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Drought Hazards and Hydrological Variations in the South Hebei Plain of China over the Past 500 Years

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Abstract: High-frequency drought hazards have presented persistent challenges for environmental management and sustainable development in the South Hebei Plain, China. In this paper, the assessment of meteorological droughts in the South Hebei Plain was conducted using a multifaceted approach to ensure a comprehensive analysis. Our results demonstrated that distinct timescale cycles, ranging from centennial–semicentennial to interdecadal variations, can be identified over the past few centuries. These cycles aligned with patterns observed in the middle Yangtze basin and corresponded to regional climatic conditions. The drought cycles in the South Hebei Plain showed significant correlations with variations in the monsoon climate, sunspot activity, global changes, and human disturbances. Changes in the frequency, duration, and intensity of droughts have notably impacted hydrological variations. Extreme droughts, in particular, have heightened concerns about their effects on river systems, potentially increasing the risk of channel migration. This study enhanced our understanding of meteorological hazard patterns in the South Hebei Plain and provided valuable insights into different stages of drought management. It thus can offer lessons for improving drought preparedness and resilience and for formulating adaptive measures to mitigate future droughts and promote regional sustainability.

Keywords: drought hazard; oscillational pattern; hydrological variation; risk mitigation; the South Hebei Plain

Citation: Yang, G.; Yao, C. Drought Hazards and Hydrological Variations in the South Hebei Plain of China over the Past 500 Years. *Atmosphere* **2024**, *15*, 1243. https://doi.org/10.3390/atmos15101243

Academic Editors: Jinping Liu, Quoc Bao Pham, Arfan Arshad, Masoud Jafari Shalamzari and Yanqun Ren

Received: 13 September 2024
Revised: 5 October 2024
Accepted: 10 October 2024
Published: 17 October 2024

1. Introduction

Drought hazards have long threatened socio-economic development and people's livelihoods [1–3]. The mismanagement of these hazards can lead to severe risks and destructive consequences, even in nations with abundant water resources [4,5]. According to the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR6), human activities have likely been dominant in contributing to climate warming since the 1950s. This ongoing global warming trend has profoundly affected the frequency, intensity, and distribution of droughts, posing major challenges for society [6–10]. Over the past 500 years, in the Holocene, climate change and extreme droughts have significantly impacted human production and daily life, with anthropogenic factors exacerbating these effects [11–13]. This period has been marked by significant climate fluctuations, including the Ming–Qing Little Ice Age and 20th-century warming, which have profoundly influenced terrestrial processes and ecosystems. Understanding these climate patterns and estimating future drought tendencies is crucial for addressing the challenges posed by both natural and anthropogenic factors [14,15].

In recent decades, research on drought hazards has garnered significant attention as scientists and policymakers have increasingly recognized the need for effective mitigation and preparedness strategies [16–19]. Efforts to establish various indices have improved the early identification of droughts, their intensity, and associated Earth surface processes. Consequently, numerous climate indicators have been estimated from ice cores, stalagmites, tree rings, and historical documents, significantly advancing the study of the paleoclimate and related warning systems worldwide [20–26]. Among these methodologies, the analysis of historical literature stands out for its unique advantages in studying climate change over long timescales. It provides precise temporal resolution, an extended time coverage, cost-effectiveness, and detailed descriptive data, making it an invaluable tool for reconstructing past climates and understanding the dynamics of climate variability at the centennial and millennial scales [11,27–30].

The Hebei Plain, located in North China, is particularly vulnerable to severe droughts due to its geographic location and semi-arid-to-arid environmental conditions. Recent research on human–land relationships has increasingly focused on drought hazards and their implications for regional sustainability [10,31–34]. Our study focuses on the South Hebei Plain, selected for its representative characteristics of meteorological hazards and pronounced water scarcity issues [10,32,35]. Situated on the east coast of the Eurasian continent, this region historically featured a network of nearly 20 lakes and depressions. However, recent climate changes and human activities have significantly altered these lakes. The combined effects of reduced water inflow and environmental changes have notably impacted the region's ecosystem, leading to a dramatic decrease in the number of lakes. Currently, only two major lakes, Baiyangdian and Qianqingwa, remain [36–38].

This study employed a variety of methods to investigate drought hazard cycles across different scales, providing valuable insights into their evolution and the implications for future climate management. Through comparative and overlay analyses, this research identified key factors influencing drought hazards in the South Hebei Plain and their potential impacts on its hydrological system. The findings shed light on the patterns and drivers of drought hazards, offering guidance for developing strategies for drought mitigation, water resource management, preparedness, and long-term sustainability in the region.

2. Study Area

The South Hebei Plain comprises 70 counties and districts across six cities. These cities are located in the southern part of Hebei Province, near the margins of Beijing and Tianjin. The cities included in this region are Baoding, Shijiazhuang, Cangzhou, Hengshui, Xingtai, and Handan. The research region covers an area of approximately 84,500 km^2, which constitutes 44.76% of the total area of Hebei Province. Distributed within this region are a total of seven meteorological stations (as shown in Figure 1).

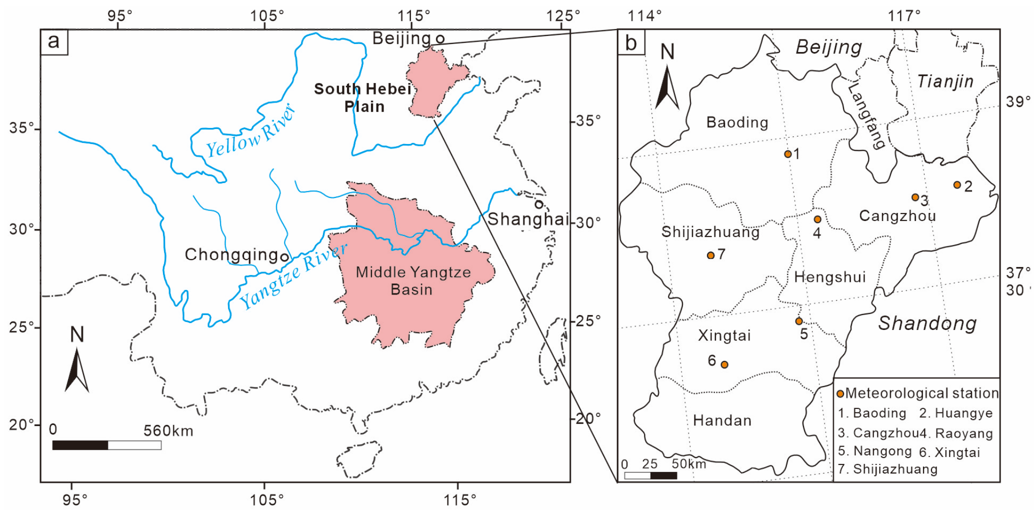

Figure 1. Geographic location of the study area and highlighted regions within the middle Yangtze basin (**a**), along with the cities and meteorological stations used in this study (**b**).

