Risk Characteristics of Drought Disasters in Southern China and Prevention and Control Strategies: Postprint

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Abstract

Using daily surface meteorological observation data and drought disaster data from 252 national basic meteorological stations across 14 provinces, autonomous regions, and municipalities in southern China from 1961 to 2015, this study investigates the spatiotemporal variation characteristics of drought disaster impacts in southern China, analyzes the variation characteristics of drought disaster risk, and proposes risk prevention and control strategies and countermeasures. The results indicate that over the past 55 years, precipitation in southern China has exhibited fluctuating changes with no significant linear trend. However, since entering the 21st century, the regional average precipitation has been notably lower, and the amplitude of interannual precipitation oscillation has increased. Over the past 55 years, the temperature in the study area has shown a significant upward trend, with the warming rate of average surface temperature in southern China exceeding that of global surface temperature; the temperature in the study area has been rising continuously since 1976, with the abrupt temperature increase occurring in 1997. High-risk areas for severe drought are mainly concentrated in the southwest. With climate warming, the frequency, intensity, and affected area of drought disasters have all increased, resulting in increased drought disaster risk. After the temperature abrupt change, the secondary high-risk areas for drought disasters have expanded significantly. In the next 10 years (2016-2025), the frequency of drought occurrence in southern China may increase. Therefore, it is necessary to strengthen drought disaster risk management, implement ecological environment restoration in ecologically vulnerable areas, prioritize food security in major agricultural production areas, address the conflict between the uneven spatiotemporal distribution of water resources and intensifying supply-demand contradictions, and improve the level of drought disaster risk prevention and control.

Full Text

Preamble

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Risk Characteristics and Control Technology Measures of Drought Disaster in Southern China

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Abstract

Using daily surface meteorological observation data and drought disaster records from 252 national basic meteorological stations across 14 provinces in Southern China from 1961 to 2015, this study analyzed the spatiotemporal variation characteristics of drought disaster impacts and risk changes in the region. Based on these analyses, control strategies and defense countermeasures for drought disaster risks are proposed. The results indicate that annual precipitation in Southern China fluctuated from 1961 to 2015 without showing obvious linear trends. However, average annual precipitation in the 21st century has been lower than in previous periods, with increasing interannual oscillation amplitude. The annual average temperature showed a significant upward trend throughout 1961–2015, with the warming rate higher than the global average surface temperature increase. Temperature began rising continuously from 1976, with a mutation point occurring in 1997. High-risk areas for drought disaster are concentrated primarily in southwestern China. With global warming, drought frequency, intensity, and affected areas have increased, along with drought disaster risk. The secondary high-risk area expanded significantly after the 1997 temperature mutation. During the next decade (2016–2025), drought disaster frequency in Southern China may increase. Therefore, the following management measures should be implemented: (1) strengthen drought disaster risk management; (2) restore ecologically fragile areas; (3) prioritize food security in major agricultural production regions; (4) resolve uneven spatiotemporal distribution of water resources and intensifying supply-demand contradictions; and (5) improve drought disaster risk prevention and control capabilities.

Keywords: drought; disaster risk; spatial characteristics; countermeasures; Southern China

1. Introduction

Humanity has suffered from drought disasters since its inception. Drought is a natural disaster that can occur globally, intimately associated with Earth' s environment [1-2]. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the global water cycle' s response to climate warming will not be uniform. Although regional anomalies may occur, the contrast in precipitation between wet and dry regions and between rainy and dry seasons will intensify. Under high greenhouse gas emission scenarios (RCP 8.5), soil moisture is projected to decrease across regional to global scales, and average precipitation will decline, increasing instability and risk in agricultural production [5]. In mid-latitude arid regions and subtropical drylands currently used for agriculture, the likelihood of agricultural drought will increase [3-4]. With future climate warming, accelerated water cycling will alter water balance through increased plant transpiration and surface evaporation. In the Mekong River Basin of Southeast Asia, where rice cultivation requires substantial water, the impacts of drought are particularly severe. In 2016, southern Vietnam experienced its most severe drought in nearly a century, causing serious agricultural damage in the delta region.

China is among countries frequently affected by drought disasters. Since the late 20th century, drought frequency has increased, with severe regional droughts occurring in southern China during 1997, 1999–2002, and 2009. Sichuan-Chongqing regions experienced once-in-a-century droughts in 2006; the middle and lower Yangtze River region recorded the lowest precipitation in history during 2010–2013; and northern China suffered regional droughts in 2003 and 2011, with the affected area reaching its largest extent in recent history [6-8]. Climate warming not only exacerbates drought hazards and complicates their formation mechanisms and development processes but also diversifies the factors influencing drought disaster risk [9-11]. Agricultural drought comprehensive loss rates correlate negatively with precipitation, with higher loss rates in regions with less rainfall, such as the main Yunnan-Guizhou Plateau area [13]. High-risk drought disaster zones include northern Guangxi and western Guangdong in southern China, where hazard-forming factors are dangerous and exposure vulnerability is high [14-16].

