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Jianghan plain, the locale of China's Great Flood four thousand years ago

Li-Xin Guo[1], Meng-Long Hsieh[2*], Olga Gorodetskaya[4], Zi-Hao Fan[5] and Shih-Ying Chiu[3]

Abstract

The Yellow River Plain (YRP), being regarded as the cradle of Chinese civilization, is traditionally thought to be the locale of the Great Flood, a hazardous flood (or floods) tamed by Yu who started China's first "dynasty", Xia, in ~ 2000 BC. However, by integrating published archaeological data, we propose that the Great Flood in fact impacted the Jianghan Plain (JHP) along the middle course of the Yangtze River. The arguments include: (1) around the era of the Great Flood, the most civilized and populated society in East Asia, named the Jianghan society, was located around the JHP (at that time, the habitation on the YRP remained limited); (2) the Jianghan society lived on river resources (shipping and rice growing) and was thus subject to flood risks (but not for the people inhabiting the YRP); (3) the people in the Jianghan society were experienced in dredging moats/ditches for shipping and irrigation; (4) unlike the floods on the YRP that were characterized by dynamic sedimentation and channel avulsion, those on the JHP typically occurred with slow-moving water manageable to ancient people; (5) the JHP has been associated with lake/wetland systems serving as detention basins during floods. Here, the recorded method for controlling the Great Flood, dredging channels to divert flood water to a "sea", was feasible. Known speleothem paleo-rainfall data from multiple sites show that the climate of the JHP had been wet since the middle Holocene (earlier than the era of the Great Flood) and significantly turned dry after ~ 1850 BC (~ 150 years later than the Great Flood). Thus, the uniqueness of the Great Flood was likely to reflect an increase in land use on the JHP with the expansion of the Jianghan society, and the success in taming this flood was mainly due to the efforts of the society, not by luck.

Key points

1. Floods on the Jianghan Plain were predictable and manageable in ancient times.
2. The most populated society in East Asia was located around the Jianghan Plain.
3. The people in the Jianghan society were experienced in dredging moats/ditches.

Keywords China's Great Flood, Yellow River, Yangtze River, Archaeology, Speleothem paleo-rainfall record

*Correspondence:
Meng-Long Hsieh
hsiehml@ntu.edu.tw
Full list of author information is available at the end of the article

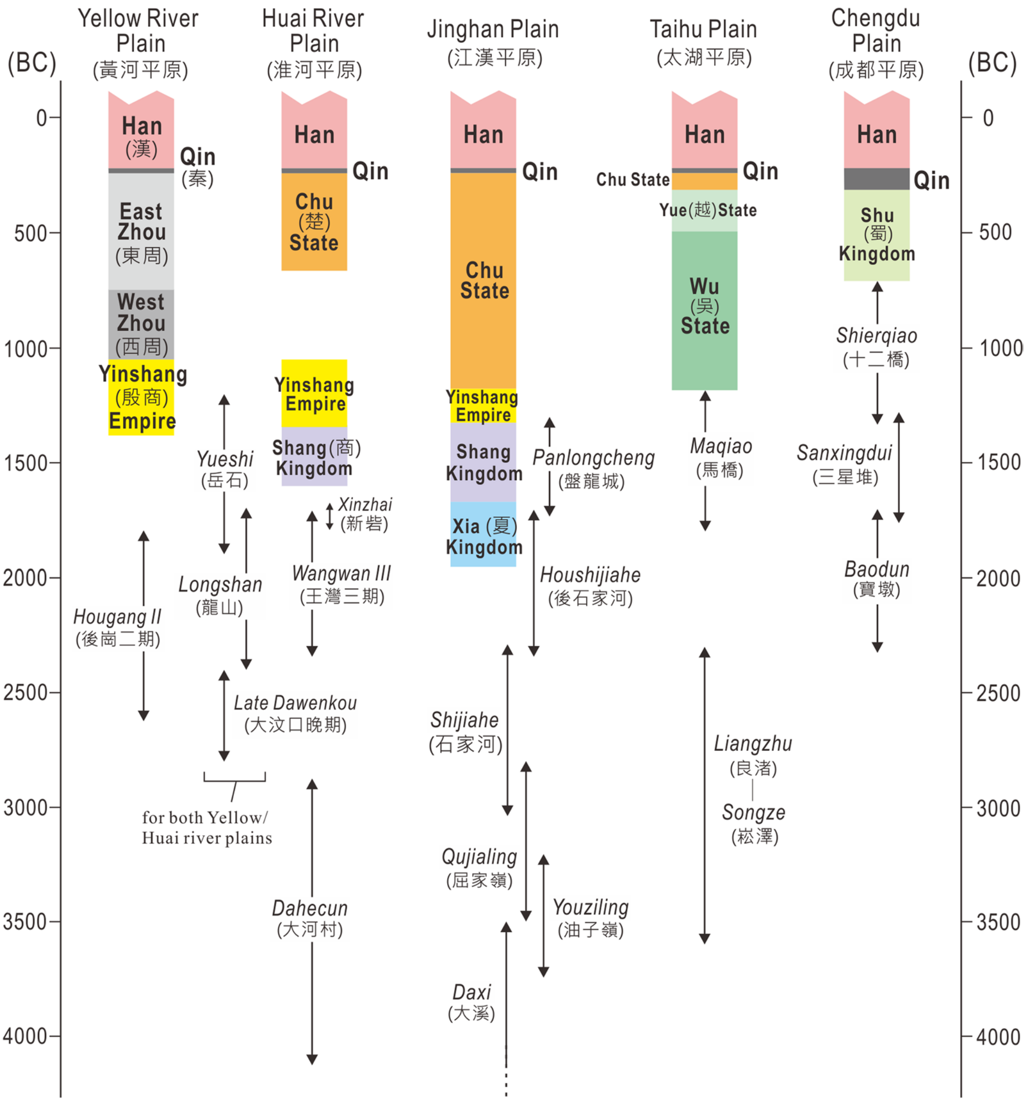

Fig. 1 Timeline of Chinese history (~4000–0 BC) used in this study, based on both historiographical and archaeological perspectives. Name of archaeological culture in Italic; age range constrained by published radiocarbon dates (calibrated). The Panlongcheng culture and Shang Kingdom referred to Gorodetskaya (2013, 2016a); the locale of the Xia Kingdom according to this study

1 Introduction

According to historical legends, there were lengthy floods (collectively called the "Great Flood") that caused significant hazards in ancient China. The taming of this flood by Yu earned him a cultural hero to establish the Xia kingdom (~2000–1700 BC). Being influential, the Xia kingdom is traditionally regarded as the first "dynasty" in Chinese history (Fig. 1). Yu's achievement, along with the prestige he earned, was unprecedented, setting a milestone in the growth of the agriculture civilization in East Asia.

Unlike many myths of "catastrophic floods" in other ancient civilizations, the accounts of the Great Flood did not mention any divine power or "creator" to mandate the flood but emphasized the method and the effort of the society in containing it. For example, Yu was depicted as a person (the successful one, though) among those in charge of the flood-control works. He was said to lead people to dredge channels to guide flood water to a "sea" (known as a place with an immense area of water). Also, during his 13-year flood-control career, Yu passed by home three times but never went in Sima (2014) [~90BC]). All these humanistic descriptions suggest the historicity of the floods, although the image of Yu, like other sages in ancient China, has been somewhat deified by descendants.

Accepting the truth of the Great Flood, many researchers have assigned its age. Based on the occurrence of an astronomical event recorded in historical texts as a sign (the clustering of five planets which can be seen through the naked eye), the starting time of the Xia Kingdom was determined at 1953 BC (Pankenier 1995; Zhang 2002). This age is close to the 2000–1968 BC age inferred from *Bamboo Annals* (Liu 2001; Zhang 2013), a historical document unearthed from a noble tomb of ~ 300 BC, and is not far from the 2070 BC age proposed by the government-sponsored Xia Shang Zhou Chronology Project (Expert Group of the Xia Shang Zhou Chronology Project 2000).

Great debates, however, exist concerning the locale of the Great Flood and the Xia Kingdom. This locale has three potential candidates: the Yellow River in the north, the Yangtze River in the south, the largest two rivers in China, and the relatively minor Huai River in the middle (Fig. 2). All these three river catchments have places named after Yu and claimed to be his hometown (Du 1992). Putting aside these toponymic views which cannot be used as direct evidence for historicity (Yang 1984), most scholars believe the Great Flood originated from the Yellow River [e.g., (An 1979; Zou 1980a; Ma 1982; Qian 1982; Jing 1984; Shen 1994; Zhou 1994; Pei 1996; Liang and Lei 2000); Xu 2003; Gu and Tong 2005; Ma 2008; Yang 2010; Chen et al. 2012; Sun 2015, 2018)].