The region is characterized by a typical warm-temperature monsoon climate, with an annual mean temperature ranging from 12.6 °C to 15.2 °C. Precipitation in the region averages approximately 500 to 900 mm per year, with 50% to 75% of this rainfall occurring between May and September. This region is drained by the Ziya River, which is part of the Haihe River catchment. Major tributaries of the Ziya River, including the Ziya and Hutuo Rivers, predominantly flow northeastward [37,39]. This dense river network facilitates their connection of surface runoff, leading to the formation of twenty lakes of varying sizes across the South Hebei Plain. However, over the past fifty years, the remaining water surface area has decreased to just 6% due to accelerated aridification and intensive human disturbance [40,41]. Vegetation coverage in the region is relatively high, reaching up to 30%. The South Hebei Plain features NE- and NWW-oriented blocks, which create several subsidence centers and zones. Its tectonic activity intensity is relatively weak, resulting in a limited intensity of tectonic activity and its implications for meteorological hazards.

3. Materials and Methods

3.1. Materials

To characterize the temporal risk levels of meteorological hazards over the past 500 years, we have compiled a dataset that includes meteorological hazards' frequency and intensity, the population growth rate (PGR), urban hydrologic variations, sunspot activity, and potential river channel migration. The major meteorological data utilized in this study are the Best Track Dataset provided by the Academy of Chinese Meteorological Science of the China Meteorological Administration (CMA), covering the period from 1873 to 2003. This dataset was originally created by the China Central Meteorological Bureau (CCMB) for the years 1873 to 1979 and has since been updated by CMA and other meteorologists [42,43]. Additionally, annual precipitation data relative to the mean value from 1901 to 2016 were employed in our study [44,45]. To meet the requirements of our present study, we collected yearly measurements of droughts and floods from various references and reports covering the period from 1500 to 1996 [42,43,46]. We also created a 3000-year database from recent and ongoing studies to ensure a comprehensive and rational dataset [13,34,36,45,47–53].

3.2. Methods

In this study, meteorological flood–drought sequences were systematically categorized into five distinct levels, ranging from major flood (Level 1) to extreme drought (Level 5). This categorization was essential for understanding the variability and intensity of hydrological events in the study area. To reconstruct the drought and flood level sequence, we utilized available precipitation data and employed a classification method developed by the China Meteorological Administration. This scientifically validated approach enabled us to categorize historical drought and flood conditions based on three key principles: the disaster period, disaster phenomenon, and size of the disaster area. This five-level framework was widely adopted for analyzing historical drought and flood data, allowing for a consistent evaluation of conditions across different meteorological stations as follows: Level 1 (flood), Level 2 (partial flood), Level 3 (normal), Level 4 (partial drought), and Level 5 (drought) [42,43,46]. Drought and flood levels were primarily determined from historical records, although precipitation data, when available, provided a more accurate classification. The specific evaluation criteria used, outlined in Table 1, incorporated parameters such as Ri (annual precipitation from May to September), S (standard deviation), and R (average precipitation for the same period).

For a comprehensive analysis, the temporal patterns of droughts and floods were compared with precipitation-based drought anomaly maps from the 1960s using data from four to five meteorological stations within the study area. Their relatively high correlation coefficients (ranging from 0.66 to 0.81) effectively reflected the variations in drought and flood conditions within the region [37]. This approach enabled the identification of drought events and drying processes at various stations over the past few centuries, with drought levels classified based on well-established research [42,43,46]. To verify the validity of the historical data, field investigations were conducted to assess the reliability of the data from various meteorological stations and hydrological records. These field surveys allowed us to cross-check the historical data with on-the-ground observations, ensuring consistency and accuracy in the meteorological and hydrological datasets. This validation strengthened the conclusions drawn from the analysis, thus providing a more robust foundation for understanding past climate variations and their impacts on the region.

Table 1. Evaluation criteria for the 5-level drought/flood classification method (referring to [37,42,43,46]).

Level	Description	Recorded Examples	The Formula for Evaluating Drought and Flood Levels
1	Prolonged and intense precipitation leading to large-scale floods	Examples include 'spring and summer rain' and 'countless people and livestock drowned in spring and summer floods'	Ri > R + 1.17 S
2	Persistent precipitation accompanied by minor disasters and localized flooding	Examples include 'spring rain damaging crops' and 'April floods'	(R + 0.33 S) < Ri ≤ (R + 1.17 S)
3	Harvest year or absence of floods and droughts	Examples include 'big harvest' and 'a year of plenty'	(R − 0.33 S) < Ri ≤ (R + 0.33 S)
4	Localized drought with minor disasters occurring within a single season or month	Examples include 'spring drought', 'autumn drought', and so on	(R − 1.17 S) < Ri ≤ (R − 0.33 S)
5	A continuous drought lasting several months or a severe large-scale drought	Examples include 'people eating grass roots and bark' and 'a thousand miles of bare land'	Ri ≤ (R − 1.17 S)

This study also included a functional spectral analysis [54,55] and continuous wavelet transform (CWT) [56] to identify the dominant temporal cycles of droughts and floods in the South Hebei Plain. The Functional spectral analysis was employed to detect dominant frequencies and energy contributions from different periodic processes in time series data. This method applied a Fourier transform to a time sequence X_t (t = 1, 2, ..., N) and oscillation cycle T_1, expressed as

$$f(t) = a_0 + \sum_{n-1}^{\infty} \left[a_n \cos(n\omega_1 t) + b_n \sin(n\omega_1 t)\right] \tag{1}$$

The parameters can be determined as follows:

$$a_0 = \frac{1}{T}\int_{t0}^{t0+T} f(t)dt \tag{2}$$

$$a_n = \frac{2}{T}\int_{t0}^{t0+T} f(t)cos(n\omega_1 t)dt \tag{3}$$

$$b_n = \frac{2}{T}\int_{t0}^{t0+T} f(t)sin(n\omega_1 t)dt \tag{4}$$

$$\omega_1 = 2\pi/T_1 \tag{5}$$

Then, the frequency intensity index for each frequency was calculated as follows:

$$D(f_n) = \left(a^2 + b^2\right)N/2 \tag{6}$$

A larger-frequency intensity index indicated a more dominant or significant periodic cycle in the data.

The CWT was also applied to decompose the signal $f(t)$ into a set of elementary waveforms, examining the wavelet coefficients, which was defined as

$$W_f(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} f(t)\overline{\varphi((t-b)/a)\, dt} \tag{7}$$

where the mother wavelet function was given by

$$\varphi(\omega) = \omega^2 e^{-\frac{\omega^2}{2}} \quad (8)$$

Additionally, an overlay analysis and a thorough review of the historical data and literature [32,37,38,47,57] were conducted to explore the potential effects of climate change on hydrological systems over time. Through these methods, this research significantly enhanced our understanding of the historical hydrological processes in the South Hebei Plain. This deeper insight into climate cycles and their long-term impacts on hydrology would provide valuable guidance for developing adaptive strategies to address changing climate conditions, mitigate environmental vulnerabilities, and promote sustainable resource management and human activities (Figure 2).

