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Monsoon Precipitation, Economy and Wars in Ancient China

Jixiao Zhang[1], Xin Zhou[1,2], Shiwei Jiang[1], Luyao Tu[1] and Xiaoyan Liu[1]*

[1] School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, [2] Laboratory for Marine Geology, Pilot National Laboratory for Marine Science and Technology (Qingdao), Qingdao, China

Northern China, particularly the Yellow River Basin, which is the birth place of Chinese civilization and has been the political center throughout most of China's history, is an ideal region for studying the response of human activities to climate change. However, studies on links between climate change and variations in earlier civilization are limited due to the scarcity of macroscale monsoon precipitation records. In the present study, a ∼4,000-year record of monsoon precipitation, which represents average rainfall in large areas in northern China, was reconstructed from sediments in Northern Yellow Sea Mud (NYSM). The record shows high monsoon precipitation during ∼4,000–2,500 BP, ∼1,350–750 BP and the past ∼250 years. In general, our record of monsoon precipitation exhibits trends similar to the percentages of planted Poaceae pollen in lake sediments and the Chinese economic index, contrasting with the frequency of wars over the past 2,000 years. We postulated that, in the agricultural society of ancient China, low monsoon precipitation in northern China may be an important factor that cause reduced agricultural production, declined economy and even the occurrence of wars.

Keywords: monsoon precipitation, Yellow Sea muddy sediment, median grain size, cereal production, war frequency in ancient China

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****Correspondence:***
Xin Zhou
xinzhou@ustc.edu.cn

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INTRODUCTION

Billions of people currently live in monsoon regions, with monsoon precipitation bringing significant influences to bear on human lives and wealth through severe climate conditions. Research on the relationship between prehistoric human activities and monsoon climate change provides long-term evidence for studying the response of human activity to climate change (Wigley et al., 1985; Pandey, 2005; Potts, 2012). This topic has been extensively researched over the past 20 years, and much progress has been achieved (Gupta et al., 2006; Xie et al., 2013; Zhang et al., 2016). However, studies of detailed links between macroscale monsoon climate change and ancient human activities have rarely been undertaken (Hsiang et al., 2013; Li et al., 2015; Wei et al., 2015), due to the lack of adequate macroscale monsoon climate records in key regions.

Northern China is an ideal region for studying the above question, because (i) it is the region known to be the birthplace of Chinese civilization, and has been the political center during most of the Chinese history (Schirokauer and Brown, 2012; Eberhard, 2013); and (ii) large areas of northern China are in monsoon regions, environments of which, especially around the monsoon margin, are sensitive to monsoon precipitation changes (Wang et al., 2013). The interactions between human activities and monsoon precipitation in northern China during the past several thousand years have been extensively studied (Fan, 2010; Yin et al., 2016).

However, macroscale monsoon precipitation records from the past several millennia in northern China are sparse, and precipitation evidence has been reconstructed from terrestrial materials, including stalagmite, lake sediment, peat sediment, tree ring and historical literature, but large regional scale records in northern China remain limited (Hong et al., 2000; Peng et al., 2005; Ge et al., 2008; Tan et al., 2008, 2011; Yi et al., 2012). Although the synthesis of precipitation records over large areas has helped toward resolving this question (Li J. et al., 2017), time series could be influenced by the distribution, resolutions and dating uncertainties of the records used. Thus, monsoon precipitation records that show average rainfall changes over large areas are essential.

Chinese coastal muddy sediments, which are transported from the land by rivers, have been widely used for reconstructing paleoclimate changes (Wang, 2018). As shown in previous studies (Zhou et al., 2012), sediments in some coastal areas were influenced by nearby runoff, and thus could be used to reconstruct average precipitation changes across river basins. In this study, we extended the macroscale monsoon precipitation records by more than 4,000 years, using coastal sediments from the Northern Yellow Sea Mud (NYSM) region. We then compared our record with records of economic index and war frequency in China reconstructed from historical literatures, and with pollen percentages of planted Poaceae from lake sediments, to discuss the links between climate change and human activities throughout Chinese history.

MATERIALS AND METHODS

Site 38002 (122°30.21′ E, 37°59.92′ N; water depth: 49.2 m) is in the southwestern part of the NYSM (**Figure 1**) region. Two sediment cores, named as 38002-A and 38002, and consisting mainly of gray clay silt, were collected in 2009 by staff of the expedition ship "Kexue 1", Institute of Oceanology, CAS, using a gravity corer and a box corer, respectively. The 238 cm long sediment Core 38002-A was subsampled at 1 cm intervals; Core 38002, 34 cm long, was subsampled at 0.5 cm intervals.

Of the samples from Core 38002, 18 were selected for ^{210}Pb–^{137}Cs analysis (Miguel et al., 2003). Radioactivity was measured using a germanium detector (AMETEK, United States) at the Institute of Polar Environment, USTC, Hefei, China. The samples were dried at 50°C, homogenized using a mortar and pestle, and passed through a 2 mm sieve. Samples (~5–10 g) were then packed into standard counting geometries for gamma analysis, sealed and stored for approximately 1 week to allow radioactive equilibration between ^{226}Ra and its daughter product ^{214}Pb. Spectra were continuously measured over 24 h to obtain sufficient counts. The resulting spectra showed ^{210}Pb activity with a peak at 46.5 keV.