We recognize that the belief of the Yellow River being the locale of the Great Flood is mainly based on the ideology regarding the river as the cradle of China's civilization [e.g., (Ho 1969; Rapp and Jing 2011; Chen et al. 2012; Wang et al. 2019)]. The Yellow River catchment, especially the Yellow River Plain (YRP) in its lower part (Fig. 2), has been the political center of China since the Yinshang period (~ 1380–1046 BC) (Fig. 1). After the Qin dynasty (~ 221–207 BC), the first united empire in China, the perception of Great China has been established. Thinking themselves to be the successors of Yu (and other sages before Yu), people would unconsciously believe that their living places were inherited from the Xia's territory. This orthodoxy inevitably led to prejudice in translating historical legends, which happened even in *Shiji*, the most popular ancient Chinese historiography compiled in ~ 90 BC (Liang 1981, Gorodetskaya 2016b). Except these ideological thoughts, there is no evidence for the YRP as the locale of the Great Flood (and the Xia

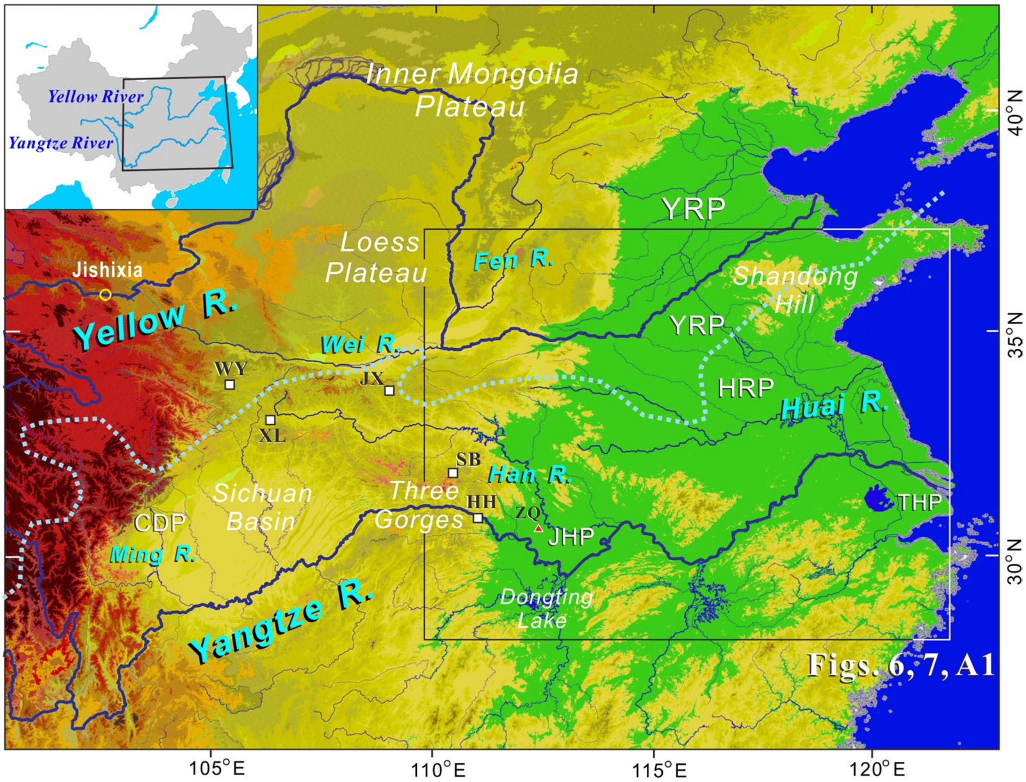

Fig. 2 Topographic map of central/eastern China showing the locations of the Yellow and Yangtze rivers. Annual 750 mm isohyet dotted. Abbreviation for plains: CDP = Chengdu Plain; HRP = Huai River Plain; JHP = Jianghan Plain; THP = Taihu Plain; YRP = Yellow River Plain. White squares are sites of limestone caves yielding speleothem paleo-rainfall records: HH = Heshang; JX = Jiuxian; SB = Sanbao; WY = Wuya; XL = Xianglong. Red triangle in the JHP: ZQ = Zhongqiao archaeological site. Yellow circle in the upper Yellow catchment: Jishixia breached landslide dam

Kingdom). It was not until recently that Wu et al. (2016), by finding an ~ 1920 BC outburst flood from the Jishixia along the upstream course of the Yellow (for location see Fig. 2), claimed that the Yellow-river origin of the Great Flood was finally attested. We however consider this inference to be unreasonable (see discussion later).

An additional issue about the Great Flood is whether or not ancient people four thousand years ago were really capable of containing this natural disaster. It has been known that the climate in the monsoonal East Asian turned dry after the middle Holocene Climate Optimum e.g., (Wang et al. 2005). This global drying suitably explains the lack of flood threats in the Xia period (e.g., Dalfes et al. 1997, Peiser 1998), which led Wu and Ge (2005) to suggest that the success of Yu in taming the Great Flood was achieved mainly by luck.

In this article, we reviewed and integrated known physiographical, historical, and particularly, archaeological data around the Yellow, Huai, and Yangtze rivers to clarify the locale of the Great Flood and the Xia Kingdom. We maintain that the archaeological data, which provide first-hand evidence for the development and living styles of ancient people, are more objective than subsequently composed historical texts that may have been biased by social/political ambiances. We consider that the locale of the Great Flood should meet the following four criteria: (1) it was subject to the flooding that was manageable to ancient people; (2) it was occupied by people living on river resources; (3) the people suffering from the flood were relatively civilized and populated so that they could be mobilized, with sufficient skills, for flood management; (4) the culture of the people remained influential after the flood (even though their descendants were conquered by other people), so that the accounts of the flood could be handed down to generations. Additionally, in order to understand the potential influence of climate on the Great Flood, we reviewed the published high-resolution speleothem δ^{18}O records around the middle courses of both the Yellow and Yangtze rivers. In fact, through this study, we not only located the Great Flood, providing perspectives to support its historicity, but also examined its significance in the context of the social development and paleoclimate conditions.

2 Physiographic setting

Both the Yellow River and the Yangtze River originate from the Qinghai-Tibetan Plateau in western China. After draining this > 4000 m-high terrain, the Yellow turns north and then east, flowing through multiple wide floodplains in sediment-filled basins in the Inner Mongolia Plateau (Fig. 2). Downstream, the Yellow heads to the south and cuts deeply into the Loess Plateau. Two major tributaries join the Yellow here, the Fen from the east and the Wei from the west (Fig. 2). After leaving the confluence with the Wei, the Yellow turns east, flows through the mountains bordering the Loess Plateau, and enters the YRP, an alluvial plain constructed by the Yellow. The YRP covers areas west and north of the Shandong Hill (Fig. 2). It has an apex of ~ 100 m in elevation. From here, the Yellow with a mean gradient of 1.2×10^{-4} and mainly of braided types trends to the northeast, flowing along the northern border of the Shandong Hill before emptying into the sea (Fig. 2).

After leaving the high mountains around the Tibetan Plateau, the Yangtze River enters the Sichuan Basin (Fig. 2). This basin is floored mainly by hills, and only its western margin has an alluvial plain (the Chengdu Plain) constructed by the Ming River (a tributary of the Yangtze) (Fig. 2). Passing through the outlet of the Sichuan Basin (the Three Gorges), the Yangtze reaches the Jianghan Plain (JHP) where the Han River, the Yangtze's longest tributary, joins the system from the north (Fig. 2). From here to the sea, the Yangtze flows amid multiple hills and plains including the Taihu Plain near the river mouth (Fig. 2). This middle-lower course of the Yangtze, with meandrous channels, has a mean gradient of 2.1×10^{-5}, significantly gentler than the lower Yellow flowing through the YRP. Also, unlike the alluvial YRP, the plains along the middle-lower Yangtze are associated with plentiful lakes and wetlands serving as detention basins during floods. One of such lakes of great size, the Dongting Lake, is located south of the JHP (Fig. 2).

The Huai River originates from the hills between the Yellow and the Yangtze rivers (Fig. 2). The Huai River Plain (HRP) associated with the Huai River connects northward to the YRP and is separated from the Yangtze system on the south by hills generally < 200 m in elevation.

The lower halves of the Yellow and the Yangtze catchments (and the entire Huai catchment), including the southeastern part of the Loess Plateau and the entire Sichuan Basin, are influenced by Monsoon. The rainfall is mainly brought by the East Asia Summer Monsoon and generally decreases to the north/northwest, with the annual 750 mm isohyet located between the Yellow and the Huai rivers (Fig. 2). As a result of this precipitation pattern, rice has been the staple crop over the Yangtze catchment, and dry crops (currently wheat) dominate the Yellow, with the transition around the Huai. Also, with generally low flow discharge and high sediment load, the Yellow river channels are typically shallow, highly mobile, and thus not boatable. In contrast, the Yangtze and its tributaries have long been important transport routes in the history of China.