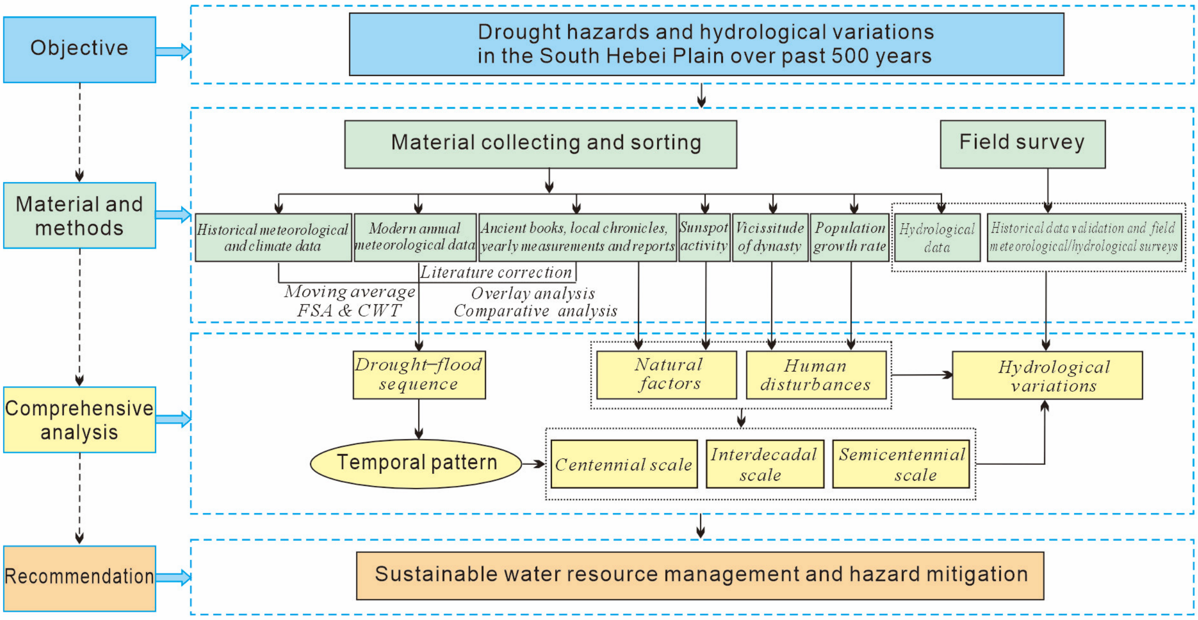

Figure 2. The flowchart illustrating the key components of the current study.

4. Results

4.1. Temporal Characteristics of Historical Droughts

Given its unique geographic location, sensitive eco-geological environment, specific climatic and hydrological patterns, and increasing anthropogenic activities, the South Hebei Plain is particularly vulnerable to droughts and floods. These extreme weather events have profound implications for resource utilization, regional planning, and the sustainability of local economies [33,34,58]. Areas such as Shijiazhuang and Handan frequently experience droughts and floods, which are major concerns in this region [44,50,58,59].

Our study indicated a total of 291 disaster years, accounting for 58.67% of the past five centuries. Of these, 143 years were marked by droughts and 148 by floods, indicating a relatively balanced occurrence of both disasters in the region. This finding aligned with broader regional and even global trends [11,53,57–68]. Notably, the recurrence interval of droughts in the South Hebei Plain has accelerated from every 4–5 years to every 2–3 years (as illustrated in Figure 3). From 1500 to the mid-18th century, droughts occurred less frequently, particularly during the middle Ming to early Qing Dynasty. However, significant changes have been observed in these drought and flood patterns over time, marked by distinct oscillations.

Using FSA and CWT methods, our research identified centennial-scale climate cycles ranging from 100 to 120 years (FSA) and 90 to 110 years (CWT). These cycles highlighted notable climate variability across the centuries. Additionally, from the mid-18th century onwards, the frequency of meteorological droughts and floods increased, with cycles occurring approximately every 70 years. At the interdecadal scale, the variability of drought hazards has been pronounced, with a discernible rhythm of approximately 20 years (cycles of 18 to 25 years based on FSA and 16 to 25 years according to CWT). The severity and frequency of these droughts and floods over the past five centuries have had significant impacts across most parts of the region [44,58]. These findings underscored the importance of understanding long-term climate cycles to effectively manage future environmental risks.

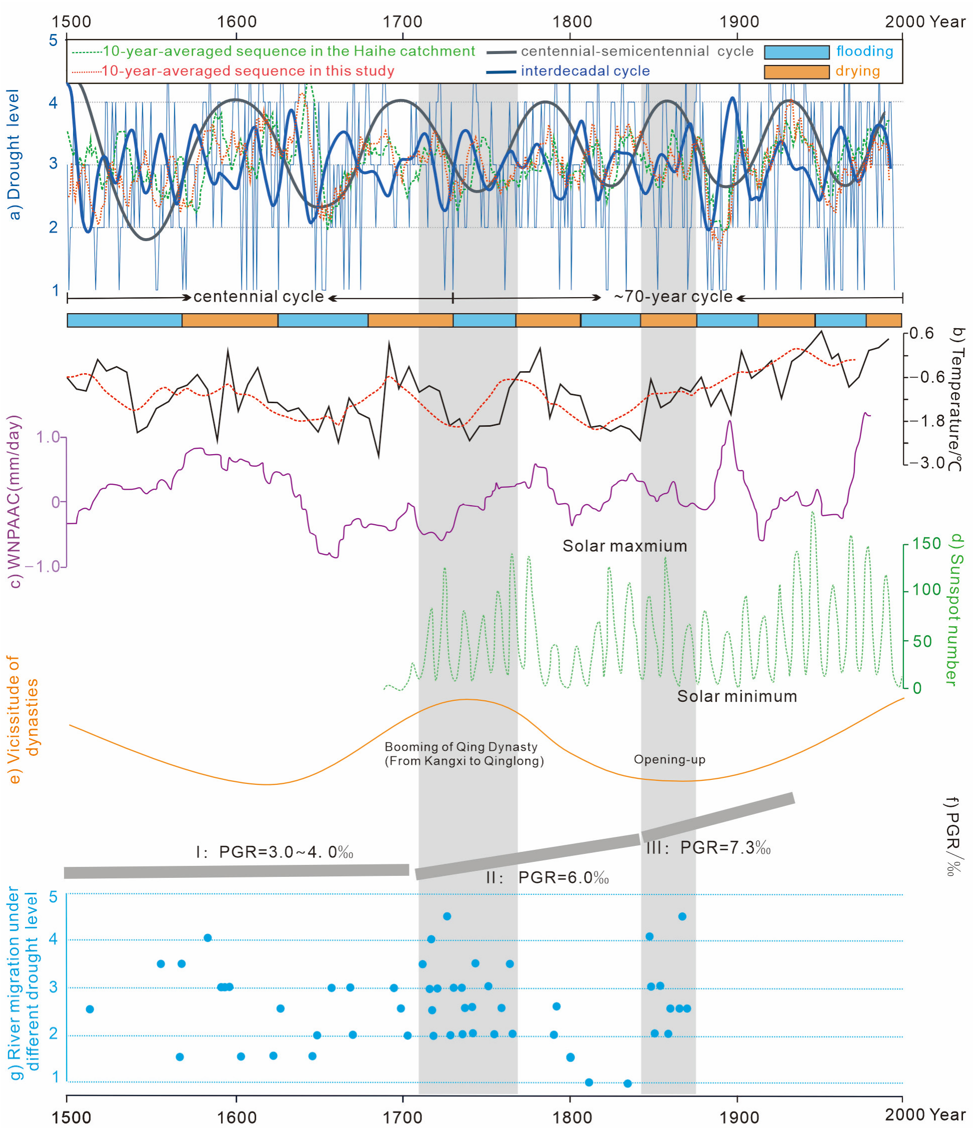

Figure 3. (**a**) Time sequence of drought–flood occurrences in the South Hebei Plain from 1500 to 1996 (Drought levels and 10-year-average sequences derived from our study dataset, with centennial and interdecadal cycles obtained through quantitative analysis using both FSA and CWT methods. The 10-year-average sequence in the Haihe catchment was sourced from previous studies [42,43,46]). (**b**) Reconstructed temperature data (Cited from [37]). (**c**) El Niño-related East Asian Summer Monsoon (EASM) anomalies, represented by the Western North Pacific Anomalous Anticyclone (WNPAAC) index(Cited from [60]). (**d**) Sunspot activity data(Derived from [61–64]). (**e**) the vicissitudes of dynasties(Drawn from [65]). (**f**) Population growth rate ((Modified from [66,67]). (**g**) River migration under different drought levels ((Modified from [37–39,68]).