Benthic foraminifera of various species from Core 38002-A were used for accelerator mass spectrometry (AMS) ^{14}C dating (Cearreta and Murray, 2000). The ^{14}C dates were calibrated to calendar ages using the Marine13 calibration dataset via the "R" code of Bacon (version 2.2). The foraminifera were placed under a stereomicroscope and the AMS ^{14}C measurements made at Beta Laboratory, Miami, United States.

Grain size distributions were analyzed in the 238 samples from 38002-A. The samples were added to a 10–20 mL H_2O_2 solution (30%), after which the mixture was heated to 100°C for 0.5 h to remove organic matter, and then treated with 10 mL of HCl (10%) for 48 h to remove calcareous cement and shell material. All the samples were then washed and dispersed by adding 10 mL of $(NaPO_3)_6$ (10%) followed by ultrasonic treatment for 10 min before measurement. The grain-size distributions were measured using an LS13 320 laser diffraction particle-size analyzer (Beckman Coulter, Inc.). Analysis range was 0.04–2000 μm, size resolution was 0.01 Φ and the relative error of repeat tests was less than 2%.

The concentrations of elements (SiO_2, Al_2O_3, Sr and Rb) were determined with an X-ray fluorescence (XRF) spectrometer (Axios^{mAX}-Minerals, PANalytical B.V.) using the fusion method (Fabb, 1976). Air-dried sediments were ground to a particle size equivalent to that of powder sieved by a No. 200 (75 μm) mesh. In total, 0.7000 ± 0.0003 g of sample and 7.0000 ± 0.0003 g of lithium borate were dried and stored in a glass desiccator, mixed uniformly and then fused into a glass disc. The samples were then analyzed using a spectrometer (Rh-anode X-ray tube) with a relative error of 0.1–1.0%. Element analysis was performed in the Institute of Geology and Geophysics, China Academy of Sciences.

RESULTS

Chronology

Core 38002 and Core 38002-A were dated using the ^{210}Pb–^{137}Cs method and ^{14}C, respectively, in our previous research (Zhang et al., 2019; **Figure 2**). The chronology of the upper part of the Core 38002-A was established by comparing the sea surface temperature (SST) between the two cores. Previous studies have shown that the trend of SSTs in the region was opposite that of the total solar irradiance (TSI) during the past 100 years (He et al., 2014). The trend of the long-term SST record was also consistent with that of the TSI record, indicating that the chronology of the Core 38002-A was reliable, though ^{14}C dating on carbonate foraminifer shells could result in some dating uncertainties.

Median Grain Size and Element Ratios

Our results show that the median grain size in the sediments of Core 38002-A varied from 22 to 60 μm, with an average of 38 μm (**Figure 3C**). The relatively high median grain size occurred during 3,870–2,500 BP, 1,350–750 BP and throughout the past 250 years, and relatively low values occurred from 2,500–1,350 BP and 750–250 BP.

The ratio of SiO_2/Al_2O_3 (**Figure 3B**) ranged between 5.3 and 6.3, while the ratio of Rb/Sr (**Figure 3A**) ranged between 0.50 and 0.63. The ratio of SiO_2/Al_2O_3 changed in accordance with the median grain size; i.e., during 3,870–2,500 BP, 1,350–750 BP and the past 250 years, the ratio was relatively high, and during 2,500–1,350 BP and 750–250 BP, the ratio was relatively low. In contrast, the ratio of Rb/Sr showed the opposite trend. The results of correlation analysis also support the inference that the ratio of

