Dean&Francis

ISSN 2959-6157

The Changing Trend of Precipitation Patterns along the Yellow Sea and Bohai Sea Coasts and Its Correlation with Global Warming

Shiyu Li

Academy of Geography, Sociology and International Studies, Hong Kong Baptist University, Hong Kong, China

24261106@life.hkbu.edu.hk

Abstract:

Anthropogenic climate change is exerting a strong influence on the water cycle, which presents a massive challenge to ecosystem and socio-economic stability, with densely populated regions especially susceptible to it. Although a lot of research has been done on the precipitation trends of the East Asian area, the relationship between early monsoon-affected Yellow and Bohai Sea coasts with global warming and the trends of precipitation is still uncontrolled. To address this problem, this study compared the pattern of precipitation of the Liaodong Peninsula between 1982 and 2024. The analysis employed NASA POWER gridded precipitation data and the GISTEMP data of global mean temperature tapering data. NASA's Goddard Institute of Space Studies manipulated such data and utilized two-sample T-tests, linear quotients, and Pearson correlations to examine monthly distinctions, extreme precipitation indexes, and how they follow global warming. Findings indicated that there were great changes in the way precipitation is distributed per month and more dramatic events of precipitation. Also, these extraordinary occurrences were positively associated with the warming of the world's climate. This work demonstrates that global warming is increasing the intensity and concentration of summer monsoons in this area, and an increase in the odds of extreme rainfall could be valuable in localized information on climate adaptation and mitigation measures.

Keywords: Global warming, Precipitation trend, Extreme precipitation

1. Introduction

Anthropogenic climate change is causing global warming and evidently modifying the human hydrological cycle of the Earth. The Clausius-Clapeyron equation includes the idea that greenhouse gas concentration increases the capacity of storage of water in the atmosphere. This thermodynamic response results in amplification of the hydrological cycle, generally manifested as the increase in frequency and intensity of extreme precipitation, alteration of the magnitude and spatial distribution of rainfall, and accumulation of rainfall [1]. These transformations are a threat to world ecosystems, water security, agricultural production, and social stability. The response to regional precipitation needs to be learned to develop effective adaptation and mitigation strategies.

The Yellow and Bohai Sea areas in coastal China can be taken as a very sensitive area to these climatic changes. This region forms a critical part of the economy of the country, encompassing the big metropolitan block of Beijing-Tianjin-Hebei as well as the Shandong Peninsula, the agricultural land of the country, and big industrial cities. It is then prone to hydrological change due to its high population and economic resources. Alterations in the precipitation regimes here have a direct impact on freshwater supply, increase the risks of floods in the cities situated at low altitudes, jeopardize erosion of the coasts, and affect the efficiency of the marine ecosystem [2].

Global warming has been recorded to have altered the precipitation patterns in East Asia in a number of studies. Studies on a continental/national level have shown wet-get-wetter tendencies overall with high regional variations [3]. Kamae has singled out the fact that there is more extreme precipitation time over eastern China [4]. There is a great gap in research. Most of the evaluations are national or subcontinental and can be confused by the complicated climatic behavior of such important locations as the Yellow and Bohai Sea coasts. The geography and topography in this area, being between land and sea, further exposes it to the complicated interplay of the East Asian monsoon, the topography of the area, and the oceanic forces [5]. Therefore, the precipitation regime of the Yellow and Bohai Sea coastline region and its relationship with global warming indices should be studied in detail and on a long-term basis. To go beyond the gross generalizations and provide specific, localized information on climate, a scientific method is needed.

In an attempt to address this gap, the proposed research is set to provide an intricate investigation of the spatiotemporal variability of the precipitation along the Yellow Sea and Bohai Sea coasts during the last 40 years (1982-2024). The primary objective is to record long-term preciosity patterns and measure their response to global warming.

2. Research Method

2.1 Data Source and Processing

The main meteorological data to be used in the study came through NASA's Prediction of Worldwide Energy Resources (POWER) project, which gives access to a globally gridded, satellite-based, reanalysis-integrated dataset [6]. The selection of this source was based on its large spatial coverage and extensive temporal coverage as well as its use in the study of climate trends in complicated coastal terrain. As the key indicator of global warming, the GMTA data were taken based on the NASA GISS Surface Temperature Analysis (GISTEMP v4) [7].

