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ISSN 2959-6157

Long-term Variation Pattern of Heavy Precipitation Events in the Taihu Economic Circle under the Background of Climate Change

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Abstract:

This study focuses on three cities (Suzhou, Wuxi, and Changzhou) in the Taihu Economic Circle to explore the long-term variation characteristics of heavy precipitation events. Based on daily precipitation data from the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources (NASA POWER) database from 1982 to 2024, this study defines a heavy precipitation event as a day with precipitation exceeding 20 mm to analyze the variation further. Results show annual precipitation increased significantly. Specifically, June 2024 precipitation surged, while July-August saw abnormal drops in some cities. Linear regression reveals annual heavy precipitation frequency rises 1.6-1.9 days per decade, with other possible influencing factors to be considered, such as the combined effects of El Niño/La Niña-Southern Oscillation (ENSO), global warming, and urbanization. This study reveals increased heavy precipitation risk, which can provide a basis for climate adaptation strategies. In the future, multivariate analysis will still be needed to further quantify the contributions of different influencing factors.

Keywords: Heavy precipitation; Taihu Economic Circle; Climate change; Trend analysis; Influencing factors

1. Introduction

In the context of global climate change, extreme weather events like heavy precipitation have become more frequent, triggering natural disasters such as mountain torrents and debris flows. These events pose threats to water resource management, damage infrastructure, and agriculture [1]. According to statistics, global flood disasters in 2019 caused $80 billion in economic losses, far exceeding those from droughts and earthquakes that year [2]. With intensified global warming, the intensity and frequency of heavy precipitation have increased synchronously. Many reports indicate that on a global scale, for ev-

ISSN 2959-6157

ery 1℃ increase in global temperature, the intensity of extreme daily precipitation events will increase by 5.22% - 8.57%, and this change has a linear relationship with the magnitude of global warming [3, 4].

Most regions in China have also been confronted with severe issues regarding changes in the frequency of heavy precipitation over the past few decades. Further researches point out that there are obvious regional differences in annual heavy precipitation in China. Some areas show an increasing trend. For instance, the south of the Yangtze River's middle and lower reaches has seen a significant rise. However, others exhibit a decreasing trend, such as the northern Huanghuai region, where heavy precipitation amounts have declined notably [5, 6].

The Taihu Economic Zone is situated in the core circle of the Yangtze River Delta, boasting an abundant water resource, and it is one of the regions with the strongest economic vitality and the highest degree of urbanization in China. However, cities such as Suzhou, Wuxi, and Changzhou within this region have been repeatedly attacked by heavy precipitation in recent years, which has caused a great impact on people's lives, urban operation, public transportation, and so on [5]. Nowadays, existing studies mostly focus on the trends of precipitation change in a single city. For example, Zhao focused on the heavy precipitation in Changzhou. The research shows that over the past nearly 70 years, extreme rainstorms in the main urban area of Changzhou have become more frequent and intense. Meanwhile, Zhou, X. et al. looked at precipitation variation in Wuxi, showing that the interannual variation of precipitation sees a significant upward trend and periodicity [7-9]. However, precipitation is often affected by the combined influences of multiple factors, such as thermal circulation and topographic features, resulting in the lack of universality for the Taihu area in China [10]. In addition, most studies put emphasis on the interannual or diurnal variation characteristics of precipitation, while insufficient attention has been paid to the changing trends of the frequency of heavy precipitation and their driving factors.

To address these gaps, this study focuses on Changzhou, Wuxi, and Suzhou in the Taihu Economic Zone, using NASA precipitation data (1982-2024) to examine heavy precipitation frequency trends. This research is expected to provide key data support and a scientific basis for revising urban flood control and formulating climate change adaptation strategies in this region.