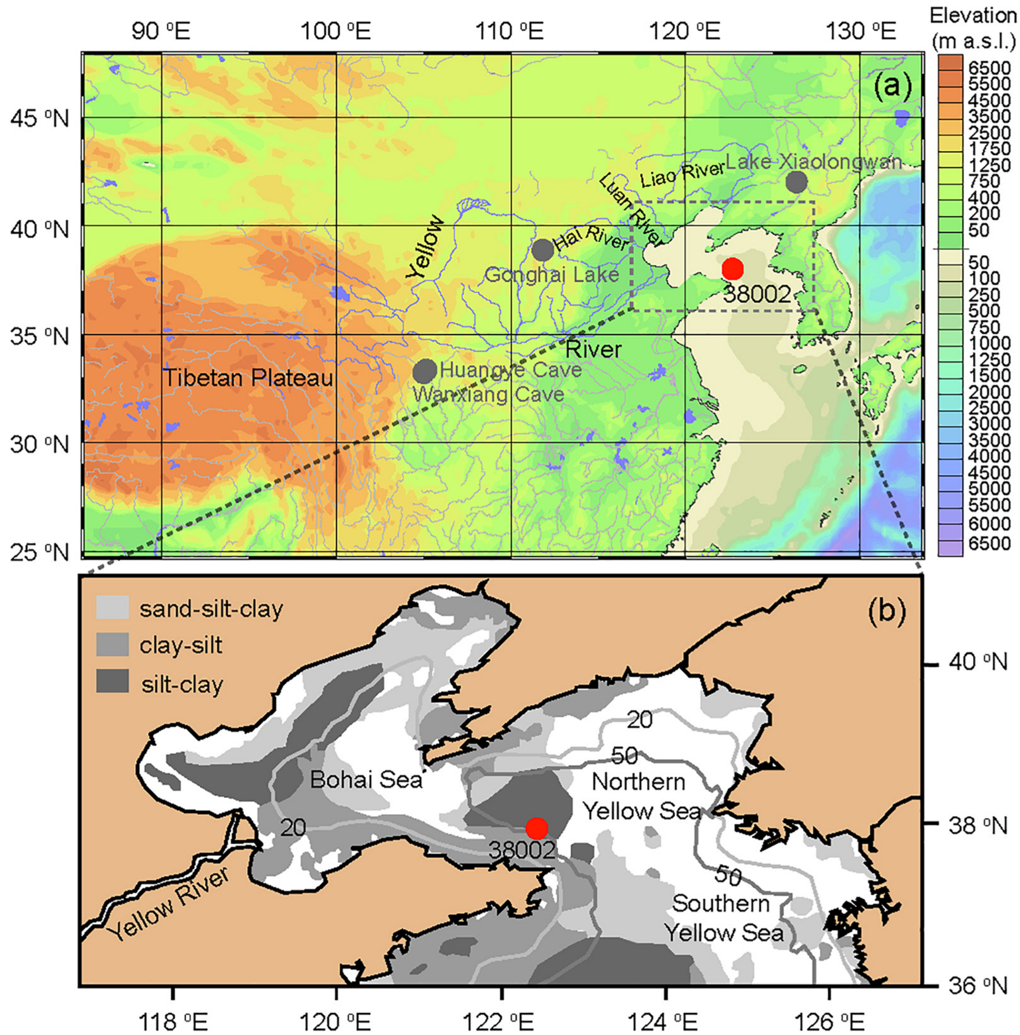

FIGURE 1 | Location of site 38002 and related sites. The base map was generated with Ocean Data View 4.0. **(a)** The main study sites involved in this article and **(b)** types of surface sediments in the Bohai Sea and the Yellow Sea.

SiO_2/Al_2O_3 exhibited strong positive linear correlation ($R = 0.76$) with the median grain size (**Figure 4A**), while the ratio of Rb/Sr exhibited negative linear correlation ($R = -0.52$) (**Figure 4B**).

DISCUSSION

Source and Climatic Significance of Median Grain Size in the NYSM Region

The sediments in Core 38002 originated mainly from the Loess Plateau and were transported by the discharge of the Yellow River and the current circulation of Bohai Sea; therefore, they reflect large regional climate especially summer monsoon precipitation in northern China (Li et al., 2016). However, the Yellow River has changed its course many times in history, during which the most significant diversion occurred between 1128–1855 AD, resulting in the instability of many indicators (Xue et al., 2011). Compared with other indicators, the median grain size was less affected by the diversion of Yellow River and had be used as an indicator of precipitation proxy in our previous study (Zhou et al., 2012, 2013).

Si and Al are relatively stable elements in the Loess Plateau; as such, the ratio of SiO_2/Al_2O_3 is not affected by pedogenic processes and can be used as an index that reflects the grain size of original eolian particles and to reconstruct the history of the East Asian monsoon (Peng and Guo, 2001). The strong positive linear correlation between the ratio of SiO_2/Al_2O_3 and median grain size in Core 38002 supports the reliability of the median grain size.

The ratio of Rb/Sr is related to regional weathering intensity and could indicate the intensity of East Asia Summer Monsoon (EASM) (Chen et al., 2003). During a strong EASM or high-precipitation period, Sr is transported more easily than Rb from inland to the coastal zone (Peng and Guo, 2001; Boulay et al., 2003; Sun et al., 2008, 2009; Zhao et al., 2008). Therefore, a low ratio of Rb/Sr in Core 38002-A indicates high precipitation,