3 Historical floods

Both the Yellow and the Yangtze rivers are well known for their hazardous floods; however, the floods from these two rivers show different characteristics. In the upper Yellow River, due to high evaporation rates (in semi-arid climate zone) and the buffering of multiple wide floodplains, the floods have never exceeded the course crossing the Inner Mongolia Plateau (Shi et al. 1990). Only summer storms or early-spring ice melting over the Loess Plateau could generate floods that impacted the YRP. These floods generally carried enormous silty sediments onto the YRP, causing deposition and repeated channel avulsion e.g., (Chien 1961; Liu and Jiyang 1989; Kidder et al. 2012; Dang et al. 2018).

According to historical accounts, people built embankments along the downstream course of the Yellow River no earlier than ~ 340 BC (in the East Zhou period) (Zou 1980b; Tan 1987). Since then, floods that hit the societies have constantly been reported (Chen et al. 2012; Kidder et al. 2012). For example, *Shiji* documented that Emperor Wu (156–87 BC), one of the most powerful emperors in China's history, sent several tens of thousands of troops to contain the Yellow River but ended up in failure. In that time and afterward, building/repairing embankments has been a routine work to prevent the YRP from flooding (Chen et al. 2012). Sediment deposition in the artificially confined channels, however, increased the potential for avulsion by elevating the riverbeds to levels even higher than the surrounding floodplains. In the eleventh century AD (in the North Song dynasty), the Yellow River burst its banks almost every year (Chen et al. 2012). This avulsion-prone nature was also used for military purposes. For example, in 1128 AD, in order to stop the advancing Jurchen army, Song troops broke the levees, which eventually led to the diversion of the Yellow River to occupy the Huai River in the southeast (Lamouroux 1998, (Zhang 2009). It was not until another avulsion event in 1855 AD that the Yellow shifted its course back to the current position.

Unlike the Yellow, storms or sustained rains brought by summer monsoon over any parts of the Yangtze's catchment could generate floods downstream (e.g., E and Huo 2016). As a result, flood frequency was higher along the Yangtze than that along the Yellow, at least in the past 100 years (Chen and Wang 2002). Different from the floods on the YRP, those generated on the gentle, low-lying plains along the middle- lower course of the Yangtze carried relatively small amounts of sediment and were characterized by lengthy and widespread coverages of overbank water (e.g., (Gong et al. 2001; Yin and Li 2001; Cheng et al. 2018). The JHP, the first plain the Yangtze meets after flowing for 4000 km in mountains, is considered the most vulnerable region to such flooding (Zhao 2000; Chen et al. 2001; Chen and Wang 2002; Ministry of Water Resources et al. 2005).

According to historical texts, the JHP and its surrounding areas were inhabited by the people of Chu as early as ~ 1100 BC. The Chu, which had a broad territory, a large population, and an influential culture, was a powerful state in both the West Zhou and East Zhou periods before being conquered by the Qin Empire in 224 BC (Fig. 1). The Chu people owned China's most complete mythological histories for their origins, from the creation of the world with the birth of humanity to the divine power to rescue people from wild lands. The plots of these myths commonly contain endless rainfall and overflow (due to the breaking of the "sky"), implying the frequent occurrence of catastrophic floods around the JHP. It is noted that in the period of the Chu state, the southern half of the present JHP was occupied by the Yunmeng Lake (Tan 1980). This ancient lake progressively shrank and eventually evolved into numerous small lakes, ponds, and wetlands no later than ~ 400 AD.

The written records of the Yangtze floods can be traced back to 185 BC (Ministry of Water Resources et al. 2005). From ~ 1000 to 1840 AD, floods were reported every 3–5 years on average (Ministry of Water Resources et al. 2005; Yu et al. 2009). Like the measures for managing the YRP floods, embankments were built to alleviate the Yangtze flood threat. The known earliest artificial levee was constructed around 350 AD, and by the twelfth century AD, a levee system took shape along the course of the Yangtze running through the JHP (Yang 1999; Chen 1990). The levee building continued and today a > 250 km-long embankment system, including the Great Jingjiang Levee, has been completed to protect the JHP (Li et al. 2007). This levee-building measure, however, does not appear to have succeeded, as the flood frequency remained high or even increased in the last 50 years (Yin and Li 2001; Li et al. 2007), perhaps due to an increase in farmland reclamation from the lakes (especially the Dongting) that were used to detain flood water (Yu et al. 2009).

4 Archaeological data

Archaeological excavations, supplemented by radiocarbon dates back to 8000 BC in age, have revealed the development of Neolithic cultures in the Yellow, Huai and Yangtze river catchments. The review of this study focused on cities and major settlements (Appendix Table 2 and references therein), as their emergence as worship, economic, and political centers reflected an advanced assemblage and labor division of societies. The "city" defined here is an assemblage of settlements surrounded by distinct walls and/or moats (the large assemblage of settlements with neither walls nor moats is

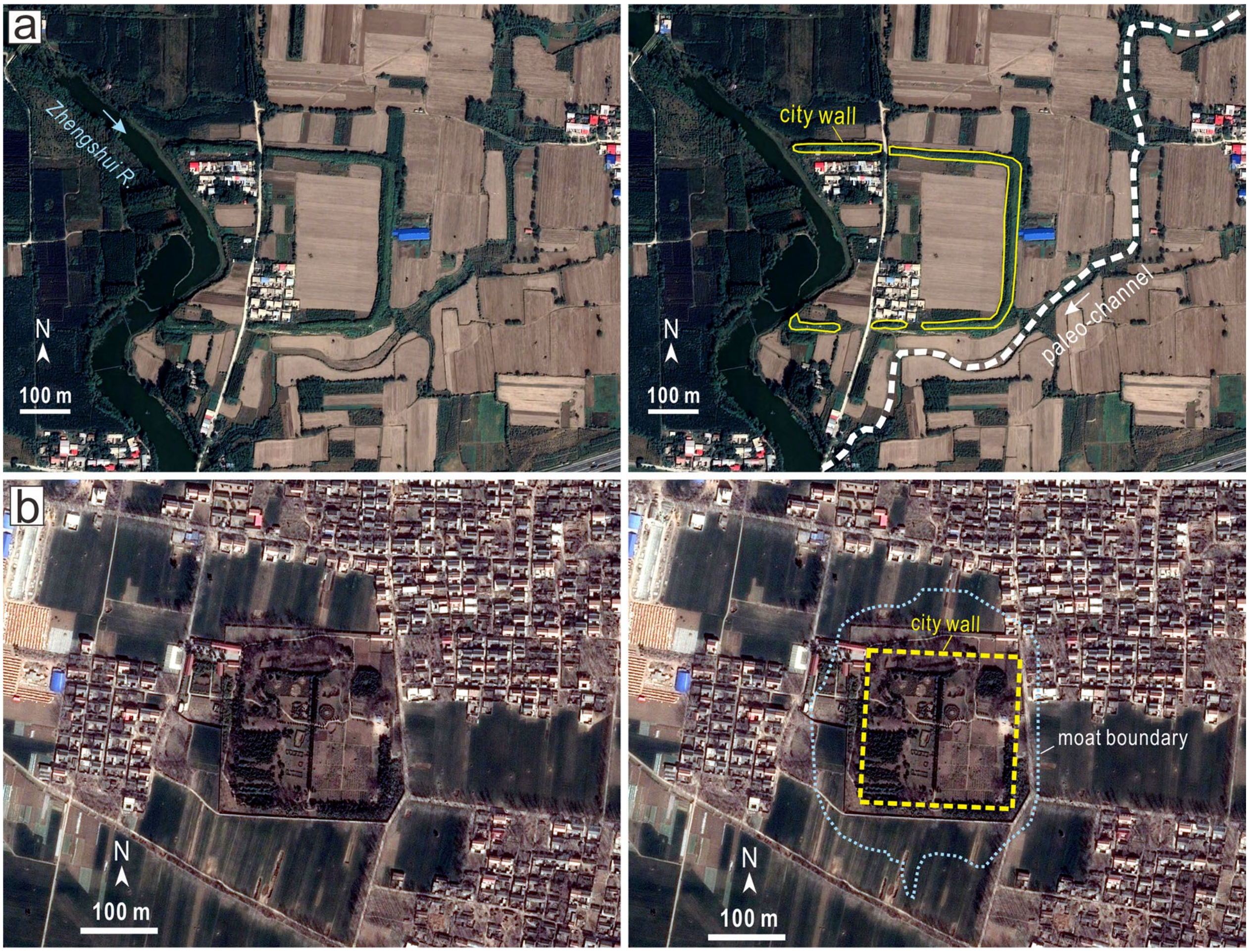

Fig. 3 Examples of ancient cities in the upper HRP (left, Google Earth satellite image; right, interpretation). For location see Fig. 6d. **a** Guchengzhai. **b** Pingliangtai; moat boundary following Cao (2019)

referred to as "major settlement"). The city walls are all made up of earth, generally 3–5 m high, 10–40 m wide, and the moats are 10–60 m wide. Some of these artificial structures in the Huai and Yangtze catchments have been well preserved and can be recognized by analyzing Google Earth satellite imagines (Figs. 3, 4, 5). The grouping of closely spaced cities/major settlements and their surrounding minor settlements with the same cultural characteristics defines a society, whose area is believed to positively correlate to its population (Guo and Gorodetskaya 2021).