The region under study is specifically set as the coastal zone of the Liaodong Peninsula, which is a very important and representative area of the larger Yellow and Bohai Sea coastal zones. The Bohai Sea, Yellow Sea, and mountains have different microclimates in this peninsula. In this field, gridded daily precipitation was obtained.

The analysis covers a 43-year time range from January 1982 to December 2024, which is long enough to be considered robust in identifying trends in climate studies. Some of the large time series were obtained using the data on daily precipitation: First, monthly and annual total precipitation: adding daily data. Second, Extreme Precipitation Indices: According to the recommendations of the Expert Team on Climate Change Detection and Indices (ETCCDI), but in regional contexts. One of the main indices was the number of days filled with precipitation of 20 mm and above annually, which has been widely adopted in East Asian research to determine severe precipitation [8]. The work with the data aggregation and visualization started with Microsoft Excel.

2.2 Analytical Methods

2.2.1 Trend analysis in monthly precipitation

The mean monthly precipitation was compared using an objective two-sample T-test to find whether there was a proper distribution of the record precipitation at the beginning and end of the record. Mean monthly precipitation of each month was collected in 1982 to create one sample, μ_1, which represented the past base throughout history. The second sample, μ_2, is the current, which is made by summing the average monthly precipitation by month in 2024. The null hypothesis was that the means of the two samples were equal ($\mu_1 = \mu_2$) and that the monthly patterns of precipitation were the same. The alternative hypothesis

ISSN 2959-6157

was that the meanings are not the same (μ_1¡Ùμ_2). Statistical significance (two-tailed testing) was determined by use of a p-value. By supporting the alternative hypothesis that changes in patterns of monthly precipitation have significantly occurred, the p-value greatly rejected the null hypothesis.

2.2.2 Analysis of extreme precipitation events

The annual time series of the≥ 20mm index (number of heavy precipitation days per year) was plotted against time. A simple linear regression model was fitted to this data to quantify the long-term trend. The form of the model was:

$$Y = \beta_0 + \beta_1 \times X + \epsilon \quad (1)$$

where Y is the annual count of extreme precipitation days, X is the year, β? is the interception, β? is the slope (representing the trend, days/year), and ϵ is the error term. The statistical significance of the trend was assessed using the F-test and the p-value associated with the regression coefficient. The coefficient of determination was calculated to indicate the proportion of variance in the extreme precipitation data explained by the temporal trend.

2.2.3 Correlation with global warming

To investigate the linkage to global warming, the annual ≥ 20mm time series was correlated with a global mean temperature anomaly (GMTA) index. Make a scatter plot using the distended versions of the two sets of data. to mitigate the influence of autocorrelation and identify the co-varying relationship. The correlation coefficient and its corresponding p-value were computed to determine the strength and significance of the statistical association.

3. Result & Discussion

3.1 Evolving Monthly Precipitation Distribution

As shown in Fig. 1, the horizontal axis represents the months and the vertical axis represents the total monthly precipitation. The orange line indicates the data for 1982. From January to August, the overall trend is upward, and from August to December, it is downward. There are slight fluctuations in individual months due to natural causes. The months with high precipitation are concentrated in July and August, with the total monthly precipitation in these two months ranging from 100mm to 150mm. The blue line represents the data for 2024. From January to July, the overall trend is upward, and from July to December, it is downward, like 1982, with slight fluctuations in individual months. Monthly data as projected in 2024 indicates a higher concentration of high precipitation in the months of July and August, but the Figs 2, 3 are 400 mm to 450 mm and 200 mm to 250 mm, respectively, which is much more than the same months of 1982. The null hypothesis, which was rejected in the T-test ($p = 0.00264$), proves that there has been a significant change in the statistical distribution of the monthly rainfall. These shifts can be observed in the form of a higher annual precipitation in 2024 and in more intra-annual distribution. The summation of precipitation is largest, which is a disproportionate percentage of the annual amount. The monthly precipitation pattern of the Liaodong Peninsula differed considerably between 1982 and 2024. With the increase in seasonal contrast in East Asia (influenced by warming) due to increased moistness since the increased circulation of the monsoon, the moisture is carried in the enhanced circle of the monsoon [9]. This trend indicates a hydrological regime that is concentrated to the north seasonally and has a positive effect on the summer floods and water shortages during other seasons.