4.2. Hydrological Migrations of the Hutuo River

The South Hebei Plain has indeed faced significant environmental challenges due to prolonged droughts, resulting in reduced river flows and declining groundwater levels. These issues have complicated water resource management and efforts to mitigate drought impacts. To investigate these challenges, we examined the Hutuo River, the second largest tributary in the region, focusing on its evolution and potential correlation with extreme droughts and floods since the middle Ming Dynasty (see Figure 4). The Hutuo River is a vital waterway in the South Hebei Plain, with both historical and contemporary significance [41,68]. Before the Ming Dynasty, the river exhibited a pattern of low-frequency diversion or relative stability. However, in the early Ming Dynasty, the Hutuo River began to shift its course more frequently, averaging one change approximately every 38 years [39,41]. This represented a departure from the previously stable course observed prior to the Ming Dynasty. By the late Ming Dynasty, around the 16th century, the stability of river channels, including the Hutuo River, significantly decreased, resulting in a notable increase in the frequency of course changes (Figure 4a). Between 1517 AD (the 12th year of Zhengde's reign) and 1644 AD (the first year of Shunzhi's reign in the Qing Dynasty), the Hutuo River underwent at least 11 major northward migrations, averaging about 1 significant shift every 12 years [39,41,47,68]. This period marked a slight instability in the river's course (Figure 4a).

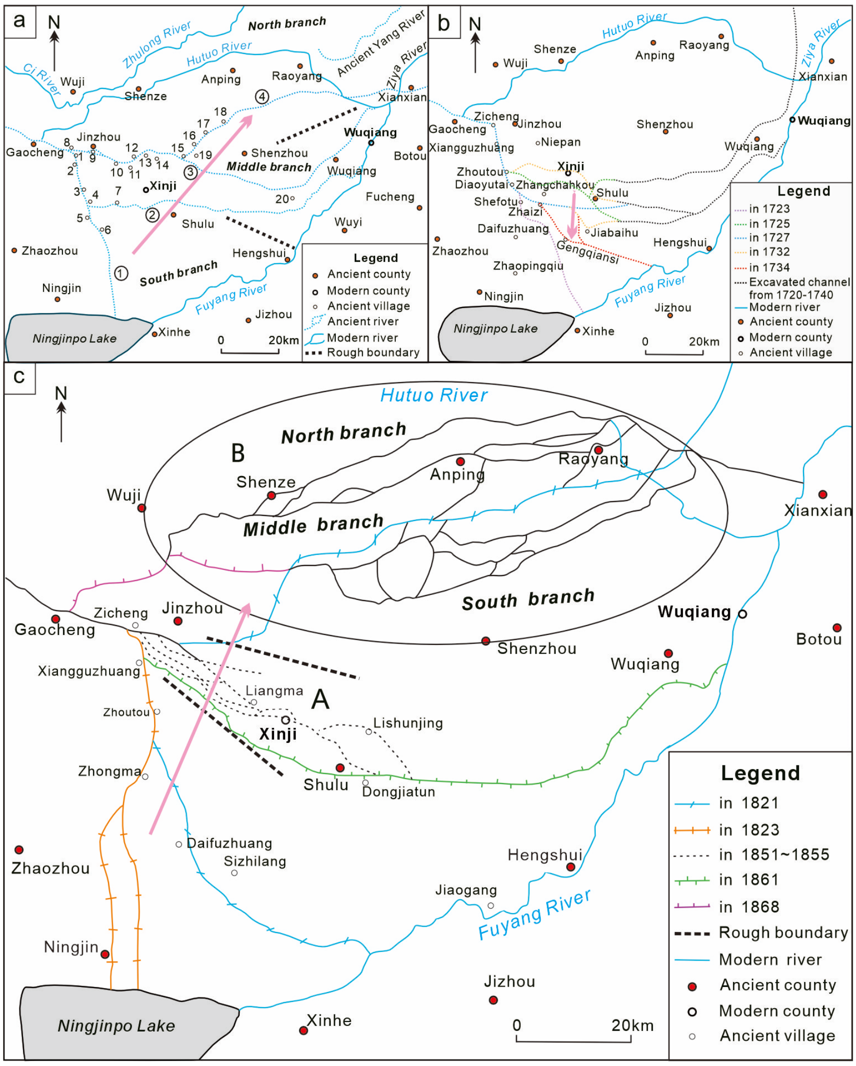

Figure 4. River channel migration during different periods of the Ming and Qing Dynasties, with the pink arrow showing the direction of the river's movement at various stages (modified from [37]).

(**a**) Migration during the Ming Dynasty, where the numbers indicate ancient villages: 1. Gudicun, 2. Xiangguzhuang, 3. Zhoutou, 4. Diaoyutai, 5. Kongmuzhuang, 6. Dashangcun, 7. Shazhuang, 8. Zicheng, 9. Yaojiazhuang, 10. Niepan, 11. Changjiazhuang, 12. Nanbaitan, 13. Nanweibo, 14. Beixiaochen, 15. Junqi, 16. Hezhuang, 17. Tiangongkou, 18. Shuangjing, 19. Jiucheng, and 20. Fuzhongchi. Here, ① and ② represented the main river channels in the early Ming Dynasty, while ③ and ④ showed the major river channels in the late Ming Dynasty. (**b**) Migration during Emperor Yongzheng's reign of the middle Qing Dynasty. (**c**) Migration from Emperor Daoguang's period to the late Qing Dynasty. Area A indicates the spread of the Hutuo River from 1851 AD to 1855 AD during Emperor Xianfeng's period, while area B refers to the scattered region of the Hutuo River after 1868 AD, during Emperor Tongzhi's period.

During the Qing Dynasty, from 1644 AD to 1868 AD, the Hutuo River channels experienced frequent migrations, with 52 migrations documented over more than 220 years, leading to an average recurrence interval of approximately 4 years. This era was characterized by considerable hydrological instability [39,41,59,68]. The river channels were dispersed and highly variable, particularly during the prosperous mid-Qing Dynasty, when the river underwent frequent southward migrations (Figures 3 and 4b). After 1868 AD, the Hutuo River began flowing along a northern route without establishing a fixed channel (Figure 4c) [37,59,68]. A significant shift occurred in 1881 AD (the seventh year of Guangxu's reign) when the river's flow pattern changed. Initially, the river entered the mouth of the Ancient Yang River but was later blocked and redirected back to the Ziya River. Since then, stabilization efforts, including the construction of embankments, channels, distributaries, and reservoirs, have gradually stabilized the river's flow.