Traditional drought disaster prevention in China primarily employs emergency crisis management, mobilizing public and social forces only after disasters occur rather than implementing institutionalized prevention beforehand. With increasing drought frequency and higher socioeconomic demands for disaster prevention, a shift from emergency management to risk management is required [17]. Effective drought risk management must be based on risk identification, supported by risk assessment and early warning technologies. Currently, understanding of drought disaster risk characteristics and patterns in southern China remains limited, and climate warming-induced variations in risk factors further complicate assessment techniques [18-21], leaving drought risk management lacking necessary technical support. Research on drought disaster risk characteristics in southern China is therefore both urgently needed and scientifically significant for developing targeted response strategies and improving disaster prevention capabilities under climate change.

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2. Study Area

Southern China generally refers to the region south of the Qinling-Huaihe line and east of the Tibetan Plateau, belonging to the southern part of the southwest and southeast monsoon zones. Due to the Tibetan Plateau's unique topography, geomorphology, and regional climate characteristics, which differ significantly from other southern regions, it is excluded from this study. The research area spans 97.4°–123.0°E, 20.2°–35.3°N, dominated by subtropical monsoon climate with annual precipitation of 600–2700 mm and annual average temperature of 16–24°C.

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3. Research Data

The study selected 252 national basic meteorological stations in Southern China with good spatial representation and consistent data records. Drought-affected area data were obtained from Ministry of Agriculture crop drought disaster records (1951–2014).

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4. Data Analysis Methods

4.1 Climate Trend Analysis

The climate trend rate was calculated using linear regression [21]. For climate variable X at time t $(i = 1, 2, \cdots, n)$, the regression equation $X = a + b$t *yields the climate tendency rate* b*, where* a* is the constant and b is the regression coefficient.

4.2 Temperature Mutation Detection

Cumulative anomaly analysis and Mann-Kendall (M-K) mutation detection methods were employed [21]. For a climate sequence x, x, $\cdots$, x without change, the M-K test defines a statistic. Given significance level , if the sequence shows strong increasing or decreasing trends, the null hypothesis H is rejected. The M-K method generates forward and backward statistical curves; their intersection within confidence limits indicates the mutation start point.

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5. Drought Disaster Risk Assessment Method

Drought disaster risk assessment evaluates the intensity and form of potential disaster risks, differing from post-disaster assessment by its predictive nature. Based on understanding of drought risk formation mechanisms, traditional disaster risk theory focused on natural environmental factors, yielding relatively stable static conclusions. A new conceptual model incorporates climate change and human activities, considering the sensitivity of the disaster-forming environment to capture the variability and dynamic processes of drought risk more scientifically.

According to this conceptual model, the drought disaster risk system decomposes into: hazard-forming factor 危险性 (h), exposure/vulnerability of disaster-bearing bodies (e), sensitivity of the disaster-forming environment (s), and disaster prevention/mitigation capability. The drought disaster risk index can be expressed as:

$$R = H \times E \times V \times V \times P$$

Where R is drought disaster risk, H is drought hazard intensity and probability, E is social-physical exposure, V is vulnerability, V is environmental sensitivity, and P is response and recovery capacity. The Analytic Hierarchy Process (AHP) was used to decompose risk elements, with assessment models established using weighted comprehensive evaluation [13,15].

[Figure 1: see original paper] The conceptual model for drought disaster risk formation mechanism

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6. Spatial Distribution Expression Method

Drought disaster risk distribution characteristics were generated from statistical calculations using ArcGIS software. Spatial grid data were interpolated using the Inverse Distance Weighted (IDW) method with a cell size of 0.005.

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7. Results

7.1 Precipitation

From 1961 to 2015, annual precipitation in the Southern China study area showed fluctuating changes without significant linear trends. The maximum annual average precipitation was 1530.7 mm (coefficient of variation: 6.9%), while the minimum was 1095.8 mm (coefficient of variation: 8.3%). Regional average precipitation anomaly percentages ranged from -17.6% to 15.0%.