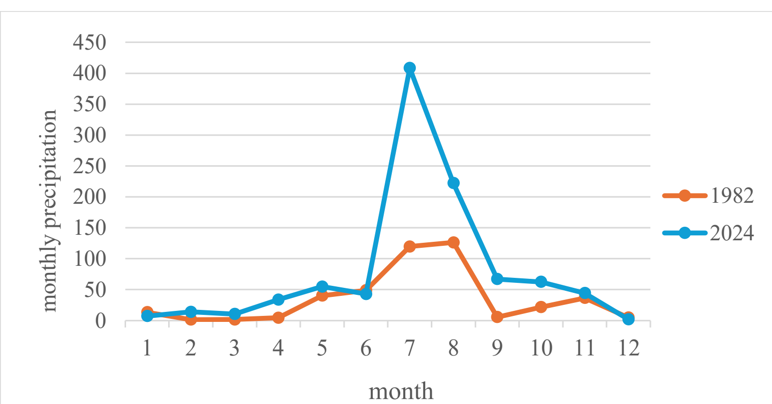

Fig. 1 Monthly precipitation in 1982 and 2024 (Photo/Picture credit: Original).

3.2 Trends in Extreme Precipitation Events

The linear skimming of the annual ≥ 20 mm index (days on which there is 20 mm or more of precipitation) indicates that there is a statistically significant upward direction ($p < 0.01$) in the 43 years of analysis. The value of R^2 of 0.4195639 indicates that a large proportion of the interannual variation in extreme days of rainfallis accounted for by the long-term trend. Local studies verify this finding, which is in accordance with the global warming theory. As an example, Chen et al. discovered that the magnitude and frequency of extreme precipitation had significantly risen in eastern China, which they attribute to thermodynamic rises in moisture content in the atmosphere [10].

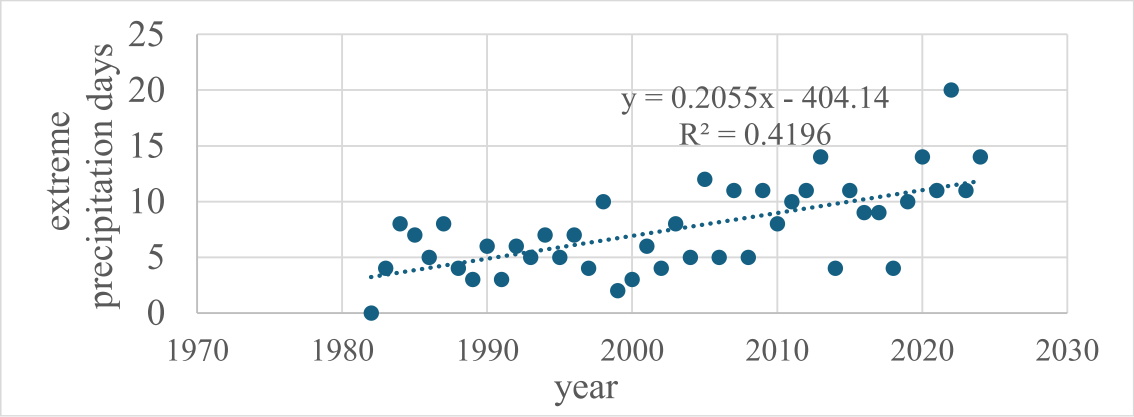

Fig. 2 The number of extreme precipitation days each year from 1982 to 2024 (Photo/Picture credit: Original).

3.3 Linkage to Global Warming and Future Projection

A significance value of less than 0.05 indicated a significant positive correlation between the Pearson correlation analysis between the detrended ≥ 20 mm and the global mean temperature anomaly (GMTA) ($r=0.635, p < 0.05$).