5. Discussion

5.1. Monsoonal Variability in Relation to Centennial- and Interdecadal-Scale Droughts

The South Hebei Plain, primarily shaped by the alluvial deposits of the Haihe River, is located between various interior basins. The terrain is relatively flat, with a gradual elevation gradient from about 100 m to approximately 3 m along the Bohai Sea coast. The plain features numerous depressions and lakes with significant coverage areas. It experiences a typical warm-temperate monsoonal climate, characterized by distinct cold and dry winters [33,45,52,58]. Due to its specific geographic location and associated monsoonal instability, the South Hebei Plain has become particularly vulnerable to meteorological droughts and floods in recent centuries [13,48].

Our study revealed that from 1500 AD to 1750 AD, the South Hebei Plain experienced pronounced climate variability on a centennial scale, with significant fluctuations in weather patterns. Historical reports from this period document an increase in the occurrences of both droughts and floods, highlighting extreme weather conditions such as consecutive dry spells and severe floods (see Figure 3). This timeframe appeared to reflect heightened climatic instability in the region, likely driven by larger shifts in environmental factors. Notably, significant drying processes were observed in the mid-16th, 17th, and 18th centuries (Figure 3a). Three distinct intensifications of winter monsoon signals were identified, closely correlating with paleoclimatic changes observed in the middle–lower Yangtze River Basin (Figures 1 and 3a) [11,55]. Given that a warm-temperate monsoon climate influences the South Hebei Plain, it likely experienced centennial-scale variations in monsoonal activity. Periods of intensified winter monsoons are typically associated with increased drought frequency, while reduced monsoon activity correlates with fewer droughts, indicating a strong relationship between monsoonal dynamics and climate variability during this era. Additionally, this study linked these variations to broader global phenomena, such as the Earth's climate system and El Niño-related East Asian Summer Monsoon (EASM) anomalies, driven by centennial-scale fluctuations in solar radiation during the Holocene. This connection suggested that regional climate changes were part of a larger global climate pattern. The use of proxies such as the Western North Pacific Anomalous Anticyclone (WNPAAC) index to correlate monsoon activity with these broader trends strengthened the study's conclusions about the interplay between local and global climatic factors (Figure 3b,c) [60–64].

Interestingly, a 20-year cycle in climate variability was observed, likely linked to solar activity. During solar maximum years, when sunspot activity was notably elevated, anomalies in the East Asian Summer Monsoon could shift the rainfall belt (Figure 3d). This shift affected the convergence of cold and warm air masses, potentially triggering regional droughts. Consequently, the frequency and intensity of droughts fluctuated, with certain interdecadal periods experiencing severe droughts due to reduced precipitation and higher temperatures. Historical records suggested a strong connection between these drought variations and fluctuations in the East Asian Summer Monsoon [11,19]. We proposed that the centennial and interdecadal cycles of climate variability were influenced by a combination of factors, including sunspot activity, monsoon climate variability, and broader global changes (Figure 3b–d) [50,57,60]. The drought patterns identified in this study thus provide new insights into regional and global climatic changes over the past 500 years.

5.2. Human Disturbance in Connection with Semicentennial-Scale Droughts

Human disturbance has significantly influenced the occurrence and intensity of semicentennial-scale droughts, particularly in regions like the South Hebei Plain in China. Historical records show that droughts occurring approximately every 70 years often coincided with periods of substantial human impact. After the early 18th century, during the reigns of Emperors Kangxi and Qianlong of the Qing Dynasty, the region experienced socio-economic prosperity, stability, and population growth (see Figure 3e) [44,65–67]. The South Hebei Plain, strategically located as a transportation hub, has undergone substantial urban and topographical changes, especially in the context of national economic development. Its favorable terrain and dense transportation network have historically connected various regions, enhancing its agricultural productivity and economic significance. The region's fertile land and high grain production have bolstered its role within China's economic framework. Population dynamics in the South Hebei Plain increased notably from the Ming and early Qing Dynasties, with a growth rate of approximately 3.0–4.0‰ (Stage I). During the Qing Dynasty's most prosperous period, this rate averaged 6.0‰ (Stage II), surging to 7.3‰ after the 1840s (Stage III) (see Figure 3f). This prosperity spurred urbanization and modernization, significantly altering the region's surface and geomorphic configuration [40,67]. This rapid population growth and its associated urbanization have impacted river distributions and Earth surface processes, potentially accelerating the recurrence of meteorological disasters (Figure 3a). Furthermore, the intensified human activities and population growth seen since the 1840s have changed regional hydrological and meteorological conditions (Figure 3), likely correlating with increased drought and flood risks in the South Hebei Plain.

To validate the natural and anthropogenic factors affecting meteorological droughts and floods, it is essential to estimate the controlling factors affecting hazard recurrence over the past 500 years. Calibrating such data can be challenging, especially since instrumental records are only available for recent decades [39,41]. However, considerable efforts have been made to reconstruct climate data for the past 1000 years using natural records [11,55,57,69]. These reconstructions have offered valuable insights into past climate variations, validated historical data, and improved hazard assessments. Numerous proxy-based climate reconstructions in the literature provide insights into historical climate variations on regional and hemispheric scales, helping to build consensus on the magnitude and amplitude of major climate deviations over time [57,69].

Our dataset, which presented evidence of centennial and interdecadal meteorological droughts and floods, aligned with the understanding that these climate anomalies were often driven by larger global phenomena. This supports previous studies identifying several large-scale drivers of climate variability [57,69]. The mechanisms driving precipitation fluctuations were complex, involving factors such as monsoon instability, fluctuations in thermohaline circulation, and solar activity. Despite the challenges in establishing long-term climatic variations, the observed reduction in recurrence intervals to around 70-year cycles should suggest a significant anthropogenic influence, corroborated by the prosperity of the Qing Dynasty and the subsequent rapid urbanization starting in the 1840s. The rapid urban population expansion seen since that time aligned with earlier observations (Figure 3) [57,65,68]. While historical data and observations have provided valuable insights into the impact of human activities on climate variability, further discussion and verification are necessary to strengthen our understanding of these complex interactions.

5.3. Hydrological Migrations in Correlation with Droughts, Floods, or Human Disturbances

The evolution of rivers and changes in water resources are intricately linked to global environmental dynamics. Previous research has underscored the significant impact of meteorological droughts on hydrological variations, highlighting the necessity of understanding how these droughts interact with broader climate variability. Meteorological droughts critically influence river runoff, soil erosion, and overall river water content, with cascading effects on water resources. However, analyzing historical river network patterns has been challenging due to the limited availability and quality of historical data. Many records are incomplete or fragmented, complicating the reconstruction of past river dynamics and rivers' responses to climatic changes. Overcoming these challenges requires innovative approaches, such as integrating historical data with modern climatic models to improve our understanding of past and present drought impacts.

A key observation in this study was the identification of two distinct periods of riverbank diversion in the South Hebei Plain (highlighted by two gray stripes)—one during flooding seasons in the early 18th century and another during drought-dominant periods. These periods provided valuable insights into the historical evolution of river systems and their interactions with both environmental and human factors (see Figures 3g and 4a). The first period of frequent riverbank diversion, observed during the early 18th century, coincided with significant flooding events. This period corresponded to larger-scale precipitation variability, where heavy rainfall or prolonged wet conditions directly influenced river dynamics. Increased moisture levels resulted in higher water volumes, elevated flow velocities, and instability in riverbeds, prompting rivers to shift their courses. This finding aligned with previous studies (Figure 4b) [39,41,57]. Cooler temperatures associated with the Little Ice Age likely exacerbated river dynamics, contributing to frequent flooding and subsequent river diversions. To manage these challenges, rulers implemented measures such as river excavation and artificial redirection to mitigate flooding and control water resources (Figure 4b). In contrast, the second period of frequent riverbank diversion occurred during drought-dominant times, where reduced water variability and lower flow contributed to river stability. However, the diversions observed during these drought periods were not solely driven by natural changes in precipitation. The intensified river migration around the time of the opening-up policy in the 1840s suggested a significant role of human activity. The socio-economic prosperity of the Qing Dynasty, marked by rapid urbanization and extensive land reclamation, led to substantial alterations in the region's hydrological infrastructure. The construction of dams, irrigation systems, and other river management projects significantly influenced the stability and behavior of river channels (Figure 4c) [39,41,68].