Decadal analysis revealed: - 1960s: Precipitation deficit of -0.5% (coefficient of variation: 4.4%) - 1970s: Precipitation deficit of -2.5% (coefficient of variation: 6.3%) - 1980s: Precipitation surplus of 2.5% (coefficient of variation: 4.4%) - 1990s: Precipitation deficit of -0.7% (coefficient of variation: 8.3%) - 2000s: Precipitation deficit of -1.8% (coefficient of variation: 8.3%) - 2010-2015: Precipitation deficit of -2.5% (higher coefficient of variation)

After the 21st century, average precipitation decreased significantly with increased interannual oscillation amplitude.

[Figure 2: see original paper] Annual precipitation and temperature departure curves for the study area in Southern China

7.2 Temperature

From 1961 to 2015, the study area showed a significant warming trend with a linear climate tendency rate of 0.192°C/10a, exceeding the global surface warming rate [2]. The cubic function fitting equation (y = -0.00003x^3 + 0.0033x^2 - 0.0747x - 0.0625, R = 0.806, $p < 0.001$) indicates continuous temperature rise after 1976, with all values before the 1990s showing negative anomalies (-0.4°C). After 1997, temperature anomalies became 0°C with increased variation coefficients and oscillation amplitude.

Decadal anomaly percentages of precipitation and temperature for the study area in Southern China

To further analyze temperature mutation characteristics, cumulative anomaly and Mann-Kendall tests were applied. The cumulative anomaly curve showed a clear pattern: decreasing from 1961-1996 and increasing from 1997-2015, suggesting ~1997 as the warming mutation point. The M-K test showed the intersection point of forward and backward statistics curves fell between critical lines (±1.96 at   = 0.05), confirming 1997 as the mutation start point. The trend passed significance tests at extremely significant levels.

[Figure 3: see original paper] Temperature cumulative anomaly and M-K test curves for the study area in Southern China

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8. Drought-Affected Area Analysis

8.1 Regional Distribution

With decreasing precipitation and increasing drought risk, Southern China' s agriculture holds vital importance, accounting for 81.2% of national rice sowing area, 34.9% of winter wheat, and 20.5% of corn. From 1951-2014, significant regional differences existed in average annual drought-affected areas. Sichuan

Province had the largest average affected area (134.4×10 ha, 17.4% of Southern China' s total), followed by Anhui (117.8×10 ha, 15.2%). Hunan and Jiangsu had 108.0×10 ha (14%), while Jiangxi and Guangdong had 83.9×10 ha (10–14%). Fujian and Hainan had the smallest affected areas (10.7×10 ha, 1.4%).

[Figure 4: see original paper] Regional distribution of average drought-affected area in Southern China

8.2 Temporal Changes

From 1951–2014, the average annual drought-affected area in Southern China showed a fluctuating upward trend with a linear tendency rate of 31.3×10 ha/10a ($p < 0.01$), reaching a maximum of 1889.5×10 ha in 2001. Southwest China showed a significant increase (28.02×10 ha/10a), South China showed slight fluctuating increase, while the middle-lower Yangtze River region showed slight fluctuating decrease.

[Figure 5: see original paper] Changes in crop drought-affected area in Southern China, South China, Southwest China, and the middle-lower Yangtze River region

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9. Drought Disaster Risk Assessment

9.1 Typical Regional Risk Assessment

Taking Southwest and South China as typical regions, risk distribution was evaluated considering hazard intensity/probability, exposure, vulnerability, environmental sensitivity, and response capacity using AHP. High-risk areas include eastern Yunnan, western Guizhou, and southern coastal Guangdong. Secondary high-risk areas cover most of Yunnan, southwestern Sichuan mountains, and eastern Sichuan basins. Medium-risk areas include the Yunnan-Guizhou Plateau, southwestern Sichuan mountains, eastern Sichuan, central-western Guangxi, and southern Guangdong.

[Figure 6: see original paper] Assessment of drought risk distribution in typical regions

9.2 Risk Changes Before and After Temperature Mutation

The warming mutation year in Southern China occurred in 1997. Before the mutation, high-risk areas were mainly in central-eastern Yunnan and southern coastal Guangdong. Afterward, high-risk areas shifted to northeastern Yunnan, while secondary high-risk areas expanded significantly to cover the Yunnan-Guizhou Plateau and central-western Guangxi.

[Figure 7: see original paper] Characteristics of drought disaster risk in typical regions after temperature abrupt change

9.3 Severe Drought Risk Probability Distribution

Analysis of drought-affected area changes reveals that severe drought high-risk areas concentrate in southwestern China, including central-eastern Yunnan, most of Chongqing, and western Hubei. With climate warming, drought frequency, intensity, and affected areas have increased, particularly in southwestern China where affected areas show significant upward trends.