4.1 Yellow and Huai river catchments

The earliest city known in the Yellow and Huai river catchments is Xishan, found near the apex of the YRP (Fig. 6b). Constrained by as many as 33 radiocarbon dates in and off the culture layer, this city was most likely built around 3000 BC and lasted for only one or two hundred years (Sino-US Liangcheng Area United Archaeological Team 1997; Yang 1997a). In ~ 2700 BC or later, some large settlements arose in the upper part of the HRP (two cities), the lower part of the HRP (one city and two major settlements), and the coastal area fringing the southeastern part of the Shandong Hill (4 cities) (Fig. 6c). After ~ 2350 BC, cities/major settlements bloomed in 4 places (Fig. 6d): (1) the valleys in the upper Huai River catchment (one major settlement and 4 cities), (2) the hills in the lower Fen River catchment (two major settlements); (3) the western margin of the YRP (4 cities); (4) the YRP bordering the northern part of the Shandong Hill (two groups, each having 8 and 4 cities respectively). In these places, three of the 4 cities in the upper Huai River catchment and the four cities in the northernmost bounding the Shandong Hill have been shown to last for less than a few hundred years (Yuan et al. 2000a; The Institute of Archaeology Chinese Academy of Social Sciences 2010; Wang and Wang 2010) (Appendix Table 2).

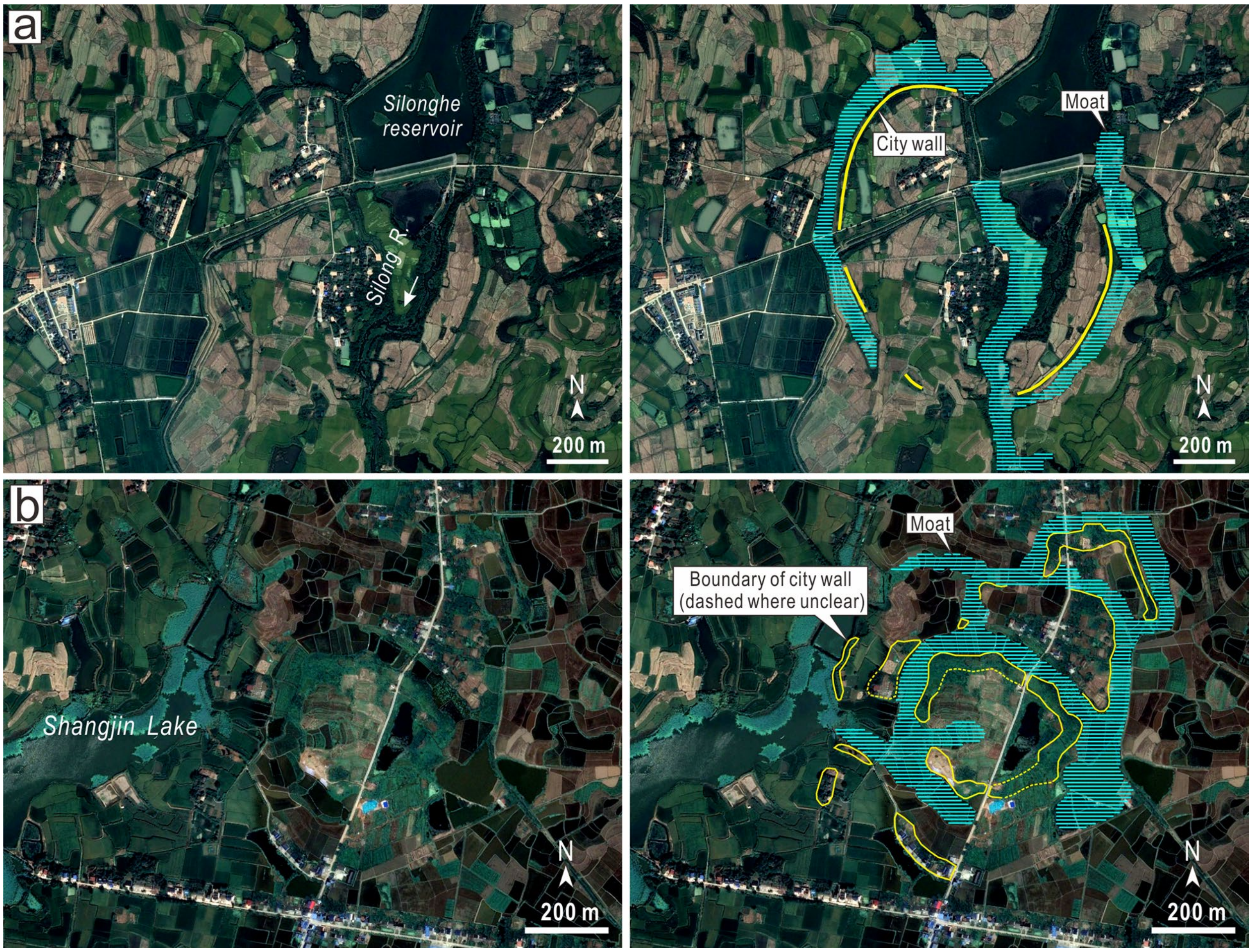

Fig. 4 Examples of ancient cities around the JHP (left, Google Earth satellite image; right, interpretation). For location see Fig. 6c. **a** Taojiahu. **b** Zoumaling; interpretation referred to (Gorodetskaya et al. 2018c; Shan and Yu 2018a)

The clustering of the above-mentioned cities/major settlements (excluding the earliest and short-lived Xishan city) defines a total of 7 societies (Figs. 6d and 7). The spatially largest society, with a maximum area of ~ 12,000 km^2, is located in the upper Huai River catchment (Fig. 7). This society owns the regionally largest city, Xinzhai, which has a moat-defined area of 70 ha (1 ha = 10,000 m^2) and a duration of ~ 400 years (2100–1750 BC) (Liu et al. 2005). It is noted that the society in the upper Huai River catchment (the Xinzhai society) and the society on the western margin of the YRP show different cultural characteristics, though they are only 60 km apart, suggesting that the Yellow River acted as a topographic barrier against the cultural communication among ancient people.

According to Zhao (2011) and Wang et al. (2019), millet became the staple food of the people in the Yellow River catchment since ~ 4000 BC. Later, influenced by the culture from the Yangtze (see below), rice was added to the diet of the people, such as those occupying the Xishan city (Wang et al. 2019) (Fig. 6b). After ~ 3100 BC, while millet remained dominated in the Yellow River catchment, a mixture of rice and millet farming prevailed in the upper Huai River catchment and along the coast bounding the southeastern Shandong Hill (Jing and Wang 2006; Gorodetskaya 2013) (Fig. 6c, d). Millet is a kind of dry crop. Thus, very few irrigation ditches or other water conservancy facilities including embankments have been found in the > 1100 BC archaeological sites around the Yellow River and its tributaries (Li 2014). This limited reliance on river resources is also reflected by the style of moats/ditches surrounding the cities which are generally narrow (< 30 m wide) and do not connect to boatable rivers (Figs. 3 and 7). Yet some of the societies must have faced flood risks, as Mengzhuang city (for location see Fig. 6d) on the western margin of the YRP was thus perished (Yuan 2000), (Yuan et al. 2000a).