2. Method

2.1 Data Sources

The precipitation data required for this study were obtained from the NASA POWER database [11]. This database integrates satellite observation data and numerical model simulation results, and provides standardized meteorological element data such as solar radiation and precipitation, which can meet the needs of global-scale climate research and applications. In this study, daily precipitation data from 1982 to 2024 for Suzhou, Changzhou, and Wuxi were acquired through the Data Access Viewer (DAV) platform of the NASA POWER database. After downloading, the data were imported into Microsoft Excel for integration and standardization, which laid a foundation for subsequent statistical analysis and charting.

2.2 Research Methods

2.2.1 Definition of heavy precipitation events

According to the standards of the China Meteorological Administration and the national standard GB/T 28592-2012, precipitation is classified into four grades: light rain (<10 mm), moderate rain (10.0–24.9 mm), heavy rain (25.0–49.9 mm), and torrential rain (≥50.0 mm).

However, the absolute threshold classification method has regional limitations: For arid and semi-arid regions, due to the low total precipitation, events reaching the "torrential rain" threshold are almost non-existent [12]. For the Suzhou-Wuxi-Changzhou region (the focus of this study), although torrential rain events (daily precipitation ≥50 mm) are highly destructive, their annual occurrence frequency is extremely low—such scarce events significantly increase the uncertainty of trend fitting, leading to a lack of statistical significance in the results.

Based on the above reasons, this study integrates the regional climate characteristics with findings from scholarly research and official criteria from the international climate index dataset CLIMDEX to define precipitation events with daily rainfall ≥20 mm as heavy precipitation days [7,13]. Then, this essay counted the annual occurrence frequency of such events. This threshold not only conforms to internationally common research methods but also aligns with the actual conditions of the study region, reducing statistical bias.

1.2.2 Data analysis methods

This article used a linear regression model to fit the interannual variation trend of heavy precipitation frequency. The least squares method was adopted to construct the regression equation:

$$y = ax + b \tag{1}$$

x represents the year, y represents the annual frequency of heavy precipitation, and a represents the trend coefficient; $a > 0$ indicates an upward trend in frequency, while $a < 0$ indicates a downward trend.

Significance testing (p-test) was further conducted to determine the statistical reliability of the trend. Meanwhile, data analysis was used to conduct t-tests to determine whether there was a significant change in precipitation in the Suzhou-Wuxi-Changzhou area and its strength relationship with the years. When the significance is less than or equal to 0.05, it indicates that the precipitation varies significantly with the years and is not caused by random fluctuations. In this article, scatter plots and bar charts are used to visualize data.

3. Results

3.1 Analysis of Monthly Precipitation Changes and Their Significance

Table 1 shows a comprehensive analysis of daily precipitation data from 1982 and 2024 for Changzhou, Suzhou, and Wuxi. Results indicate significant changes in both the total amount and spatiotemporal distribution of precipitation in the region (all p-values were far less than 0.05, which led to the rejection of the null hypothesis and confirmed that the increase in average daily precipitation is not due to random fluctuations). Furthermore, compared to 1982, the variance of precipitation in all three cities increased substantially in 2024, suggesting greater variability in daily precipitation and a higher frequency of heavy precipitation events.

Table 1. T-test results of daily precipitation in Suzhou, Wuxi, and Changzhou in 1982 and 2024

City	1982 average daily precipitation/mm	2024 average daily precipitation/mm	T Stat	P value (Two-tailed test)
Changzhou	2.13	4.31	-3.67	0.00026
Suzhou	2.25	4.54	-3.73	0.00021
Wuxi	2.32	4.65	-3.67	0.00026

At the monthly scale, the changes in precipitation structure in Suzhou, Wuxi, and Changzhou were largely consistent. In Fig. 1, the horizontal axis represents the month, and the bar chart represents two years, which are 1982 and 2024 respectively. The vertical axis represents the monthly precipitation in millimeter. In 2024, spring, autumn, and winter precipitation all exceeded that in 1982, indicating an overall increase in total precipitation (Fig. 1). Meanwhile, June 2024 experienced a dramatic surge in rainfall. Suzhou's precipitation jumped from 88.47 mm to 299.31 mm, Wuxi's from 96.75 mm to 301.29 mm, and Changzhou's from 64.49 mm to 241.50 mm. This pattern suggests an increasingly extreme regional precipitation distribution. However, Suzhou and Wuxi exhibited an unusual decrease in precipitation during July and August in 2024, potentially linked to that year's specific climatic conditions and other influencing factors.