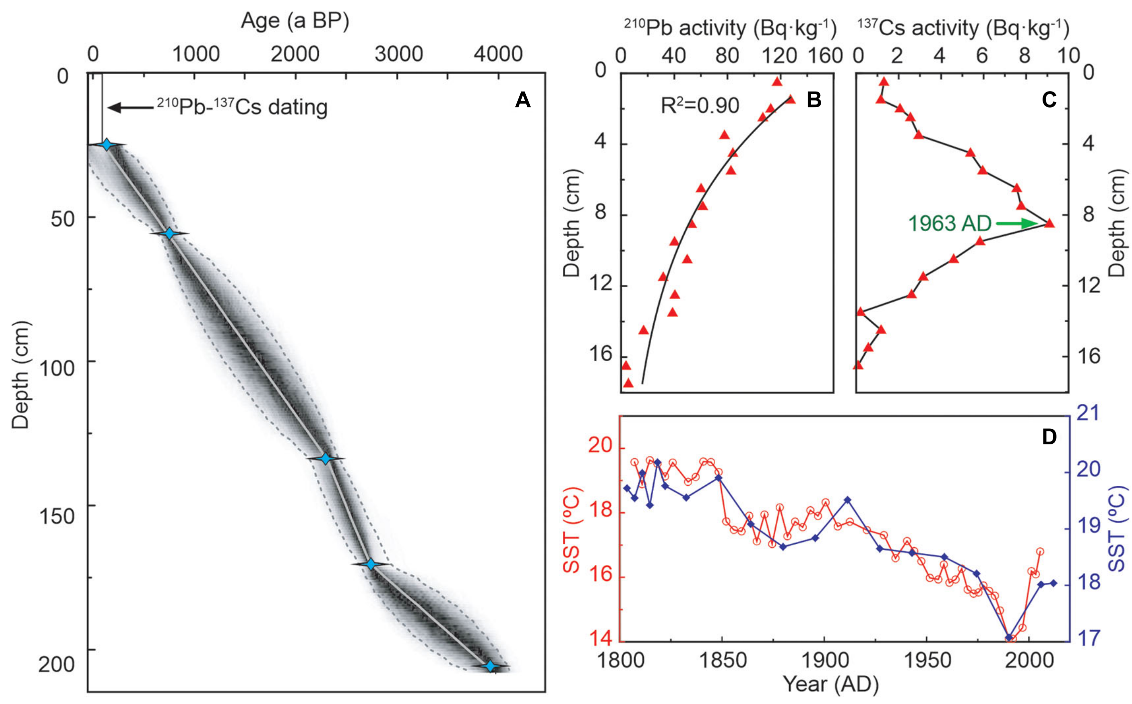

FIGURE 2 | Chronology of gravity Core 38002-A and box Core 38002. **(A)** ^{14}C age for Core 38002-A (Zhang et al., 2019), **(B,C)** ^{210}Pb and ^{137}Cs activities for Core 38002 (Zhou et al., 2012), **(D)** Comparison between SSTs from Cores 38002 (red) and 38002-A (blue) (Zhang et al., 2019).

and vice versa. When considering the linear correlation, the element ratios further support the reliability of median grain size in Core 38002-A as an indicator of historical precipitation in northern China.

In summary, the Rb/Sr and SiO_2/Al_2O_3 ratios of Core 38002, supported the reliability of median grain size as the indicator of monsoon precipitation changes in large areas of northern China. During 3,870–2,500 BP, 1,350–750 BP and the past 250 years, high median grain size, high ratio of SiO_2/Al_2O_3 and low ratio of Rb/Sr indicate there were high monsoon precipitation. In contrast, during 2,500–1,350 BP and 750–250 BP, there was low monsoon precipitation.

Monsoon Precipitation Changes and Civilization in Northern China During the Last 4,000 Years

Multiple studies have shown that temperature change plays important roles in the development and demise of human civilization (Haug et al., 2003; Issar and Zohar, 2004; Tsonis et al., 2010). Precipitation is closely related to the occurrence of floods and droughts, so it is as equally important as temperature in terms of climate change. In the past ∼4,000 years, northern China has been ruled by many dynasties. Although some studies have discussed about regional precipitation changes and cultural development (Yin et al., 2005; Gu et al., 2007; Zhang et al., 2008; Tan et al., 2011), there are few research materials discussing the relationship between precipitation and cultural development in large areas.

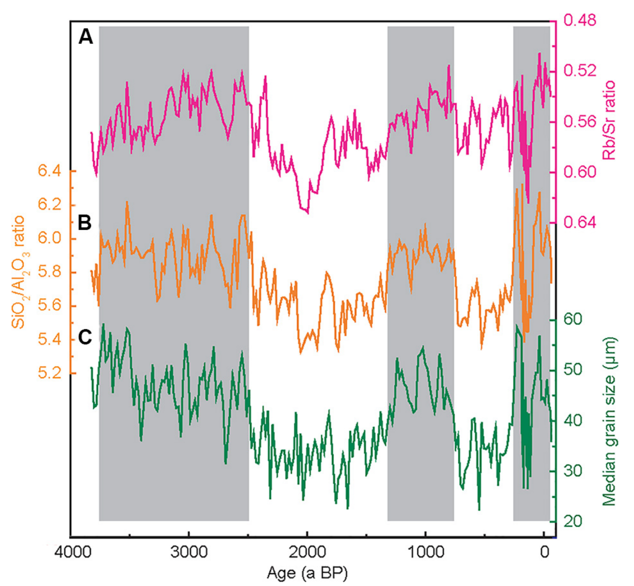

FIGURE 3 | Proxies from Core 38002-A. **(A)** Rb/Sr ratio, **(B)** SiO_2/Al_2O_3 ratio, **(C)** Median grain size.