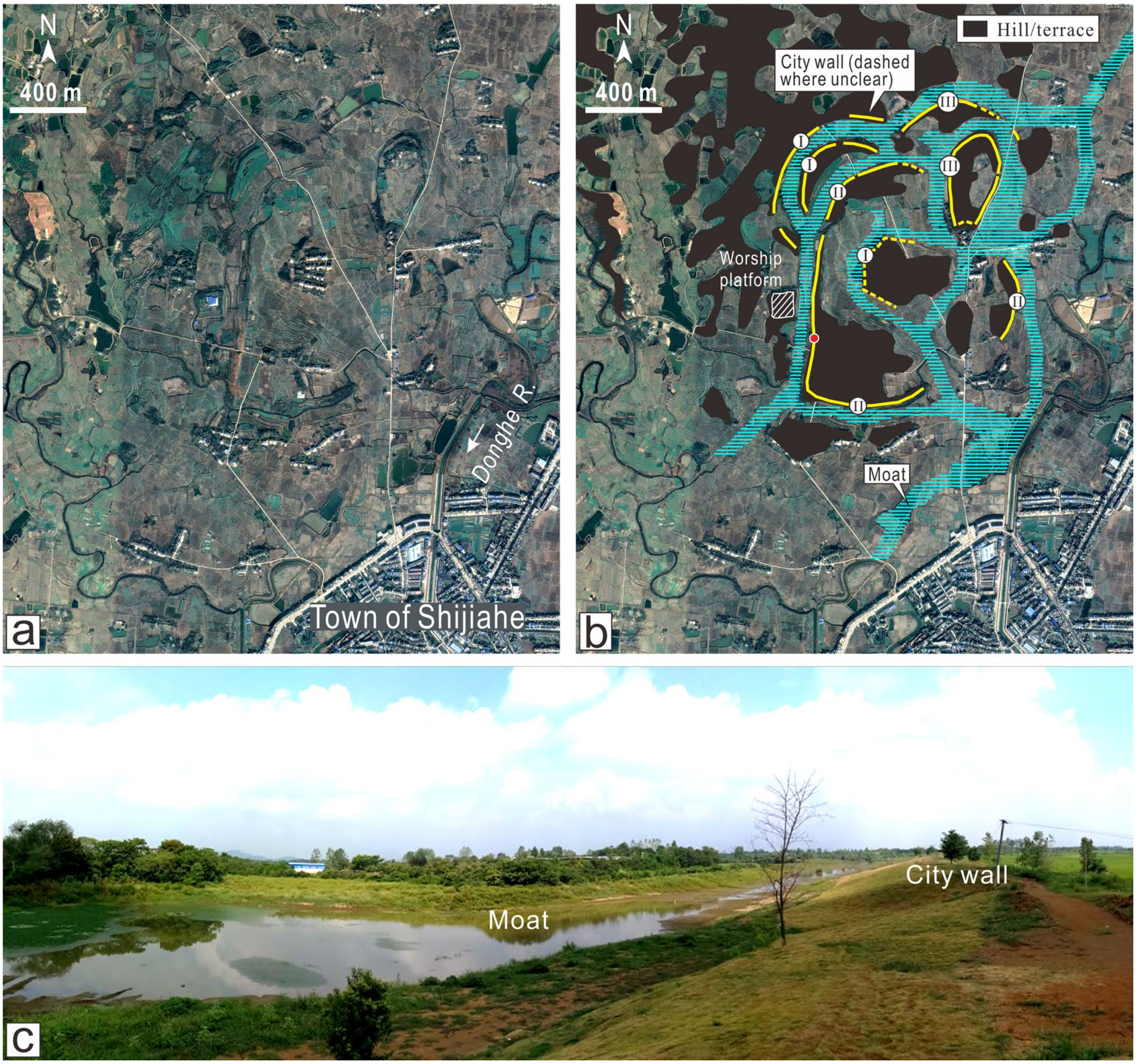

Fig. 5 Shijiahe, the largest city in East Asia 4000 years ago. For location see Fig. 6. **a** Google Earth satellite image. **b** Interpretation, modified from Guo and Gorodetskaya (2021). Note the sequence of city-wall building from I to III periods. **c** A view to moat and city wall; standing on the city wall (the red dot in **b**) looking to the north/northwest

Taosi settlement (dated 2350–1850 BC) in the Fen River catchment (Fig. 6d), with palaces, noble tombs, and other valuable artifacts unearthed, has been considered an important social/political center in ancient China (Yan and He 2005; (Xie 2007). This settlement, however, was destroyed by war and the society rapidly declined afterward (He 2015).

There are two sites in the Huai River catchment that may be related to Yu (Fig. 6d): Wangchengang city (dated 2170–2100 BC) in the Xinzhai society (An and Li 1992; Fang 2006a; Fang and Liu 2006; Liu 2019), and Yuhuicun settlement (dated 2300–2200 BC) adjacent to the lower HRP (Wang et al. 2013). Wangchengang is located near a place with the same name as the capital of Yu (and thus regarded as Yu's capital) (An 1979; Jing 1984; Pei 1996; Ma 2008). Yuhuicun is named semantically as "Yu's meeting with people." This naming may be considered to coincide with a historically recorded ceremony in which Yu assembled feudal leaders for his successful control of the Great Flood. This perspective, along with the revealing of some relics of ritual structures in the settlement, led to the inference that Yuhuicun was the place where Yu's

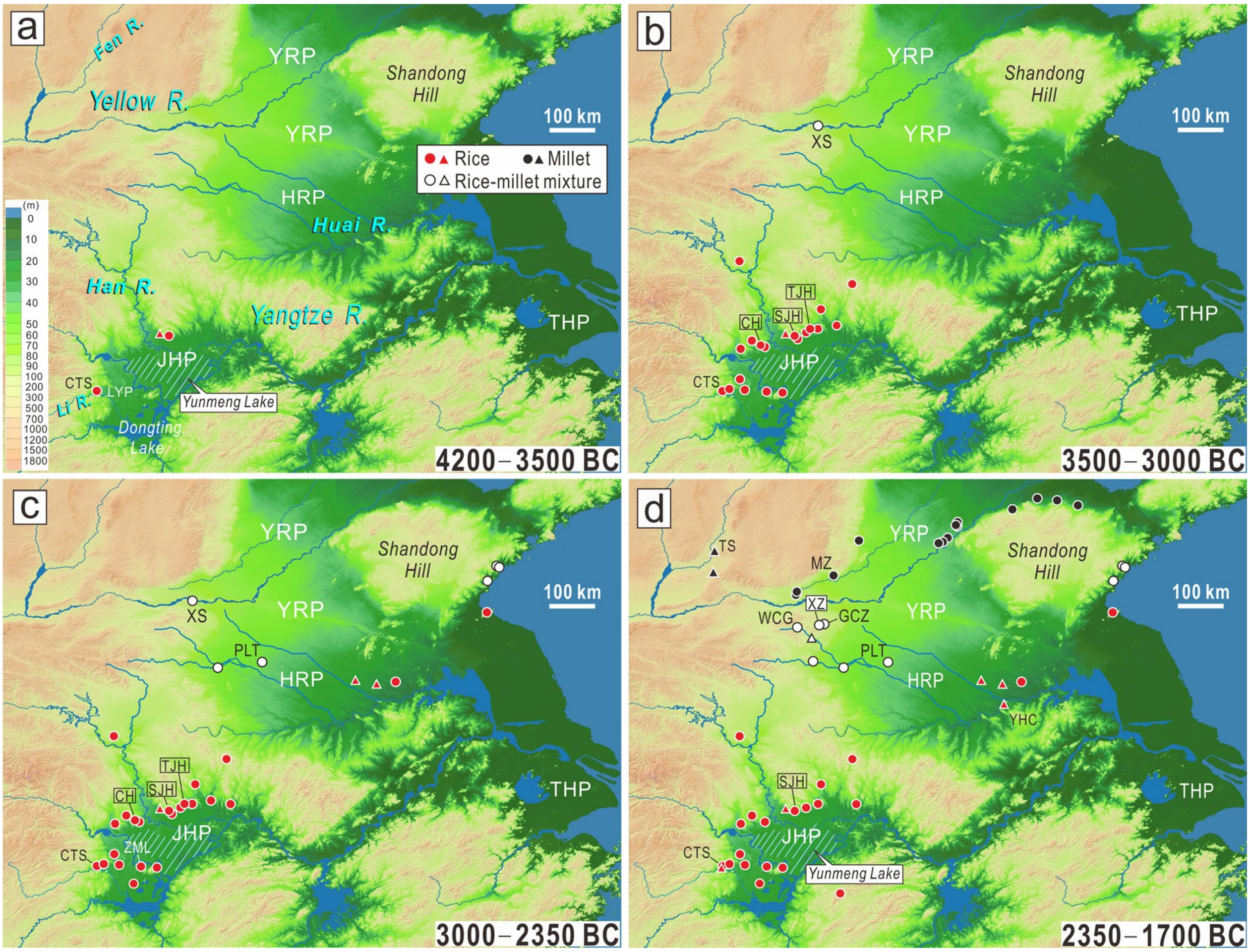

Fig. 6 Growth of city (circle) and major settlement (triangle) in eastern China from 4200 to 1700 BC, with type of staple crop in distinct colors. For map location see Fig. 2. CH = Chenghe; CTS = Chengtoushan; GCZ = Guchengzhai; MZ = Mengzhuang; PLT = Pingliangtai; SJH = Shijiahe; TJH = Taojiahu; TS = Taosi; WCG = Wangchengang; XS = Xishan; XZ = Xinzhai; YHC = Yuhuicun; ZML = Zoumaling. Cities with abbreviations in boxes have moat-defined areas ≥ 70 ha. LYP = Liyang Plain. Other notes as in Fig. 2. For raw data see Appendix

ceremony was held (Wang 2012), (He 2014), (Shang and Wang 2016).