9.4 Future Drought Disaster Prediction

CMIP5 ensemble projections under RCP4.5 and RCP8.5 scenarios show Southern China' s temperature will increase by ~0.6–0.7°C (2016–2025). Under high emission scenarios, precipitation will decrease in most areas, with annual precipitation days decreasing by over 5% and continuous dry days (CDD) increasing. Under RCP8.5, CDD increase will extend across Southern China with enhanced magnitude, while under RCP4.5, CDD increase will be ~2 days in Jianghan and western Jiangnan regions.

[Figure 8: see original paper] Spatial distribution of consecutive dry days (CDD) changes in RCP4.5 and RCP8.5 scenarios (2016–2025)

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10. Drought Disaster Risk Management and Control Strategies

10.1 Risk Management Strategy Structure

Drought disaster risk management involves designing, implementing, and evaluating strategies, policies, and measures to enhance risk understanding, transfer risks, and improve response and recovery, aiming to increase human security, resilience, and sustainable development [4].

A conceptual model for drought risk control strategy structure targets different risk control factors: - **High hazard areas**: Strategies include artificial precipitation enhancement, dew utilization, avoiding high-risk periods, and mulching to reduce evaporation. - **High exposure areas**: Strategies include developing drought-resistant crop varieties, industrial diversification, and migration projects to reduce exposure duration and socioeconomic vulnerability. - **High environmental sensitivity**: Strategies include ecological restoration, improving water conservation capacity, and enhancing soil moisture retention. - **Weak prevention capacity**: Strategies include strengthening drought monitoring, mitigation technology development, and public scientific literacy.

[Figure 9: see original paper] Conceptual model of drought risk control strategy structure (targeting risk control factors)

A second conceptual model addresses different risk-bearing sectors: - **Agriculture**: Establish monitoring/early warning systems, develop refined planting patterns, improve infrastructure, and establish agricultural insurance systems. - **Water resources**: Enhance engineering safety standards, strengthen management and decision-making systems, and optimize water allocation through market mechanisms. - **Ecosystems**: Establish ecological red lines and compensation mechanisms, implement ecological restoration pilots, and improve disaster defense capabilities.

[Figure 10: see original paper] Conceptual model of drought risk control strategy structure (targeting risk-bearing sectors)

10.2 Risk Control Technical Countermeasures

Based on the management strategies, specific technical countermeasures are proposed for different regions and sectors:

1) Weather Modification in High-Risk Areas
High-risk areas with low precipitation and high agricultural loss rates (e.g., Yunnan-Guizhou Plateau) should develop atmospheric water resources through artificial precipitation enhancement. Located in southwest water vapor channels, these regions have substantial cloud water resources that can be exploited during drought periods to increase water supply and reduce disaster risk.

2) Ecological Restoration in Environmentally Fragile Areas
Areas with high drought risk and ecological fragility (Yunnan-Guizhou Plateau, most of Guangxi, upper-middle Yangtze) should implement ecological restoration through returning farmland to forest, protecting ecological shelterbelts and water conservation forests, and developing compound ecological agriculture. This improves ecosystem resilience and reduces vulnerability.

3) Food Security Priority in Major Agricultural Regions
Drought increases food production instability, agricultural costs, and threatens food security. Comprehensive countermeasures include: establishing climate change monitoring and response systems, improving water conservancy engineering standards, perfecting agricultural insurance, adjusting crop cultivation patterns, and promoting water-saving and conservation tillage technologies.

4) Addressing Water Resource Spatiotemporal Imbalance
Drought exacerbates uneven water distribution and supply-demand contradictions. Countermeasures include: improving monitoring and emergency management systems for extreme hydrological events, enhancing engineering safety standards, strengthening flood-drought mitigation systems in key areas, optimizing water allocation through market mechanisms, and promoting water rights reform and water-saving technologies.

5) Sustainable Land Resource Utilization
Drought affects land quality and sustainable use, increasing geological disaster risks. Countermeasures include: strengthening land use planning, assessing environmental carrying capacity, evaluating meteorological-geological risks for major projects, implementing engineering and ecological restoration measures

to reduce soil erosion, and strengthening geological environment monitoring and early warning.

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11. Conclusions and Discussion

From 1961 to 2015, precipitation in Southern China showed fluctuating changes without significant linear trends, but average precipitation decreased significantly after the 21st century with increased interannual oscillation amplitude. Temperature showed significant upward trends from 1961–2015, with warming rates exceeding global averages. Temperature began continuous rise from 1976, with negative anomalies before the 1990s (-0.4°C) and positive anomalies (0°C) after 1997, accompanied by increased variation coefficients and oscillation amplitude. The temperature mutation year was 1997.