The median grain size of NYSM region, as discussed above, is a good indicator of monsoon precipitation over a large area, which can compensate for the deficiency of previous research. To reconstruct past precipitation of the Yellow River Basin, we

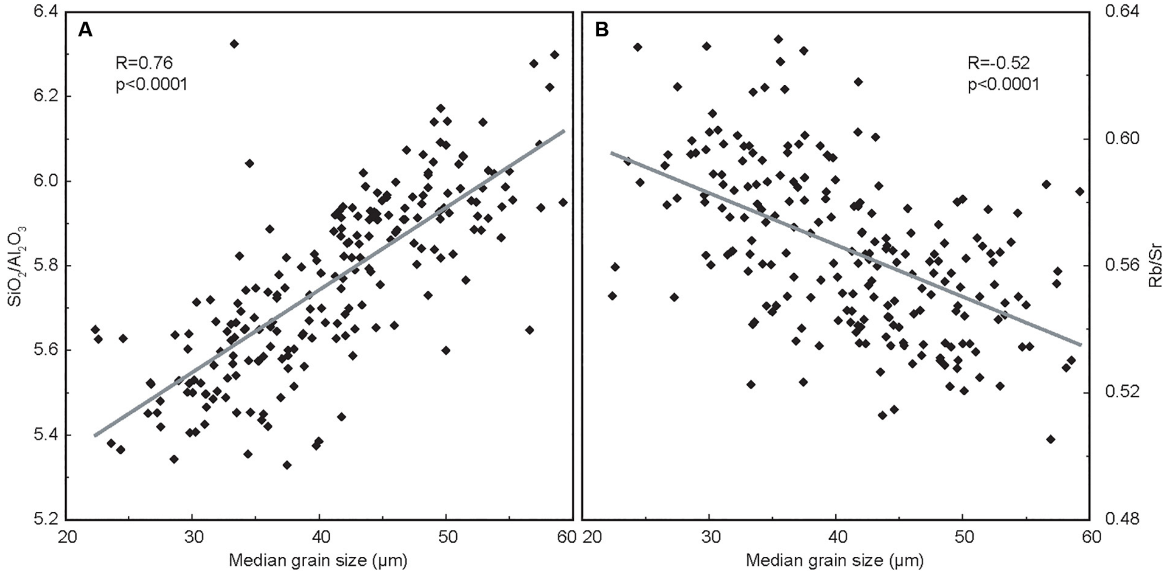

FIGURE 4 | Linear correlations between median grain size and element ratios in sediments from Core 38002-A. **(A)** Relationship between SiO_2/Al_2O_3 and median grain size, **(B)** Relationship between Rb/Sr and median grain size.

further compared these data with other indicators in northern China (**Figure 5**). Although the chronological results between them may have some errors that make it difficult to discuss specific climate events in detail, it is still possible to explore the precipitation and civilization history on centuries time scales.

In terms of the different physical–geographical settings, the Yellow River Basin has been divided into three water source areas: upper (above the Hekou station), middle (from the Hekou station to the Taohuayu station), and lower (below the Taohuayu station) reaches (He et al., 2013). Nearly 40% of runoff in Yellow River comes from the upstream basin. Therefore, changes in upstream precipitation and runoff have an important impact on the hydrodynamics of the entire Yellow River, and further affect the sediments exported to the Yellow Sea (Li X. et al., 2017; Wang et al., 2017). The area of the Qilian Mountains is located in the northwest of the Tibetan Plateau. Hence, the precipitation reconstructed by tree-ring of Qilian juniper (**Figure 5A**) can partially reflect the regional precipitation changes in the upper Yellow River Basin.

The wet-dry index data (**Figure 5B**) were extracted from ∼1,500-year flood and drought records from within the North China Plain region that mainly located in the middle and lower reaches of the Yellow River Basin (approximately 34–40°N) (Zheng et al., 2006); therefore, these data can indicate precipitation changes in large areas of the Yellow River Basin. In addition, the $\delta^{18}O$ values in stalagmites of Wanxiang cave (**Figure 5C**) and Huangye cave (**Figure 5D**), both located in the upper reaches of the Yellow River, were also considered as indicators of precipitation in the Yellow River Basin (Zhang et al., 2008; Tan et al., 2011).

Consistent changes among the above records show that the median grain size of the NYSM region can be used as a reliable indicator of monsoon precipitation changes in large areas of northern China, although there were slight variations between them due to regional differences or sensitivity of different indicators. The $\delta^{18}O$ values in stalagmites showed inconsistent trend changes with median grain size from ∼1,850 to 1,350 BP, as there factors other than monsoon precipitation may exist that can influence $\delta^{18}O$ values (Liu et al., 2015; Zhao et al., 2018).

Based on the median grain size and other indices, the precipitation history and civilization of northern China during the past ∼4,000 years can be broadly divided into the following intervals:

(i) ∼4,000 to ∼2,500 BP, roughly equivalent to the Xia Dynasty-Spring and Autumn Period during Chinese history (Li, 2002). Precipitation was generally high, but there was a slight downward trend, with short-term fluctuations. During this period, society was relatively stable and conflicts were infrequent.

(ii) ∼2,500 to 1,350 BP, roughly equivalent to the Warring States Period-Southern and Northern Dynasties during Chinese history. The precipitation during this period is comparably low, and shows a trend of descending first before rising again. During most of this period, the temperature was lower than that during modern times (Zheng, 2005).