4.2 Yangtze River catchment

The earliest Neolithic settlements of the Yangtze catchment, dated 8000–5800 BC (Jiang 2007), Guo (2010), (Gorodetskaya and Guo 2014), (Wu et al. 2017a), were found in the Liyang Plain drained by the Li, a tributary of the Yangtze entering the Dongting Lake (Fig. 6a). The progressive growth of the society led to the rise of Chengtoushan, the first city in East Asian (Fig. 6a) (Hunan Provincial Institute of Cultural Relics and Archaeology 2007; Guo 2010; Guo and Gorodetskaya 2021). The culture continuously developed and spread out across the trunk Yangtze. By 3000 BC, a total of 19 cities had existed in/around the Liyang Plain and along the northern margin of the JHP (Fig. 6b). Near the Yangtze river mouth, multiple settlements collectively named the Songtze-Liangzhu were built on the Taihu Plain since 3600 BC. These settlements were however small. They were abandoned and the culture rapidly declined by 2300 BC (Zhejiang Provincial Institute of Cultural Relics and Archaeology 2005; Qin 2019). Around and after this time, as many as 8 cities emerged in the Chengdu Plain of the Sichuan Basin (Appendix Table 2).

The cities in/around the Liyang Plain and the JHP were closely spaced and had similar cultural characteristics (Fig. 6). Grouping these cities and their surrounding minor settlements with similar cultural characteristics defined a society covering an area of 65,000–100,000 km^2, the largest in East China (Fig. 7). This society (the Jianghan society hereafter) contained the three spatially largest cities in the region: Shijiahe (180 ha in its heyday) (Fig. 5), Taojiahu (72 ha) (Fig. 4a), and Chenghe (70 ha), all located near the northern margin of the JHP (Fig. 7). The cities in the Jianghan society were generally

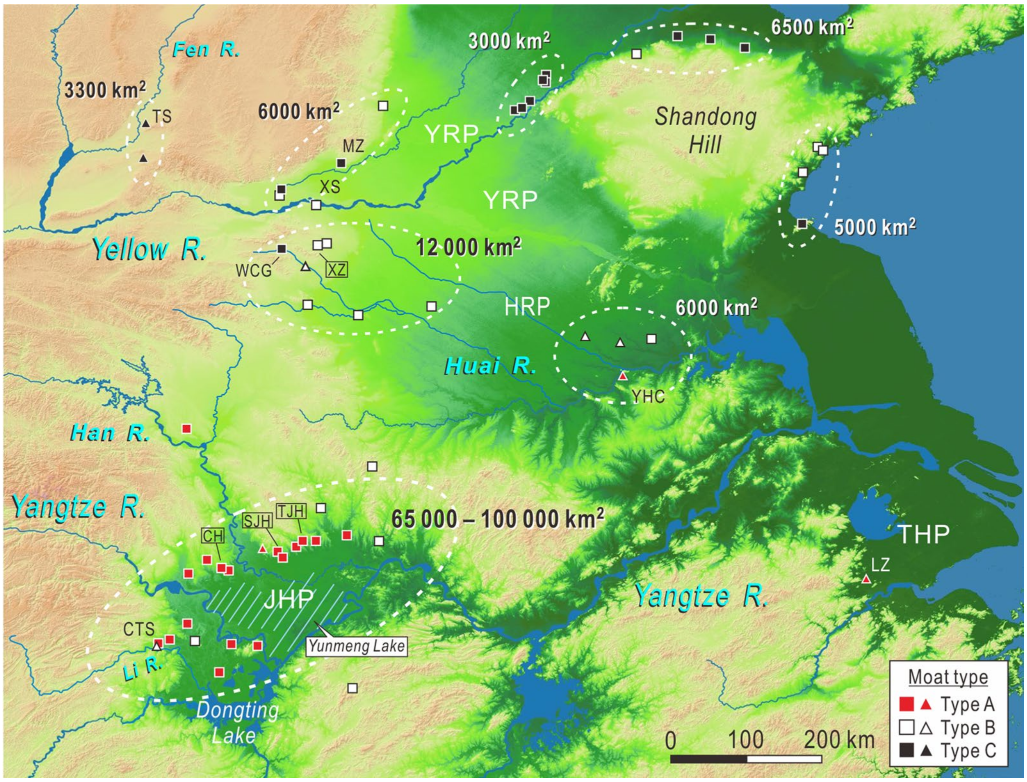

Fig. 7 Distribution of city (square) and major settlement (triangle) in eastern China during 3000–1700 BC, with type of moat (ditch) in distinct color. Type A, moat (ditch) connecting to boatable river; Type B, moat (ditch) connecting to river or paleo-river that may have been boatable; Type C: moat (ditch) not connecting to boatable rivers. Dashed oval groups closely spaced cities/major settlements that belong to the same societies, whose maximum area is shown nearby. The area (3300 km^2) of the Taosi (TS) society after Liu (2007); other areas are estimated in this study. Other notes as in Fig. 6

larger than those in the Yellow/Huai river catchments (Fig. 8) and had longer durations of occupation (Appendix Table 2). They continuously developed, with repeated repair or rebuilding, before being succeeded by the people of the Panlongcheng culture of the Shang Kingdom which was subsequently conquered by the Yinshang Empire from the Yellow River catchment (Fig. 1) (Gorodetskaya 2013, 2016a; Wu et al. 2017a).

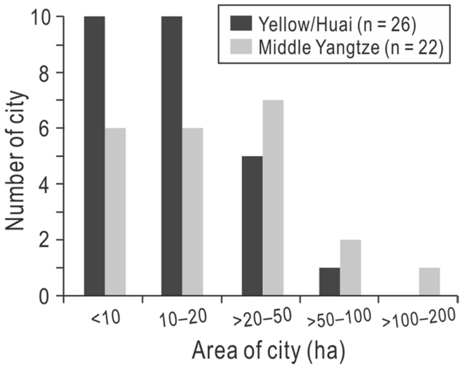

Fig. 8 Histogram comparing the sizes of the cities (4200–1700 BC, in their heydays) in the Yellow/Huai river catchments and around the middle course of the Yangtze River (in the Jianghan society). City boundary is defined by inner parts of moats. For raw data see Appendix Table 2

The civilization in the Yangtze River catchment was closely aligned with rice cultivation that started in the Liyang Plain as early as 7000 BC (Pei 1998, 2004; Gorodetskaya and Guo 2014), spread to the Taihu Plain around 5000 BC, and influenced the societies of the YRP by 3300 BC (Gorodetskaya 2013). In the following one thousand years, this rice culture entered the Sichuan Basin (Jiang 2015; Huang et al. 2017), extended to the HRP, and reached the periphery of the Shandong Hill (Jing and Wang 2006; Jing et al. 2017) (Fig. 6c, d). Not surprisingly, water conservancy facilities such as irrigation ditches and water storage pits were widely found in the < 3000 BC archaeological sites around the Yangtze River from the Taihu Plain to the Chengdu Plain e.g., (Zhuang et al. 2014; Wang and Liu 2015; Guo and Gorodetskaya 2016; Huang et al. 2017). In addition to these facilities, fish bones and net pendants were also commonly unearthed, suggesting the prevalence of fishing along the Yangtze River and its tributaries (Gorodetskaya and Guo 2019).

It is noted that moat/channel systems unearthed in/around the cities/settlements in the Yangtze River catchment were generally larger and more complicated than their counterparts in the Yellow/Huai river catchments (Pei 2004; Guo 2010; Guo and Gorodetskaya 2021). For example, there were many channels entering or crossing cities of the Yangtze (Figs. 4 and 5), with gates built by city walls probably used to control water levels. Some cities even had double or multiple moats connected by channels (Figs. 4b and 5) which were further extended to ditch systems over the surrounding settlements, or to river/lake systems that appear to have been boatable (Fig. 7). These channels are inferred as dredged for the purpose of shipping (Guo and Gorodetskaya 2021).

5 Paleo-rainfall records

We reviewed high-resolution speleothem δ^{18}O records from 5 limestone caves (for cave locations see Fig. 2): the Wuya (Tan et al. 2018a) on the southwestern margin of the Loess Plateau,the Xianglong (Tan et al. 2018b) and Jiuxian (Cai et al. 2010) in the upper Han River catchment, the Sanbao (Dong et al. 2010) and Heshang (Hu et al. 2008) near the Three Gorges (Fig. 9a–e). All these data reveal an overall decrease in precipitation (i.e., increase in δ^{18}O value) since the middle Holocene (due to the weakening of the Eastern Asian Summer Monsoon), consistent with other speleothem records elsewhere in the monsoonal China e.g., (Wang et al. 2005). However, the observed long-term drying trend is superimposed by centennial-to-decadal-scale fluctuations of rainfall with patterns varying from cave to cave (Fig. 9a–e), which suggests the local variations in precipitation and/or in sensitivity of the records to rainfall events (i.e., not all rainfall events could be recorded by the growth of speleothem).