The differential impacts of flooding and drought conditions on riverbank diversions in the South Hebei Plain emphasize the complex interplay between natural and anthropogenic factors in shaping river systems. Flooding seasons drove changes in river dynamics through increased moisture and flow variability, while drought periods saw altered river behaviors influenced by human interventions. This dual influence highlights the need for an integrated approach to river management that considers both climatic variability and socio-economic factors. In conclusion, understanding the historical context of riverbank diversions offers valuable insights into how environmental and human-induced factors interact to shape the river systems of the region. This knowledge is crucial for developing effective water management strategies and mitigating future risks related to both climatic and anthropogenic changes.

5.4. Recommendations for Water Resource Management

Water resource management in the South Hebei Plain has historically been quite basic, contributing to significant challenges in local water availability. The findings from this study provide valuable insights to guide and prioritize water resource allocation, which is essential for reducing people's vulnerability to meteorological hazards in the region.

Firstly, optimizing the meteorological database system for risk prevention and mitigation is essential. Regions like Shijiazhuang and Handan, which are particularly vulnerable to droughts, should be prioritized in efforts aimed at minimizing meteorological risks. Implementing advanced automatic monitoring systems, such as the 3S system (GIS, RS, and GPS), will facilitate a more comprehensive assessment of meteorological disasters. Establishing real-time monitoring systems in central urban areas will enhance the accuracy of weather forecasts and improve disaster preparedness. By deploying advanced weather stations, integrating real-time data, and employing sophisticated forecasting models, cities can better manage meteorological hazards and provide timely information to residents. Effective public communication, regular system maintenance, and fostering collaboration with various organizations are also key to the success of these initiatives, ultimately contributing to greater urban resilience against weather-related challenges.

Secondly, enhancing geological–geomorphological research related to weather events and updating meteorological disaster monitoring and evaluation systems are critical. Special focus should be placed on high-precision disaster prediction. Ongoing collaboration, capacity-building, and continuous improvements in technology and expertise will strengthen the region's disaster preparedness and resilience in the face of changing weather patterns. Effective urban planning, coupled with robust early warning systems and efficient emergency response mechanisms, is vital for managing meteorological hazards and enhancing resilience.

By integrating sustainable urban planning, deploying advanced warning technologies, and developing comprehensive response strategies, communities will be better equipped to prepare for and mitigate the impacts of extreme weather events. Continuous improvement in these areas, along with increased public awareness, will further bolster the region's disaster preparedness and contribute to creating a more resilient urban environment.

6. Conclusions

The South Hebei Plain has historically been prone to severe droughts, significantly impacting its water resources and socio-economic development. This low-lying, flat region has faced various challenges related to water scarcity and environmental stress, particularly influenced by its climate and human activities. This historical and climatic complexity of the area, coupled with limited data availability, has hindered accurate assessments of its drought and flood patterns over the past centuries. This article presented a comprehensive analysis of historical meteorological hazards in the South Hebei Plain, focusing on the control and impacts of droughts. Our preliminary findings indicate that the region's unique topography and variable monsoon circulation make it particularly susceptible to various meteorological hazards. Our results identified several notable drought and flood events influenced by both natural climate variability and human factors. Centennial- and interdecadal-scale metrological variations appeared to be driven by monsoon dynamics, sunspot activity, and broader global changes, whilst semicentennial oscillations might be largely modified by economic development and social stability. Human disturbance and the Earth's surface processes likely amplified these effects. Additionally, our results indicated that droughts have rephrased river parameters, such as water volume and flow velocity, thereby affecting riverbed stability and accelerating the diversion or migration of rivers. In light of ongoing drought conditions, enhancing water management practices is crucial for ensuring sustainable water resources and mitigating drought impacts. We have proposed several adaptation and mitigation measures aimed at promoting socio-economic harmony and sustainable regional development.

Author Contributions: Methodology, G.Y. and C.Y.; Formal analysis, G.Y. and C.Y.; Investigation, G.Y.; Writing—original draft, C.Y.; Writing—review & editing, G.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Beijing Municipal Natural Science Foundation (grant number [8162038]) and Beijing Municipal Social Science Foundation (grant number [22GLA014]). And The APC was funded by Beijing Municipal Social Science Foundation (grant number [22GLA014]).

Informed Consent Statement: All individuals included in this section have consented to the acknowledgement.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