ISSN 2959-6157

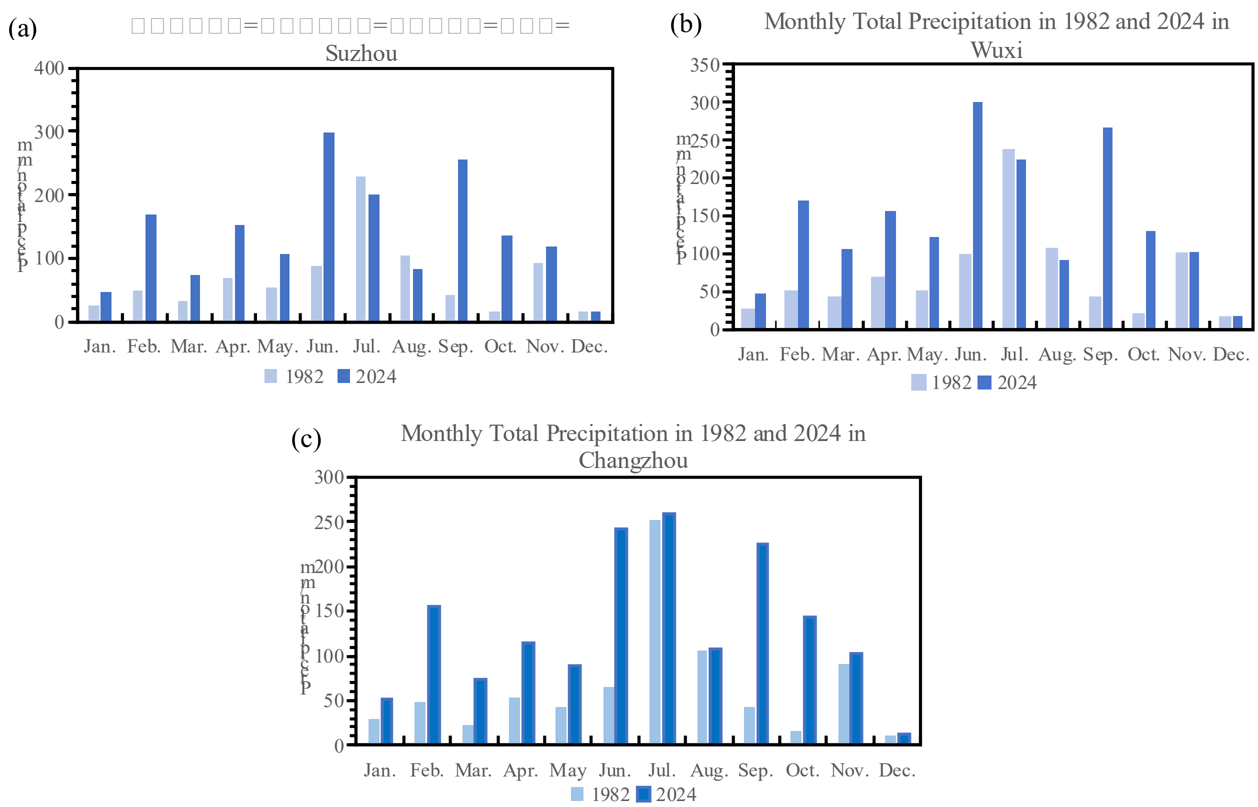

Fig. 1 Comparison of monthly total precipitation between 1982 and 2024. (a) is the monthly total precipitation between 1982 and 2024 in Suzhou. (b) is the monthly total precipitation between 1982 and 2024 in Wuxi. (c) is the monthly total precipitation between 1982 and 2024 in Changzhou.