The records from the Sanbao cave are the least fluctuated (Fig. 9d). In contrast, the data from the Xianglong and Jiuxian caves show the highest amplitudes of oscillation (Fig. 9b, c). By picking up the peaks of these oscillations (minimum δ^{18}O values), many potential rainfall events (or their clusters) before and around the era of the Great Flood may be identified. For example, a 2046 BC rainfall event shown in the Wuya record (Fig. 9a) was used by Tan et al. (2018a) to support the historicity of the Great Flood. Rainfall events close to this 2046 BC age, ~ 2050 BP and ~ 2020 BC, are also shown in the Xianglong and Heshang caves respectively (Fig. 9b, e). Notably, the rainfall events revealed in the Xianglong, Jiuxian, and Heshang caves consistently show a decrease in magnitude/frequency after ~ 1850 BC, which corresponds to an acceleration of climate drying recorded in the Sanbao cave (Fig. 9b–e).

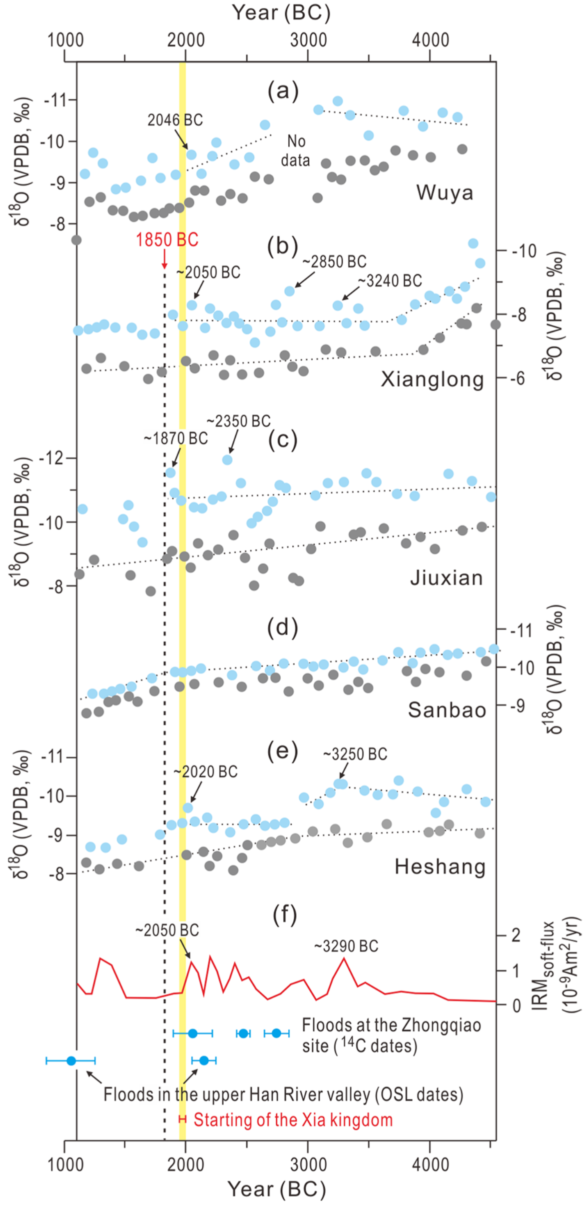

Fig. 9 Paleo-rainfall records reviewed in this study. **a**–**e** Summaries of speleothem δ^{18}O records from limestone caves: **a** Wuya (Tan et al. 2018a), **b** Xianglong (Tan et al. 2018b), **c** Jiuxian (Cai et al. 2010), **d** Sanbao (Dong et al. 2010), **e** Heshang (Hu et al. 2008). Only major peaks (suggesting relatively wet conditions) and troughs (suggesting relatively dry conditions) are picked. Dotted lines are data trends. **f** Magnetic signals from a stalagmite in the Heshang cave (Zhu et al. 2017), with age ranges of paleo-floods at the Zhongqiao site (Wu et al. 2017a, b) and along the upper Han River valley (Zhang et al. 2013). The age range of the beginning of the Xia Kingdom (2000–1950 BC) based on Zhang (2002, 2013)

There are more studies on the ancient rainfall/flood events around the JHP. The magnetic signals from a stalagmite in the Heshang cave recording the influx of soils from groundwater suggest an increase in rainfall events during 2550–1950 BC (Fig. 9f) (Zhu et al. 2017). At the Zhongqiao archaeological site in the JHP (for location see Fig. 2), muddy overbank slack-water deposits were identified and dated to be 2850–2650, 2530–2420, and 2220–1900 BC by radiocarbon methods (Wu et al. 2017a). Similar deposits, resulting from floods larger than any modern ones, were found along the upper Han River valley (Zhang et al. 2013). One of them was dated 2250–2050 BC by optically stimulated luminescence (OSL) methods (Fig. 9f). All these lines of evidence suggest a relatively wet period before and around the era of the Great Flood, consistent with the speleothem records.

It is worth noting that the above-documented wet condition in central China is contradictory to the coeval regional dryness (centered around 2250 BC) associated with the weakening of the Eastern Asian Summer Monsoon e.g., (Mayewski et al. 2004; Walker et al. 2019). This dryness is supported by the data from the Wuya cave (showing a rapid decline of precipitation since ~ 3000 BC, Fig. 9a) and by lacustrine deposits in both the Loess Plateau (Zhao et al. 2010; Chen et al. 2015) and the Inner Mongolia Plateau (Goldsmith et al. 2017) in northern China. Tan et al. (2018b) has attributed the "abnormal" wet climate condition in central/southern China to an atypical movement of the Westerly jet that remained relatively strong despite the weakening of the Eastern Asian Summer Monsoon. As a result, rain belts were able to stay in central/southern China (and caused heavy rains there) during the ~ 2250 BC climate drying.

6 Discussion

6.1 The problems of Yellow River as the locale of the Great Flood

Despite being deeply rooted in the society, the belief that the Great Flood was originated from the Yellow River is not supported by any data or perspectives (Table 1). Perhaps the biggest issue in this belief which has long puzzled archaeologists is the failure to find large, persistent cities/settlements suggestive of the territory of the Xia kingdom around the YRP. In fact, most of the YRP remained scarcely inhabited (not even occupied by small settlements) by 1700 BC (Fig. 6d). Although as many as 16 cities arose after 2350 BC, they were relatively small, short-lived, and located only on the margins of the plain (Fig. 6d). We believe this limited human occupation reflected the active flooding/alluviation of the plain that made it unsuitable for habitation. Ancient people would have settled down on the parts of the plain that had been inactive for some generations. However, once they did, they put themselves at risk, as the unpredictable nature of the floods caused by powerful channel avulsion could result in fatal disasters, as shown by the destruction of Mengzhuang city. From this point of view, even if there are some undiscovered ancient settlements now buried in the YRP, as suggested by Kidder et al. (2012), they are unlikely to have been large.

Taosi settlement (2350–1850 BC) in the Fen River catchment, as an important social/political center in northern China (Fig. 6d), might be considered a candidate for Yu's hometown. However, the Taosi society was relatively small in area and declined rapidly, inconsistent with the image of the Xia Kingdom. Also, Taosi settlement was built on a hill, and its residents, having millet as staple food, did not live on river resources (and thus had no urgent need for flood control). Moreover, the region where the settlement was located appeared to undergo droughts around the era of Yu (Zhao et al. 2010), (Chen et al. 2015), a climate condition not favoring the occurrence of the Great Flood.

Wu et al. (2016) linked the ~ 1920 BC Jishixia outburst flood occurring along the upper Yellow River to the origin of the Great Flood. The uncertainties of this remote

Table 1 Comparison of flood characteristics and ancient human activities on the Yellow River Plain (YRP) and the Jianghan Plain (JHP)

	YRP	JHP
Flood characteristics (general)		
Topographic setting	Alluvial fan (plain); steeper than the JHP	*Lowland associated with plentiful lakes/ponds and wetlands
Nature	Channel avulsion induced by high rates of sedimentation	*Lengthy and widespread coverages of overbank water
Spatial predictability	Unpredictable	*Predictable (lower-lying areas are more likely to be flooded)
Human activities (before 1700 BC)		
Social development	Only small, short-lived cities/settlements developed on the margin of the plain	*Having developed into the Jianghan society, the most civilized and populated society in East Asia
Reliance on river resources	Weak (having millet as staple food; no shipping)	*Strong (rice growing, fishing, and shipping)
Capability of dredging channel	(no evidence)	*Great (being able to dig large-scale moat/ditch systems)

*Characteristics consistent with the historically documented Great Flood outburst flood regarding its age and influences on the upper Yellow have been addressed by Han (2017) and Wu et al. (2017b). Here, we provide two additional perspectives to question the relation of this flood to the Great Flood. First, it is unlikely that the Jishixia flood, after being transmitted through multiple wide plains in the semi-arid Inner Mongolia Plateau (Fig. 2), remained significant as it reached the YRP (in contrast to the JHP which is the first plain the Yangtze meets after flowing out of mountains). Second, the catastrophic Jishixia flood is different from what historical texts recorded about the nature/impact of the Great Flood which lasted for at least two generations. Note that even nowadays, engineering measures to prevent or alleviate natural hazards are designed mainly for relatively frequent but small-magnitude events, not for rare, unpredictable catastrophes. An implication here is that the significance of the flood (or floods) faced by Yu could mainly reside in its (or their) high frequency, long duration, or critical location (i.e., near the habitation area), it (or they) may not be correlated with any specific high-magnitude rainfall/flood events recorded by stratigraphic or geomorphic evidence.