(iii) ∼1,350 to ∼750 BP, roughly equivalent to the Sui Dynasty to the early Southern Song Dynasty during Chinese history. The precipitation during this period is relatively high, with some small fluctuations. During this period, China was in a state of unification for most of the time, with a developed economy, prosperous culture and fewer hostilities. Previous research shows that the temperature during this period was comparable to or slightly higher than in modern times (Ge et al., 2003; Liu et al., 2011).

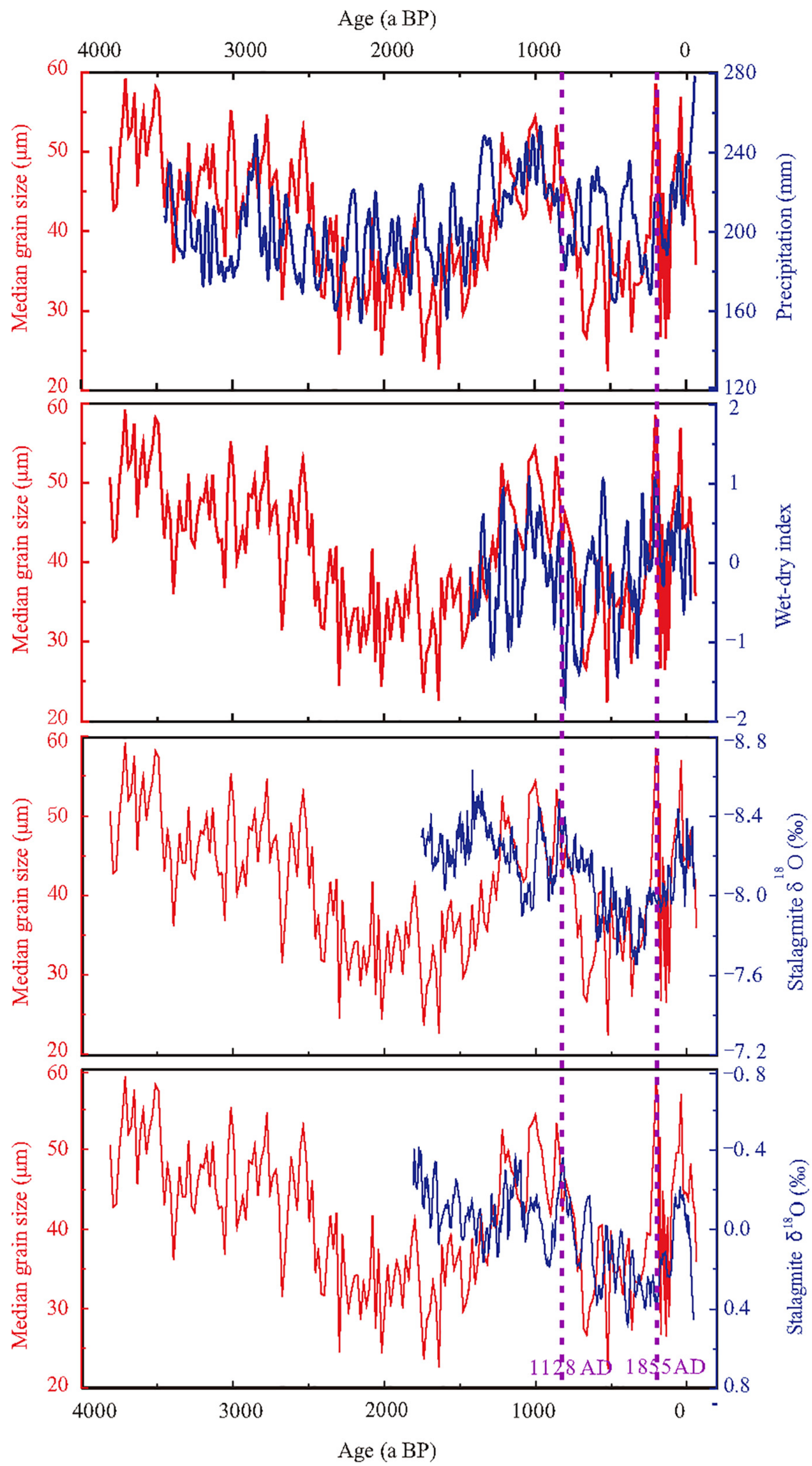

FIGURE 5 | Comparison of median grain size in sediments from Core 38002-A and other monsoon precipitation records. **(A)** Precipitation reconstructed by tree-ring analysis (Yang et al., 2014), **(B)** Wet-dry index of northern China (Zheng et al., 2006), **(C)** Stalagmites $\delta^{18}O$ from Wanxiang cave (Zhang et al., 2008), **(D)** Stalagmites $\delta^{18}O$ from Huangye cave (Tan et al., 2011).