This measures that the inter-annual average global climate data have a positive relationship with extreme precipitation frequency at Liaodong Peninsula. With the trend to be linear, the regression model predicts that in 2050, the number of extreme rain days per year may reach 20 in the region. It should be kept in mind that this is a simple extrapolation of a recent warming pattern, and nonlinearities and future climate forcing are not considered. The prediction cautions about the risk of greater floods and focuses on adaptive planning.

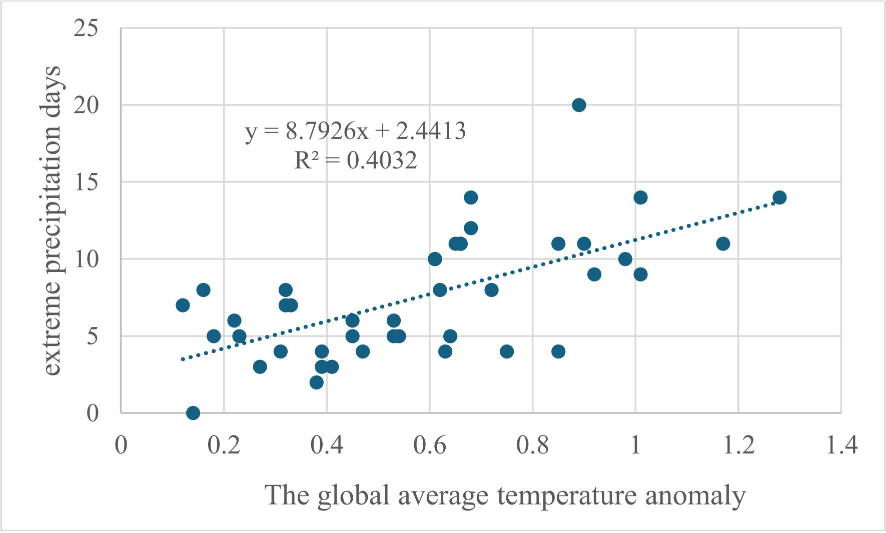

Fig. 3 The global average temperature anomaly and the number of extreme precipitation days in the same year (Photo/Picture credit: Original).

ISSN 2959-6157

3.4 Inter-Hemispheric Comparison

Liaodong Peninsula vs. the East Coast of North America. There is an interesting parallel that may be made with a parallel study done on the U.S. East Coast in the region of Washington, D.C., which also has a similar location in the middle latitude on an eastern seaboard of a continent [11]. The significant rise in the frequency of extreme precipitation in both regions is found to be statistically significant and is very much connected to the rise in the temperature of the Atlantic Ocean and the rise in moisture in the atmosphere [11]. This fact that is common across the hemisphere lends credence to the thought that the changes that have happened with the Liaodong Peninsula are a section of the changing east coast tendencies of the planetary warming. The topicality of our study, based on grasping Liaodong Peninsula microclimatic and monsoon processes, is a strong source of Asian equivalents, which have been previously studied in North America.

3.5 Physical Mechanisms

There are beneficial physical mechanisms to uphold these trends. The thermodynamic effect is the most noticeable in the first place: the Clausius-Clapeyron relationship can store about 7% of additional moisture per degree Celsius of heating in the warmer atmosphere [1]. It is the gas of good heavy rain clouds. Secondly, there are dynamic effects: global warming is postulated to be breaking up some of the large-scale atmospheric circulation patterns, such as the East Asian Summer Monsoon, and having an overall effect of increasing the percentage of stalled weather patterns, but also increasing the frequency of heavy rainfalls [12]. Higher temperatures cause more charge and updrafts in the atmosphere and result in more devastating storms and heavy rains [4].

3.6 Limitations and Uncertainties

This research can be limited in several ways. To begin with, the NASA POWER reanalysis data, though beneficial because of its spatial coverage, might be inaccurate in its ability to capture localized extreme events because of the lack of a dense ground-station network. Secondly, the analysis is performed on one index of extreme precipitation ($\geqslant$ 20 mm); a wider range of indices of ETCCDI would give a more holistic image. Thirdly and lastly, but not least, the identified trend is due to anthropogenic forcing as well as natural climate variability [13]. This method fails to strictly apportion the contribution of these elements, which would require complicated climate model experiments.