Acknowledgments: We extend our sincere gratitude to C.S. Huang and H.X. Peng for their invaluable and critical comments, which significantly enhanced the quality of this study. We also wish to thank J.J. Shao for her participation in the field survey, which was crucial to our research. Special appreciation goes to Y. Zhao and Z. Wang for their insightful contributions to the analytical methods used in this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dracup, J.A.; Lee, K.S.; Paulson, E.G., Jr. On the definition of droughts. *Water Resour. Res.* **1980**, *16*, 297–302. [CrossRef]
2. Wilhite, D.A. Drought as a natural hazard: Concepts and definitions. *Drought Glob. Assess.* **2000**, *1*, 3–18.
3. Sternberg, T. Regional drought has a global impact. *Nature* **2011**, *472*, 169. [CrossRef]
4. Walsh, J.E.; Ballinger, T.J.; Euskirchen, E.S.; Hanna, E.; Mård, J.; Overland, J.E.; Tangen, H.; Vihma, T. Extreme weather and climate events in northern areas: A review. *Earth-Sci. Rev.* **2020**, *209*, 103324. [CrossRef]
5. Ahopelto, L.; Kallio, M.; Veijalainen, N.; Kouki, R.; Keskinen, M. Drought hazard and annual precipitation predicted to increase in the Sirppujoki river basin, Finland. *Clim. Serv.* **2023**, *31*, 100400. [CrossRef]
6. Zhang, P.; Cheng, H.; Edwards, R.L.; Wang, Y.; Kong, X.; Tan, M.Q.; Li, L.D.; Wang, Y.R.; Wu, T.A.L.; Chen, X.Z. A test of climate, sun, and culture relationships from an 1810-year Chinese cave record. *Science* **2008**, *322*, 940–942. [CrossRef]
7. Dai, A.G. Drought under global warming: A review. *Clim. Chang.* **2011**, *2*, 45–65. [CrossRef]
8. Xie, S.; Evershed, R.P.; Huang, X.; Zhu, Z.; Pancost, R.D.; Meyers, P.A.; Gong, L.; Hu, C.; Huang, J.; Zhang, S.; et al. Concordant monsoon-driven postglacial hydrological changes in peat and stalagmite records and their impacts on prehistoric cultures in central China. *Geology* **2013**, *41*, 827–830. [CrossRef]
9. Liao, H.; Chang, W. Integrated assessment of air quality and climate change for policy-making: Highlights of IPCC AR5 and research challenges. *Natl. Sci. Rev.* **2014**, *1*, 176–179. [CrossRef]
10. Asrari, E.; Masoudi, M.; Hakimi, S.S. GIS overlay analysis for hazard assessment of drought in Iran using standardized precipitation index (SPI). *J. Ecol. Field Biol.* **2012**, *35*, 323–329. [CrossRef]
11. Chen, Z.H.; Yang, G. Analysis of historical meteorological drought and flood hazards in the area of Shanghai City, China, in the context of climatic change. *Episodes* **2014**, *37*, 182–189. [CrossRef]
12. Fan, J.W.; Xiao, J.L.; Wen, R.L.; Zhang, S.R.; Wang, X.; Cui, L.L.; Li, H.; Xue, D.S.; Yamagata, H. Droughts in the East Asian summer monsoon margin during the last 6 kyrs: Link to the North Atlantic cooling events. *Quat. Sci. Rev.* **2016**, *151*, 88–99. [CrossRef]
13. Li, Q.; Chen, L.T.; Xu, Y.J. Drought risk and water resources assessment in the Beijing-Tianjin-Hebei region, China. *Sci. Total Environ.* **2022**, *832*, 154915. [CrossRef]
14. Trenberth, K.E.; Dai, A.; van der Schrier, G.; Jones, P.D.; Barichivich, J.; Briffa, K.R.; Sheffield, J. Global warming and changes in drought. *Nat. Clim. Chang.* **2014**, *4*, 17–22. [CrossRef]
15. Chiang, F.; Mazdiyashi, Q.; AghaKouchak, A. Evidence of anthropogenic impacts on global drought frequency, duration, and intensity. *Nat. Commun.* **2021**, *12*, 2754. [CrossRef]
16. Pandey, S.; Pandey, A.C.; Nathawat, M.S.; Kumar, M.; Mahanti, N.C. Drought hazard assessment using geoinformatics over parts of Chotanagpur plateau region, Jharkhand, India. *Nat. Hazards* **2012**, *63*, 279–303. [CrossRef]
17. Nam, W.-H.; Hayes, M.J.; Svoboda, M.D.; Tadesse, T.; Willhite, D.A. Drought hazard assessment in the context of climate change for South Korea. *Agric. Water Manag.* **2015**, *160*, 106–117. [CrossRef]
18. Ortega-Caucin, D.; Ceballos-Trvares, J.A.; Sánchez, A.O.; Castellano-Bahena, H.V. Agricultural drought risk assessment: A spatial analysis of hazard, exposure, and vulnerability in Zacatecas, Mexico. *Water* **2021**, *13*, 1431. [CrossRef]
19. Zhao, C.R.; Feng, Y.; Liu, W.B.; Wang, H.; Wang, T.T.; Liu, Y.H.; Sun, F.B. Provincial-scale assessment of vulnerability and resilience to drought in China. *Sci. Total Environ.* **2024**, *934*, 173199. [CrossRef]

20. Porter, S.C.; An, Z.S. Correlation between climate events in the North-Atlantic and China during the last glaciation. *Nature* **1995**, *375*, 305–308. [CrossRef]
21. Bond, G.; Showers, W.; Cheseby, M.; McManus, J.; Labeyrie, L.; Weiss, A.; McCave, I.N.; Edwards, R.L.; Thunell, R.C.; Lee, M.H.K.; et al. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. *Science* **1997**, *278*, 1257–1266. [CrossRef]
22. Heim, R.R., Jr. A review of twentieth-century drought indices used in the United States. *Bull. Am. Met. Soc.* **2002**, *83*, 1149–1165. [CrossRef]
23. Cook, E.R.; Woodhouse, C.A.; Eakin, C.M.; Meko, D.M.; Stahle, D.W. Long-term aridity changes in the western United States. *Science* **2004**, *306*, 1015–1018. [CrossRef]
24. Meehl, G.A.; Hu, A. Megadroughts in the Indian monsoon region and southwest North America and a mechanism for associated multidecadal Pacific Sea surface temperature anomalies. *J. Clim.* **2006**, *19*, 1605–1623. [CrossRef]
25. Elagib, N.A.; Elhag, M.M. Major climate indicators of ongoing drought in Sudan. *J. Hydrol.* **2011**, *409*, 612–625. [CrossRef]
26. Mukherjee, S.; Mishra, A.; Trenberch, K.E. Climate change and drought: A perspective on drought indices. *Curr. Clim. Chang. Rep.* **2018**, *4*, 145–163. [CrossRef]
27. Woodhouse, C.A.; Overpeck, J.T. 2000 years of drought variability in the central United States. *Bull. Am. Meteorol. Soc.* **1998**, *79*, 2693–2714. [CrossRef]
28. Zhang, D.E.; Li, H.C.; Ku, T.L.; Zhang, Z.H.; Wang, Y.L.; Yang, Z.M.; Zhang, M.H. On linking climate to Chinese dynastic change: Spatial and temporal variations of monsoonal rain. *Chin. Sci. Bull.* **2010**, *52*, 824–834. [CrossRef]
29. Ashcroft, L.; Gergis, J.; Karoly, D.J. A historical climate dataset for southeastern Australia, 1788–1859. *Geosci. Data J.* **2014**, *1*, 158–178. [CrossRef]
30. Brázdil, R.; Kiss, A.; Luterbacher, J.; Nash, D.J.; Řezníčková, L. Documentary data and the study of past droughts: A global state of the art. *Clim. Past* **2018**, *14*, 1915–1960. [CrossRef]
31. Zhang, J.L.; Liu, X.F.; Yu, C.W. Analysis on distribution and Variation of drought in Hebei Province. *Arid Zone Res.* **2012**, *29*, 41–46, (In Chinese with English Abstract).
32. Zhang, H.; Li, Y. Spatiotemporal variation of drought in Hebei Province and its impacts. *Environ. Res. Lett.* **2017**, *12*, 104003. [CrossRef]
33. Chen, X.; Liu, Y.L.; Sun, Z.L.; Zhang, J.Y.; Guan, T.S.; Jin, J.L.; Liu, C.S.; Wang, G.Q.; Bao, Z.X. Centennial precipitation characteristics change in Haihe River Basin, China. *Atmosphere* **2022**, *13*, 1025. [CrossRef]
34. Shi, X.L.; Zhang, Y.; Ding, H.; Yang, Y.Q.; Chen, J.J.; Shi, M.Q.; Chen, F. Drought risk assessment considering ecosystem resilience: A case study in the Huang-Huai-Hai Plain, China. *Ecol. Indic.* **2023**, *156*, 111102. [CrossRef]
35. Wang, F.; Lai, H.X.; Li, Y.B.; Feng, K.; Tian, Q.Q.; Zhang, Z.Z.; Di, D.Y.; Yang, H.B. Terrestrial ecological drought dynamics and its response to atmospheric circulation factors in the North China Plain. *Atmos. Res.* **2023**, *294*, 106944. [CrossRef]
36. Liu, J.G.; Yang, W.L. Spatiotemporal variation and impact of drought disasters in Hebei Province. *Acta Meteorol. Sin.* **2016**, *74*, 1147–1157, (In Chinese with English Abstract).
37. Shao, J.J. Climate Change and Hydrological Response in the Southern Hebei Plain over the Past 500 Years. Master's Thesis, China University of Geoscience, Beijing, China, 2017. (In Chinese with English Abstract).
38. Wen, Z.J. Climate Events, Climate Change, and Ecological Effects during the Ming and Qing Dynasties in the Central and Eastern Regions of Northern China. Ph.D. Thesis, Shaanxi Normal University, Xi'an, China, 2018. (In Chinese with English Abstract).
39. Shi, C.Y. Research on the Changes of Water Environment in the South China Sea Since the Ming Dynasty. Ph.D. Thesis, Fudan University, Shanghai, China, 2005. (In Chinese with English Abstract).
40. Chang, Q.W. The cultivation and influence of the Dahuze and Ningjinpo areas during the Ming-Qing dynasties. *J. Xingtaio Univ.* **2011**, *26*, 8–10. (In Chinese)
41. Zhu, J.Z. Study on the Evolution of Water Network Structure and Its Driving Force in the Haihe River Basin Since the Ming and Qing Dynasties. Master's Thesis, Tianjin University, Tianjin, China, 2017. (In Chinese with English Abstract).
42. Zhang, D.E.; Liu, C.Z. Supplement of atlas of drought and waterlogging distribution in China (1980–1993). *Meteorology* **1993**, *19*, 41–45. (In Chinese)
43. Zhang, D.E.; Li, X.Q.; Liang, Y.Y. Resupplement to yearly charts of dryness/wetness in China for the last 500 years period (1993–2000). *J. Appl. Meteorol. Sci.* **2003**, *14*, 379–384. (In Chinese) [CrossRef]
44. China Meteorological Administration. *Yearbook of Chinese Meteorological Hazards*; China Meteorological Press: Beijing, China, 2010. (In Chinese)
45. Ma, S.X.; Zhang, B.; Yang, M.; Wang, G.Q.; Cao, B.; Liang, J.J.; Zhang, J.Q. Analysis on drought and flood disasters in North China Plain from 1901 to 2015. *J. Arid Land Resour. Environ.* **2019**, *33*, 62–68, (In Chinese with English Abstract).
46. Academy of Chinese Meteorological Science. *Yearly Charts of Dryness/Wetness in China for the Last 500-Year Period*; China Map Press: Beijing, China, 1981. (In Chinese)
47. Tang, X.R.; Bo, S.R. Analysis of drought situation in the Ming and Qing Dynasties in Hebei Province. *Acta Geogr. Sin.* **1962**, *28*, 73–82. (In Chinese)
48. Ling, M.H.; Guo, X.M.; Shi, X.L.; Han, H.B. Temporal and spatial evolution of drought in Haihe River Basin from 1960 to 2020. *Ecol. Indic.* **2022**, *138*, 108809. [CrossRef]
49. Li, Y.P. The Characteristics of Drought Disasters in North China during the Ming and Qing Dynasties. Master's Thesis, Nanjing University of Information Science & Technology, Nanjing, China, 2015. (In Chinese with English Abstract).