Sichuan Province had the largest average drought-affected area (17.4% of Southern China' s total), followed by Anhui. Southwest China showed significant increases in drought-affected areas. Severe drought high-risk areas concentrate in southwestern China, where warming has increased drought frequency, intensity, and risk, with secondary high-risk areas expanding significantly after the 1997 temperature mutation.

Future projections (2016–2025) indicate Southern China' s temperature will increase by ~0.6–0.7°C, with annual precipitation days decreasing and continuous dry days increasing, suggesting potentially higher drought frequency.

The conceptual model of drought disaster risk formation provides deeper understanding, revealing not only formation mechanisms but also variability and dynamic processes. Drought disasters have both natural and social attributes, requiring risk assessment to integrate meteorology with ecology and socioeconomic systems. Under climate warming, Southern China' s drought frequency and impacts are increasing, necessitating strengthened scientific risk assessment and countermeasure research to shift from reactive disaster response to proactive risk management.

References

[1] Research progress and prospects on monitoring, early warning and mitigation technology of drought meteorological disasters in Northwest China. *Advances in Earth Science*, 2015, 30(2): 196–213.
[2] Mishra A K, Singh V P. A review of drought concepts. *Journal of Hydrology*, 2010, 391(1/2): 202–216.
[3] IPCC. *Climate Change 2013: The Physical Science Basis.* Cambridge: Cambridge University Press, 2013.
[4] Allen S K, Barros V, Burton I, et al. Summary for Policymakers. In: IPCC,

ed. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge, UK, and New York, NY, USA: Cambridge University Press, 2012: 1-19.
[5] Characteristics of drought disaster chains in Southwest and South China. *2009*.
[6] Analysis of causes for severe spring drought in Southwest China in 2009/2010. *2013*.
[7] Characteristics of regional severe drought in Southwest China in 2009. *2015*, 33(4): 537-545.
[8] Severe high temperature and drought in Hunan in summer 2013 and atmospheric circulation anomalies. *2014*, 32(4): 593-598.
[9] Lu J, Vecchi G A, Reichler T. Expansion of the Hadley cell under global warming. *Geophysical Research Letters*, 2007, 34(6): L06805.
[10] Neelin J D, Münnich M, Su H, et al. Tropical drying trends in global warming models and observations. *Proceedings of the National Academy of Sciences of the United States of America*, 2006, 103(16): 6110-6115.
[11] Sheffield J, Wood E F. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. *Climate Dynamics*, 2008, 31(1): 79-105.
[12] Impact of climate change on agricultural drought loss rates in China and its regional differences between North and South. *2015*, 73(6): 1092-1103.
[13] Drought disaster risk characteristics and countermeasures in Southern China under climate warming. *Ecology and Environmental Sciences*, 2016, 25(3): 432-439.
[14] Drought risk characteristics in Southern China based on Copula functions. *2015*, 73(6): 1080-1091.
[15] Drought disaster risk assessment in Southern China. *2015*, 24(5): 12-24.
[16] Drought vulnerability assessment in Southern China based on principal component analysis. *Ecology and Environmental Sciences*, 2014, 23(12): 1897-1904.
[17] Discussion on drought and drought disaster risk characteristics and management strategies under climate warming. *Advances in Earth Science*, 2014, 29(1): 80-91.
[18] Feyen L, Dankers R. Impact of global warming on streamflow drought in Europe. *Journal of Geophysical Research*, 2009, 114(D17): D17116.
[19] Tol R S J, Leek F P M. Economic analysis of natural disasters. In: Downing T E, Olsthoorn A A, Tol S J R, eds. *Climate, Change and Risk*. London: Routledge, 1999, 308-327.
[20] Development and scientific challenges of drought monitoring and evaluation technology. *Advances in Earth Science*, 2011, 26(7): 763-778.
[21] Modern Climate Statistical Diagnosis and Prediction Technology. *Meteorological Press*, 2007: 36-69.
[22] Agricultural Meteorological Disasters and Mitigation Technologies. *Chemical Industry Press*, 2010.
[23] Theory and practice of disaster research. *Journal of Natural Disasters*, 2002, 11(3): 1-9.

[24] Risk assessment and zoning of agricultural drought disaster in Northwest Liaoning. *Journal of Disaster Prevention and Mitigation Engineering*, 2012, 32(3): 300–306.
[25] Impacts of arid climate change on agriculture and ecology in Northwest China and countermeasures. *Meteorological Press*, 2012: 442–448.

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