3.2 Variation Trends in Heavy Precipitation Frequency in the Suzhou-Wuxi-Changzhou Region

Linear regression analysis indicates a consistent upward trend in the annual frequency of heavy precipitation (daily precipitation ≥ 20 mm) in the Suzhou-Wuxi-Changzhou region from 1982 to 2024 (Fig. 2). The horizontal axis of this graph represents the years from 1982 to 2024, and the vertical axis shows the frequency of heavy precipitation in each year. The slope values of the trends for Suzhou, Wuxi, and Changzhou are 0.1811, 0.1607, and 0.1863, respectively, suggesting an average increase in heavy precipitation days of approximately 1.6 to 1.9 days per decade across the three cities. Despite the clear upward trend, the relatively low R^2 values of the regression models indicate that the year factor alone accounts for only 15%–20% of the frequency variation, which implies that the heavy precipitation events are significantly influenced by other climate systems.

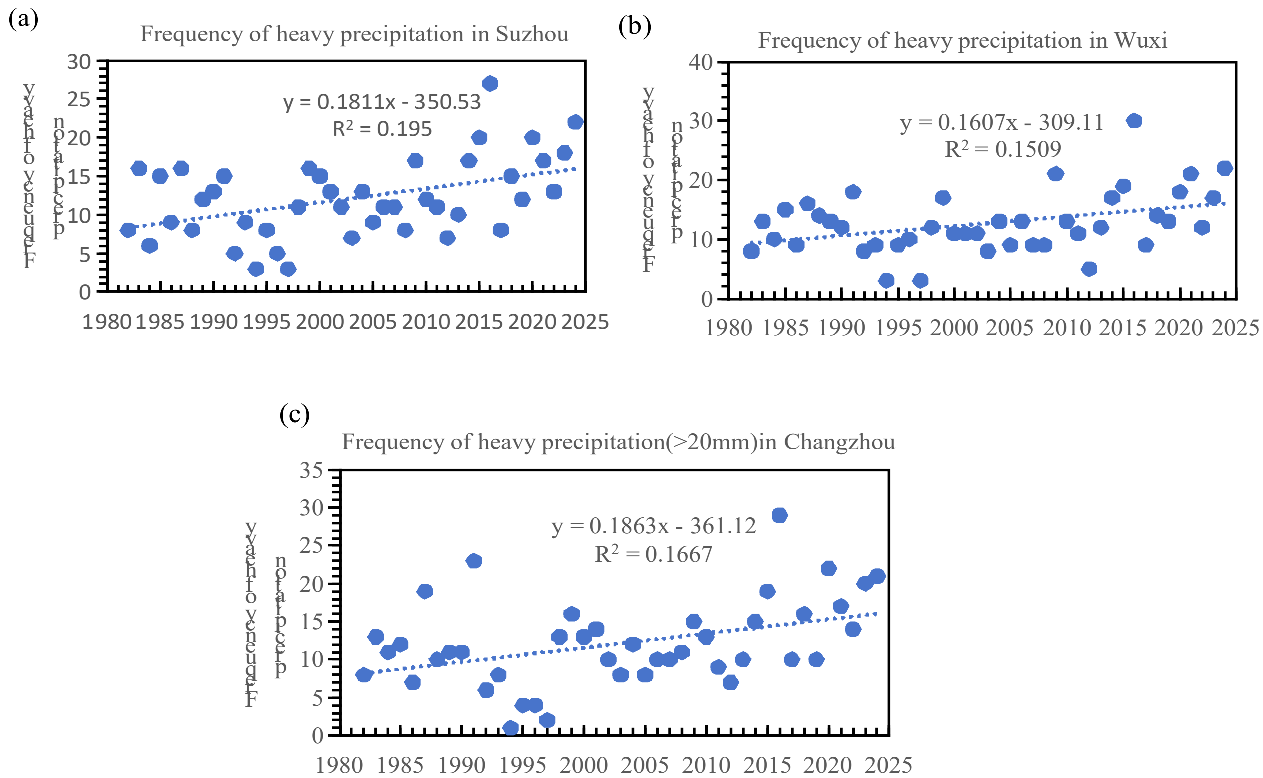

Fig. 2 Trends in heavy precipitation frequency from 1982 to 2024. (a) The trend in heavy precipitation frequency from 1982 to 2024 in Suzhou, (b) The trend in heavy precipitation frequency from 1982 to 2024 in Wuxi, (c) The trend in heavy precipitation frequency from 1982 to 2024 in Changzhou.

