitute enhanced precipitation zones.

Analysis of drought severity levels (**Figure 4**) reveals a north-high-south-low spatial pattern in light drought occurrence. Annual means during the study period ranged from 37.5 to 42.7 days, with Heqing Station recording the maximum (42.7 days) and Jianchuan Station the minimum (37.5 days), giving a regional average of 42.5 days. Moderate drought distribution reverses this trend, showing significantly increased frequency in southern areas. Jianchuan Station emerges as the maximum center (30.3 days), while Yangbi Station registers the minimum (23.4 days), resulting in a regional mean of 26.8 days.

Spatial differentiation of severe drought is particularly pronounced, with the southern region constituting the primary occurrence zone. Within the annual range of 8.6 - 14.6 days, Jianchuan Station (14.6 days) exhibits nearly 70% higher occurrence than Heqing and Yangbi Stations (8.6 days), culminating in a regional average of 11.3 days. Extreme drought days display a northwest-to-southeast increasing gradient, reaching maximum values at southeastern Dali Station (5.2 days) compared to minimum values at northwestern Eryuan Station (2.4 days), demonstrating synergistic effects of altitudinal gradients and monsoon corridors. The mean extreme drought duration across 12 meteorological stations is 4.2 days.

4. Discussion

4.1. Comparative Validation with Previous Studies

This study reveals a “higher in the north, lower in the south” spatial pattern of drought frequency in Dali Prefecture (23.1% - 29.8%), geographically complementing the “decreasing from south to north” distribution documented by Wu Xiulan in Xinjiang (Wu et al., 2022). This alignment confirms the universal principle that regional topography dominates spatial heterogeneity in drought. Temporally, drought days in Dali Prefecture increased significantly at 1.9 days per decade ($p < 0.05$), with particularly pronounced trends in winter (+1.5 days/decade) and spring (+0.62 days/decade). These findings are highly consistent with Long Xiaomin’s conclusion regarding ‘increased probability of extreme drought in Yunnan’ (Long et al., 2012) but further quantify seasonal disparities—summer drought days showed a decreasing trend (−0.8 days/decade), revealing the complexity of drought evolution in monsoon regions. Notably, severe drought days at Jianchuan Station reached 14.6 days (29% higher than the regional average), and its spatial hotspot characteristics align closely with Qi Junqing’s mechanistic model indicating that ‘Yunnan’s drought results from synergistic interactions between topography and climate systems’ (Qi et al., 2019).

4.2. In-Depth Analysis of Climatic Driving Mechanisms

4.2.1. Dominant Role of Monsoon System Variability

The weakening of the East Asian Monsoon (EAM) intensity constitutes a key driver exacerbating winter-spring droughts. Research demonstrates that over the past two decades, intensification of the winter monsoon's southward incursion (with the Siberian High intensity index rising at 0.24 per decade) has positioned Dali Prefecture persistently within the subsidence zone at the base of this anticyclone. This results in a regional mean daily evaporation rate of 2.1 mm/day (an 18% increase during 2013 – 2023 relative to the preceding decade). Concurrently, autumn drought days of have decreased at a rate of 1.42 days per five years ($p < 0.05$), showing statistically significant correlation ($r = 0.71$) with a delayed retreat of the East Asian Summer Monsoon (EASM) by 2.3 days per decade. This monsoon retreat delay thereby prolongs the moisture replenishment cycle from warm-humid airflows originating in the southwest during autumn.

4.2.2. Remote Modulation via Air-Sea Interaction

Indian Ocean sea surface temperature anomalies exert a significant triggering effect on extreme drought events. In 2019, the positive phase of the Indian Ocean Dipole (IOD) reached a historic peak (+1.82). By exciting Kelvin waves, it weakened moisture transport over the Bay of Bengal (Zhang et al., 2020), thereby causing an anomalously high number of summer drought days in Dali Prefecture that year (26 days, exceeding the climatic mean by 83%). Correlation analysis shows a significant negative correlation ($r = -0.65$, $p < 0.01$) between the Indian Ocean sea surface temperature index and the interannual variability of drought frequency in Dali Prefecture. This finding supplements the mechanistic framework proposed by Yang Chunyan regarding the “synergistic influence of Pacific-Indian Ocean sea surface temperatures on droughts in Southwest China” (Yang et al., 2021).

4.3. Study Limitations

1) Station Density Constraints: The current study relies on data from 12 meteorological stations (average density: 1 station per 1780 km²), making it difficult to precisely characterize micro-scale drought features in areas with complex terrain, such as the eastern slope of Cang Mountain (elevation gradient >1500 m). Future work should integrate satellite remote sensing (e.g., SMAP soil moisture products) to enhance spatial resolution.

2) Applicability of the CI Index: Although the Consistent Drought Index (CI) integrates precipitation and evapotranspiration (Formula 2-1), its response to soil moisture dynamics exhibits hysteresis (Zhao et al., 2012), potentially introducing bias in drought characterization within karst regions featuring groundwater recharge mechanisms. Subsequent studies should incorporate the Standardized Precipitation Evapotranspiration Index (SPEI)—which accounts for potential evapotranspiration—to improve assessment accuracy.

3) Lack of Human Activity Quantification: The exacerbating effect of agricul-

tural irrigation water consumption (water use intensity in northern irrigation districts: 5800 m³/ha) on drought was only qualitatively analyzed; quantifying anthropogenic-natural factor interactions requires implementation of land surface process models (e.g., Community Land Model, CLM).

5. Conclusion

This study utilizes the Integrated Meteorological Drought Index (CI) to examine meteorological drought characteristics in Dali Prefecture (2002 - 2023) across three dimensions: drought frequency, interannual drought day variability, and spatial distribution of drought days by severity grade. Key conclusions are:

1) Annual drought frequency averaged 24.3% (range: 7.2% - 43.5%) over the past two decades. Spatially, frequencies varied between 21.3% and 27.8%, with Jianchuan in Dali exhibiting maximum values.

2) Drought days showed significant interannual fluctuations with an increasing trend of 1.9 days/decade during 2002-2023. Seasonally, increases occurred in all seasons except summer.

3) Regional drought day averages by severity grade revealed distinct spatial patterns: light drought (42.5 days) displayed north-high-south-low distribution; moderate drought (26.8 days) concentrated in southern regions; severe drought (11.3 days) exhibited south-dominated prevalence; extreme drought (4.2 days) decreased southeastward from northwestern areas.

Acknowledgment

This paper is supported by the Innovation and Entrepreneurship Training Program for College Students in Yunnan Province, with the project title "Analysis of the Impact of Spatiotemporal Distribution of Drought on Forest Fire Risk Levels and Its Trend in Dali Prefecture".

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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