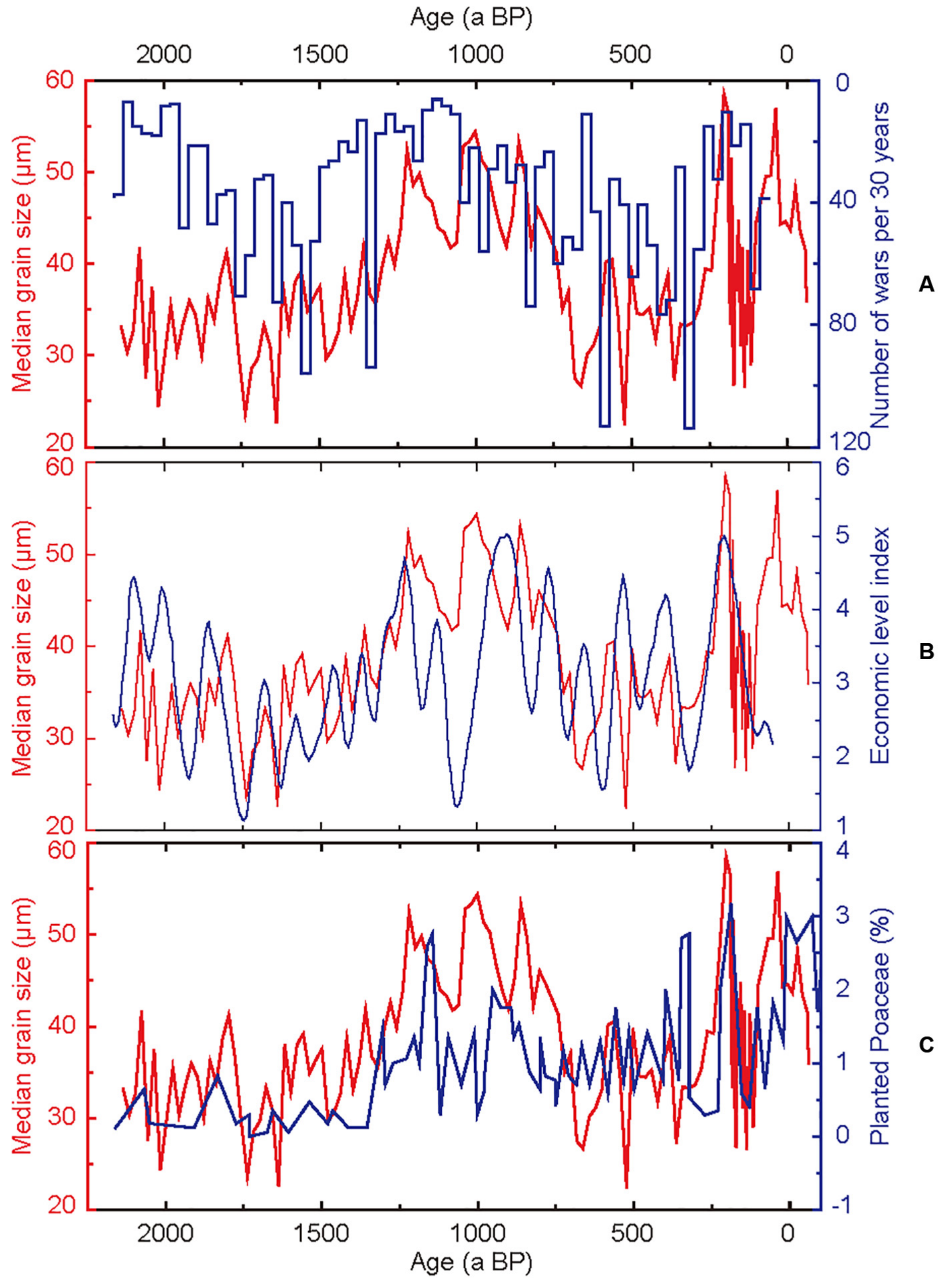

FIGURE 6 | Comparison of median grain size in sediments from Core 38002-A and records of **(A)** war frequency (Ge et al., 2014), **(B)** economic index (Wei et al., 2015), and **(C)** pollen percentages of planted Poaceae from Lake Gonghai (Xu et al., 2017).

It can be inferred that abundant precipitation and advantageous temperature may be the reasons for the prosperity and development of society during this period.

(iv) ~750 to ~250 BP, roughly equivalent to late Southern Song Dynasty to the early Qing Dynasty during Chinese history. Although the estuary of the Yellow River changed (1128 and 1855 AD, marked as purple dash lines in **Figure 5**) around this period' the median grain size still exhibited good consistency with other indices in the mass and thus can indicate precipitation. Precipitation during this period was relatively low, and showed a decreasing trend. This period was also approximately equivalent to the Little Ice Age, characterized by low temperatures (Wang et al., 2010).

(v) The past 250 years. Precipitation, as reconstructed by references to tree-ring and stalagmite $\delta^{18}O$ analysis is relatively high, but the median grain size of Core 38002-A does not correlate well with the perceived precipitation. The human activities during the past 200 years may well have interfered with the change of the median grain size (Wang and Li, 2011; Yang et al., 2015).