4. Discussion

This study compared monthly precipitation between 1982 and 2024 in the Suzhou-Wuxi-Changzhou region using t-test analysis. It confirms that the total precipitation in 2024 was significantly higher than in 1982, with a marked increasing trend in the frequency of heavy precipitation events. At the seasonal scale, rainfall in June 2024 increased dramatically, while July and August exhibited an anomalous decline. These changes are likely driven by multiple factors. According to research, the significant increase in June 2024 precipitation was directly caused by an anomalous connection between the Western Pacific Subtropical High and the North African High, forming an inverted Ω circulation pattern [14]. This system converged abundant moisture from the Bay of Bengal and the Western Pacific toward the Jiangnan region, substantially enhancing early summer rainfall—consistent with the sharp increase observed in June 2024. Meanwhile, the precipitation decline in July and August aligns with findings from Tao, M. and Sun, S., demonstrating that it was influenced by El Niño events within the ENSO cycle [15,16]. The strong northward oscillation of the subtropical high enhanced regional subsidence, which suppressed cloud and precipitation formation and led to reduced rainfall in Suzhou and Wuxi.

Meanwhile, this essay used linear regression to analyse the annual frequency of heavy precipitation events (daily precipitation $\geq$ 20 mm) across the three cities, and the results revealed a consistent upward trend, with an average increase of approximately 1.6–1.9 days per decade. However, the low explanatory power (R^2) of the linear models suggests that heavy precipitation is also modulated by other climatic variables, and a univariate linear relationship is insufficient to fully reveal the driving mechanisms. Specifically, global warming has increased atmospheric moisture retention, elevating the climatic potential for heavy precipitation [17]. Urbanization-induced heat island effects and alterations in underlying surfaces may further intensify local convective activity, promoting the occurrence of heavy precipitation [7,18]. Additionally, interannual variability in the Western Pacific Subtropical High and the East Asian Summer Monsoon regulates the spatiotemporal distribution of regional precipitation [14].

ISSN 2959-6157

To obtain a more accurate contribution of the impact factor, the Gamma regression model can be adopted. When dealing with complex impact factors, the random forest model can also be applied.
The findings highlight the growing risk of heavy precipitation in the Suzhou-Wuxi-Changzhou region and reveal potential climatic and anthropogenic influencing factors. However, this study only identified a univariate relationship between heavy precipitation and temporal trends using linear regression, without quantifying the contributions of other key factors such as the intensity of the Western Pacific Subtropical High, urbanization rate, or ENSO indices. Future research should improve methodologies to address these limitations.

5. Conclusion

This study examined the long-term characteristics of heavy precipitation events (daily precipitation ≥ 20 mm) in Suzhou, Wuxi, and Changzhou—cities within the Taihu Economic Zone. It used daily precipitation data from the NASA POWER database for the period between 1982 and 2024. Methods such as linear regression and t-tests revealed a significant increasing trend in both total annual precipitation and the frequency of heavy precipitation events, alongside a tendency toward more extreme precipitation distribution. Notably, June 2024 saw a dramatic surge in rainfall, while July and August in that year experienced a decline. The results indicate that the number of heavy precipitation days increased by approximately 1.6–1.9 days per decade on average, influenced collectively by factors such as ENSO, global warming, and urbanization.
This research reveals the heightened risk of heavy precipitation in the Taihu Economic Zone and provides a scientific basis for urban flood prevention and climate adaptation planning. However, the study did not quantify the contributions of key factors such as urbanization and ENSO to changes in heavy precipitation. Future work should adopt multivariate analysis models to deeper investigate the interactions and driving mechanisms among these variables.

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