50. Qin, Y.; Yang, D.; Lei, H.; Xu, K.; Xu, X. Comparative analysis of drought based on precipitation and soil moisture indices in Haihe basin of North China during the period of 1960–2010. *J. Hydrol.* **2015**, *526*, 55–67. [CrossRef]
51. Yuan, Z.J.; Liang, C.; Li, D.Q. Urban stormwater management based on an analysis of climate change: A case study of the Hebei and Guangdong provinces. *Landsc. Urban Plan.* **2018**, *111*, 217–226. [CrossRef]
52. Bi, S.B.; Bi, S.J.; Chen, C.C.; Nkunzimana, A.; Li, Y.P. Analysis of the spatiotemporal characteristics of drought disasters in North China during the Ming and Qing dynasties. *Geomat. Nat. Hazards Risk* **2020**, *11*, 2509–2539. [CrossRef]
53. Yan, X.L.; Zhang, J.Y.; Bao, Z.X.; Wang, G.Q.; Guan, T.S. Evolution of drought and flood in the Haihe River Basin for the last 500 years. *Hydro-Sci. Eng.* **2020**, *4*, 17–24, (In Chinese with English Abstract).
54. Yang, G.F.; Yin, H.F.; Li, C.A.; Chen, Z.Y. Functional spectral analysis of paleoclimatic evolution in Lanzhou area over the last 15 ka. *Chin. J. Geochem.* **2003**, *22*, 377–380.
55. Chen, Z.H.; Yang, G.F. Multiscale variability of historical meteorological droughts and floods in the middle Yangtze River basin, China. *Nat. Hazards Rev.* **2020**, *21*, 04020036. [CrossRef]
56. Yang, G.F.; Peng, H.X.; Huang, C.S.; Yin, H.F.; Li, C.A. Climatic instability study of Lanzhou since last glacial maximum. *J. China Univ. Geosci.* **2005**, *16*, 11–15.
57. Ge, Q.S. *Chinese Historical Climate Change*; Science Press: Beijing, China, 2011. (In Chinese)
58. Chen, Z.H.; Yang, G.F. Analysis of drought hazards in North China: Distribution and interpretation. *Nat. Hazards* **2013**, *65*, 279–294. [CrossRef]
59. Zhao, S.X. *Water Conservancy Chronicles of Shijiazhuang Region*; Hebei People's Publishing House: Shijiazhuang, China, 2000. (In Chinese)
60. Xing, C.; Kong, Y.; Liu, F.; Zhou, X.Y. Interdecadal variability of the El Niño-East Asian summer monsoon relationship over the past half century in reconstructions and simulations. *Quat. Sci.* **2021**, *41*, 486–496, (In Chinese with English Abstract).
61. Balachandran, N.K.; Rind, D.; Shindell, D.T. Effects of solar cycle variability on the lower stratosphere. *J. Geophys. Res.* **1999**, *104*, 27321–27339.
62. Shindell, D.; Rind, D.; Balachandran, N.; Lean, J.; Lonergan, P. Solar cycle variability, ozone, and climate. *Science* **1999**, *284*, 305–309. [CrossRef]
63. Solanki, S.K.; Usoskin, I.G.; Kromer, B.; Schüssler, M.; Beer, J. Unusual activity of the sun during recent decades compared to the previous 11,000 years. *Nature* **2004**, *431*, 1084–1087. [CrossRef]
64. Xiao, S.B.; Li, A.C.; Liu, J.P.; Chen, M.H.; Xie, Q.; Jiang, F.Q.; Li, T.G.; Xiang, R.; Chen, Z. Coherence between solar activity and the East Asian winter monsoon variability in the past 8000 years from Yangtze River-derived mud in the East China Sea. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2006**, *237*, 293–304. [CrossRef]
65. Fan, W.L. *A General History of China*; Beijing United Publishing Company, Ltd.: Beijing, China, 2000. (In Chinese)
66. Gao, S.L. Overview of ancient population development in Hebei Province. *Hebei J.* **1985**, *5*, 68–72. (In Chinese)
67. Ge, J.X. *Chinese Population History*; Sichuan People's Publishing House: Chengdu, China, 2020. (In Chinese)
68. Zhu, L.L. Changes of the Hutuo River during the Ming and Qing Dynasties. *J. Chin. Hist. Geogr.* **1989**, *5*, 103–116. (In Chinese)
69. Wang, Z.H.; Chen, Z.Y.; Kou, Y.; Chen, N. Dry/wet climatic changes since 960 A.D in Taihu drainage basin of China. *Sci. Geogr. Sin.* **2002**, *22*, 546–551. (In Chinese)