In general, during most periods of the past ∼4,000 years, the median grain size of NYSM reflects a microscale precipitation change in the Yellow River Basin or northern China. The period of high precipitation usually corresponded to a warm phase and also a period of cultural prosperity, and a period of low precipitation usually corresponded to a cold phase and also a period of social unrest.

During 1128–1855 AD, although Yellow River changed its estuary, the median grain size still had a good correlation with other indicators. There are multiple reasons may cause the median grain size to be less affected by the diversion: (i) during 1128–1855 AD, the lower reaches of the Yellow River still flowed into the Bohai Sea, only the water from the middle and upper reaches was affected by the diversion; (ii) judging from the circulation of the Bohai Sea, the stronger circulation mainly passes through the Luanhe estuary, which is relatively far from the Yellow River estuary, may further weakened the impact of the Yellow River runoff during diversion (Ji et al., 2019); (iii) most time of 1128–1855 AD was in the Little Ice Age, which was a period of less monsoon precipitation, this may also weakened the impact of the Yellow River diversion.

Relationship Among Precipitation, Economy and War in Northern China During the Last 2,000 Years

By comparing the precipitation reconstructed by the median grain size in sediments from Core 38002-A with historical records, we made a preliminary assumption that precipitation is closely related to culture development. To further explore the underlying mechanism, we compared it with other indicators (**Figure 6**) during the last 2,000 years.

In ancient China, rice was the main crop in the southern region, while wheat and millet were the main crops in the northern region (Zeng, 2005; Betts et al., 2014). All these cereal crops belong to the Poaceae plant family. Therefore, the pollen percentage of planted Poaceae (>35 μm grain size) in Lake Gonghai sediments (**Figure 6C**) can be considered as a rough indicator of the cereal yield of nearby areas (Xu et al., 2017). Based on the planted Poaceae pollen in Gonghai, cereal production nearby can be divided into several phases. Before ∼1,300 BP, the planted Poaceae pollen percentage was relatively low, indicate that agricultural activities were limited. Throughout ∼1,300–750 BP, the planted Poaceae pollen percentage increased significantly, indicating increased agricultural activity and higher cereal yields in this region. From ∼750 to 250 BP, the decreased planted Poaceae pollen percentage indicated weakened agricultural activity and lower cereal yields in this region. Throughout the recent 250 years, the planted Poaceae pollen percentage increased again, indicating flourishing agricultural activities and higher cereal yields.

In northern China, cereal yields are closely related to precipitation, and low precipitation leads to a shortage of water resources, which in turn leads to a reduction in cereal yields. The Lake Gonghai is located in the Yellow River Basin, and its precipitation is related to the regional monsoon strength (Chen et al., 2013, 2015); thus, the median grain size in sediments from Core 38002-A and the Planted Poaceae pollen percentage in Lake Gonghai showed a similar trend although there were some differences in detail.

The cereal yields may further affected the economic level (Wei et al., 2015) and the number of wars (Ge et al., 2014). Looting for food may cause ancient conflicts: in the case of adequate food resources, society was relatively stable with increased economic level, there was no need to wage war for food; in the case of food shortage, humans needed to snatch limited food resources and thus may reduce economic level and cause war. As an example, there was a peak in number of wars between ∼600 and 300 BP, roughly equivalent to the Little Ice Age, which occurred during a period of drought and reduced cereal reduction (Wang et al., 2003).

However, the relationship among the economic level, the number of wars and the cereal yields was not always consistent. For instance, ∼1,100 to 900 BP corresponded to a period of humid climate and had relatively high cereal yields, but the economic index was extremely low. This shows that although precipitation could affect cereal production, it was not necessarily the only factor that determined economic level and wars in history, other factors such as technological development level and social structure may also play important roles.

CONCLUSION

In this study, we used sediments in the NYSM regions as the research material and reconstructed a ∼4,000-year record of monsoon precipitation via median grain size. The ratio of SiO_2/Al_2O_3 and the ratio of Rb/Sr showed close linear correlation with the median grain size, thus supporting the reliability of median grain size as an indicator of macroscale monsoon precipitation in northern China.

Based on the median grain size and indices including $\delta^{18}O$ values in stalagmites, wet-dry index from historical records and precipitation reconstructed by tree-ring data, the precipitation and civilization history of northern China during the past ∼4,000 years can be broadly divided into five intervals: throughout ∼4,000–2,500 BP, ∼1,350–750 BP and the past ∼250 years, the monsoon precipitation was relatively high, corresponding to the periods of cultural prosperity. During ∼2,500–1,350 BP and ∼750–250 BP, the monsoon precipitation was relatively low, corresponding to the periods of social unrest and change in dynasties.

Monsoon precipitation may play an important role on the economic index and frequency of wars in northern China during the last 2,000 years by affecting cereal yields. Relatively low precipitation could cause a decrease in cereal yields, and could lead to further instabilities in society, a downturn of the economy and even wars. Nevertheless, factors other than monsoon precipitation may also play roles in changing the economy and war frequencies.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

XZ designed the research. SJ, LT, and XL performed the research. JZ analyzed the data and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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