3.7 Future Work

The present study, from which future research must develop, can be divided into a number of directions. To obtain the percentage of anthropogenic forcing versus natural variability of trends, first, attribution studies based on high-resolution regional climate models are required. Second, it would be more mechanistic to study the impact of local sea surface temperature response in the Bohai and Yellow seas to peninsula precipitation patterns. Lastly, the multi-index analysis based on all ETCCDI indices would offer a more detailed perspective of the precipitation characteristics, such as the intensity, frequency, and duration.

4. Conclusion

It was systematic research on the dynamics of the precipitation patterns in the Liaodong Peninsula between 1982 and 2024 and the association with global warming. The three research questions have been addressed. To begin with, the rainfall has risen during the summer season as a result of changing the makeup of monthly precipitation. Second, the number of events of extreme precipitation (daily precipitation $\geqslant$ 20 mm) has shown a statistically significant increasing pattern. Last, the frequencies of such extreme events show an interannual relationship with the world mean temperature anomaly, which implies that there are anthropogenic effects on the hydroclimate of the area. Finally, the area is shifting towards an increased summer monsoon and increased precipitation threat. The work contributes to the developing literature of research on regional climatic responses to global warming, especially in the case of a crucial East Asian coastal region. It helps to promote the concept that thermodynamic processes have extreme precipitation. Real impacts are short-term and strong. The water resource managers and Dalian planners are obliged to upgrade the drainage systems and update the flood risk maps. The agricultural processes might be forced to be more flexible to the more unpredictable water supply, and both waterlogging and temporary drought may occur. This will be in a better position to provide the alteration of the precipitation induced by global warming.

References

[1] IPCC. Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 2021.

[2] Huang X, Wang D, Ziegler A, Liu X, Zeng H, Xu Z, Zeng Z. Influence of urbanization on hourly extreme precipitation over China. Environmental Research Letters, 2022, 17.

[3] Gao X, Hao Q, Wang L, Song Y, Ge J, Wu H, Xu B, Han L, Fu Y, Wu X, Deng C, Guo Z. Changes in monsoon precipitation in East Asia under a 2°C interglacial warming. Science Advances, 2024, 10.
[4] Kamae Y, Imada Y, Kawase H, Mei W. Atmospheric rivers bring more frequent and intense extreme rainfall events over East Asia under global warming. Geophysical Research Letters, 2021, 48.
[5] Ren X, Sha Y, Shi Z, Liu X. Response of summer extreme precipitation over East Asia during the mid-Holocene versus future global warming. Global and Planetary Change, 2021, 197: 103398.
[6] NASA. ArcGIS web application. NASA.gov, https://power.larc.nasa.gov/data-access-viewer/.
[7] GISTEMP Team. GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies, Dataset accessed 2025-09-01, https://data.giss.nasa.gov/gistemp/.
[8] Guo H, Chen S, Bao A, Hu J, Gebregiorgis A, Xue X, Zhang X. Inter-comparison of high-resolution satellite precipitation products over Central Asia. Remote Sensing, 2015, 7(6): 7181–7211.
[9] Jo A, Lee J, Sharma S, Lee S. Season-dependent atmosphere-ocean coupled processes driving SST seasonality changes in a warmer climate. Geophysical Research Letters, 2024, 51.
[10] Chen Y, Li W, Jiang X, Zhai P, Luo Y. Detectable intensification of hourly and daily scale precipitation extremes across Eastern China. Journal of Climate, 2020, 1: 1–56.
[11] Kirchmeier-Young M, Zhang X. Human influence has intensified extreme precipitation in North America. Proceedings of the National Academy of Sciences of the United States of America, 2020, 117: 13308–13313.
[12] Sun Q, Zhang X, Zwiers F, Westra S, Alexander L. A global, continental, and regional analysis of changes in extreme precipitation. Journal of Climate, 2021, 34: 243–258.
[13] Myhre G, Alterskjær K, Stjern C, Hodnebrog Ø, Marelle L, Samset B, Sillmann J, Schaller N, Fischer E, Schulz M, Stohl A. Frequency of extreme precipitation increases extensively with event rareness under global warming. Scientific Reports, 2019, 9.