Becoming the social/political center, the YRP has been known by its notorious flood hazards since ~ 340 BC. We believe this increase in flood hazard mainly reflected the increase in land use on the YRP associated with the population growth. Before dam construction in modern times, building embankment has been the only solution for the floods on the YRP. This method, however, differs from the dredging method depicted in historical texts to contain the Great Flood. The flood control on the YRP has barely succeeded. Given that even the troops of the powerful Emperor Wu were defeated, it is unlikely that the people in the era of Yu, ~ 1800 years earlier than the Emperor Wu, could have been capable of taming the Yellow River.

6.2 Jianghan plain as the locale of the Great Flood

In contrast to the lack of the support to the Yellow-river origin of the Great Flood, all kinds of evidence indicate the JHP as the locale of the Great Flood and the Jianghan society, the social/political center of the Xia Kingdom (Table 1). The Jianghan society, having the largest area with the greatest number of cities (including the three largest ones), is likely to have been the most populated society in East Asia in the era of Yu (Fig. 7). We suspect that one of the largest cities in this society (e.g., Shijiahe; Figs. 5 and 7) was the hometown of Yu which he bypassed three times during his 13-year flood-control career. The culture of the Jianghan society was originated and transmitted from the Liyang Plain, a place known by the earliest development of the Neolithic culture in East Asia (including the first settlement, rice cultivation, and city building) (Fig. 6). Although the culture of the Jianghan society underwent rise and fall (Wu et al. 2017b), it continuously evolved into (and succeeded by) the cultures of the Panlongcheng (Shang), Yinshang Empire, and the Chu state in chronological order (Fig. 1). All these regimes were influential, helping spread the account of the Great Flood and the deeds of Yu to descendants. In short, it is the scale and cultural continuity of the Jianghan society that make it more likely to have been the social/political center of the Xia Kingdom than other societies on the HRP and along the Yangtze River (Figs. 1, 6, and 7).

The people in the Jianghan society, like others residing around the Yangtze River and its tributaries, lived on river resources such as rice growing, fishing, and shipping. As for the shipping, note that the southern part of the JHP had once been occupied by the Yunmeng Lake which remained large in the period of the Chu state. We believe that by the era of Yu, this ancient lake had already existed and served as a route for shipping, like the modern Dongting Lake (Figs. 6 and 7). Shipping facilitated transport and helped unite people, which explains the reason why the Yangtze River, unlike the Yellow, has never acted as a barrier against the spread of cultures. Also, through digging large-scale moat/ditch systems (and maintaining them), the people in the Jianghan society showed their capability in dredging channels, well fitting the method used to regulate the Great Flood.

Modern and historical accounts, along with the topographic backgrounds, have shown that unlike the YRP floods that are typically associated with dynamic sedimentation and channel avulsion, the floods on the JHP have the following three characteristics. First, parts of the floods, especially where they inundated the margins of the JHP with stagnant or slow-moving water, are not powerful and thus could be controlled (or adaptable) by ancient people. An example of such mild flooding is shown at the Zhongqiao archaeological site. Unlike Mengzhuang city on the YRP that was destroyed by flooding, the Zhongqiao site only underwent minor deposition of muddy sediments during the three dated flood events and was reoccupied by people afterward (Wu et al. 2017a). Second, the floods on the JHP could be spatially predictable (Yu et al. 2009) (i.e., lower-lying areas were more likely to be inundated). This characteristic could rouse people's awareness of flood risk and flood management in advance. Third, the floods on the JHP could be alleviated once the flood water can be diverted to the lake/wetland systems in/around the plain. This concept (implemented by the "returning farmland to lakes" policy) has been recently applied to regulate the floods along the entire middle-lower course of the Yangtze River (Xing et al. 2022). The above three characteristics well fit the scenarios of the Great Flood depicted by historical texts. We propose that the Great Flood was a series of relatively mild floods taking place on the northern margin of the JHP where the population was the densest. Here, people dug channels and successfully divert the flood water to a "sea" which we believe was the Yunmeng Lake.

6.3 The significance of the Great Flood

Why is the Great Flood so significant that its accounts deserve to go down in history? Our proposition that the flood impacted the Jianghan society, the then largest and most populated/civilized society, has provided an answer. The occurrence of the Great Flood required a suitable climate condition, which is supported by the paleo-rainfall data showing that around the era of the Great Flood, the areas surrounding the JHP were characterized by relatively wet climate. However, notice that under the long-term climatic drying since the middle Holocene (Fig. 9), the Great Flood did not occur when the climate was the wettest, and there were periods before (e.g., around 2350, 2850, and 3250 BC) that appeared to be wetter or characterized by greater or more frequent rainfall events (Fig. 9). Apparently, climate was not the only factor rendering the uniqueness of the Great Flood.

We propose that the timing and the impact of the Great Flood were strongly related to the expansion of the Jianghan society, a situation similar to the flooding on the YRP which has been known only after large-scale occupation on the plain. Imaging that after developing for more than one thousand years, the Jianghan society may have encountered population pressure and gradually expanded its territory toward the southern parts of the JHP, which was likely promoted by the shrinkage of the Yunmeng Lake (Guo 2005). People would be attracted by the lands newly exposed, but after moving in, they unavoidably faced flood threats. A key perspective here is that the impact of the Great Flood, to a great extent, could reflect the contemporary increase in land use on the JHP. In other words, the account of the Great Flood was not simply an episode of a powerful flood (or floods) but a history documenting the struggle of an influential agriculture society in ancient East Asia with fluctuating physiographical environments. This society survived and continuously developed afterward, with its epic flood-control achievement living on in history.

The establishment of the Xia Kingdom after the Great Flood has demonstrated the political significance of this natural disaster. Since then, devastating floods in the history of China have never been treated as crucially as the Great Flood. We believe this reflects the continuous increase in the social and economic diversity (and thus the resilience to natural hazards) of the Xia Kingdom and its successors. Also, notice the progressive increase in occupation on the JHP after the era of the Great Flood. It is possible that by ~ 400 AD, associated with the complete dry-up of the Yunmeng Lake, human habitation has approached major river channels such as the Han and the trunk Yangtze. This increase in land use must have significantly decreased the capacity of the JHP to contain flood water, which explains the reason why channel diversion has no longer been a primary method to regulate floods.

Finally, was the control of the Great Flood achieved by luck, as suggested by Wu and Ge (2005)? In fact, by virtue of the high-resolution speleothem records and their detailed chronologies (by the U-Th dating methods), we have found a significant decrease in precipitation (along with a decrease in the magnitude/frequency of rainfall events) after the Great Flood (Fig. 9). This climate drying, however, started at ~ 1850 BC, at least one hundred years after Yu. In other words, the flood-control work managed by Yu was effective for at least some generations, during which rainfall conditions (or flood magnitudes/frequencies) did not significantly change. We thus argue that even though the general lack of flood threats throughout the Xia Kingdom could be attributed to climate drying (e.g., Dalfes et al. 1997, Peiser 1998), it was the wisdom of Yu, and the efforts of the entire society, that tamed the Great Flood.

7 Conclusions

Although the Yellow River Plain (YRP) of the Yellow River is traditionally thought to be the locale of the Great Flood, the following observations suggest that this flood in fact occurred on the Jianghan Plain (JHP) along the middle course of the Yangtze River and that the society around the JHP at that time (named the Jianghan society) was the social/political center of the Xia Kingdom:

1. The Jianghan society was the most civilized and populated society in East Asia around the era of the Great Flood (at that time, the habitation on the YRP remained limited).
2. The Jianghan society strongly lived on river resources (shipping, fishing, and rice cultivation) and thus was subject to flood risks (in contrast, the Yellow River was not boatable, and the people inhabiting the YRP had millet as staple food).
3. The people in the Jianghan society were experienced in dredging channels for shipping and irrigation.
4. Floods on the JHP, typically occurring with stagnant or slow-moving water, were predictable and man-

ageable to ancient people (in contrast to the floods on the YRP that were characterized by dynamic sedimentation and channel avulsion).

(5) The JHP has been associated with lake/wetland systems serving as detention basins during floods. Here, the historical documented method for controlling the Great Flood, dredging channels to divert flood water to a "sea", was practicable.

Paleo-rainfall records show that the climate of the JHP had been wet since the middle Holocene (earlier than the era of the Great Flood) and significantly turned dry after ~ 1850 BC (at least one hundred years later than the Great Flood). Given this, we propose (1) the uniqueness of the Great Flood, to a great extent, reflected the contemporary increase in land use on the JHP, and (2) the success in controlling the Great Flood was due to the efforts of the society, not by luck.

Appendix

See Figs. 10, 11 and Table 2.

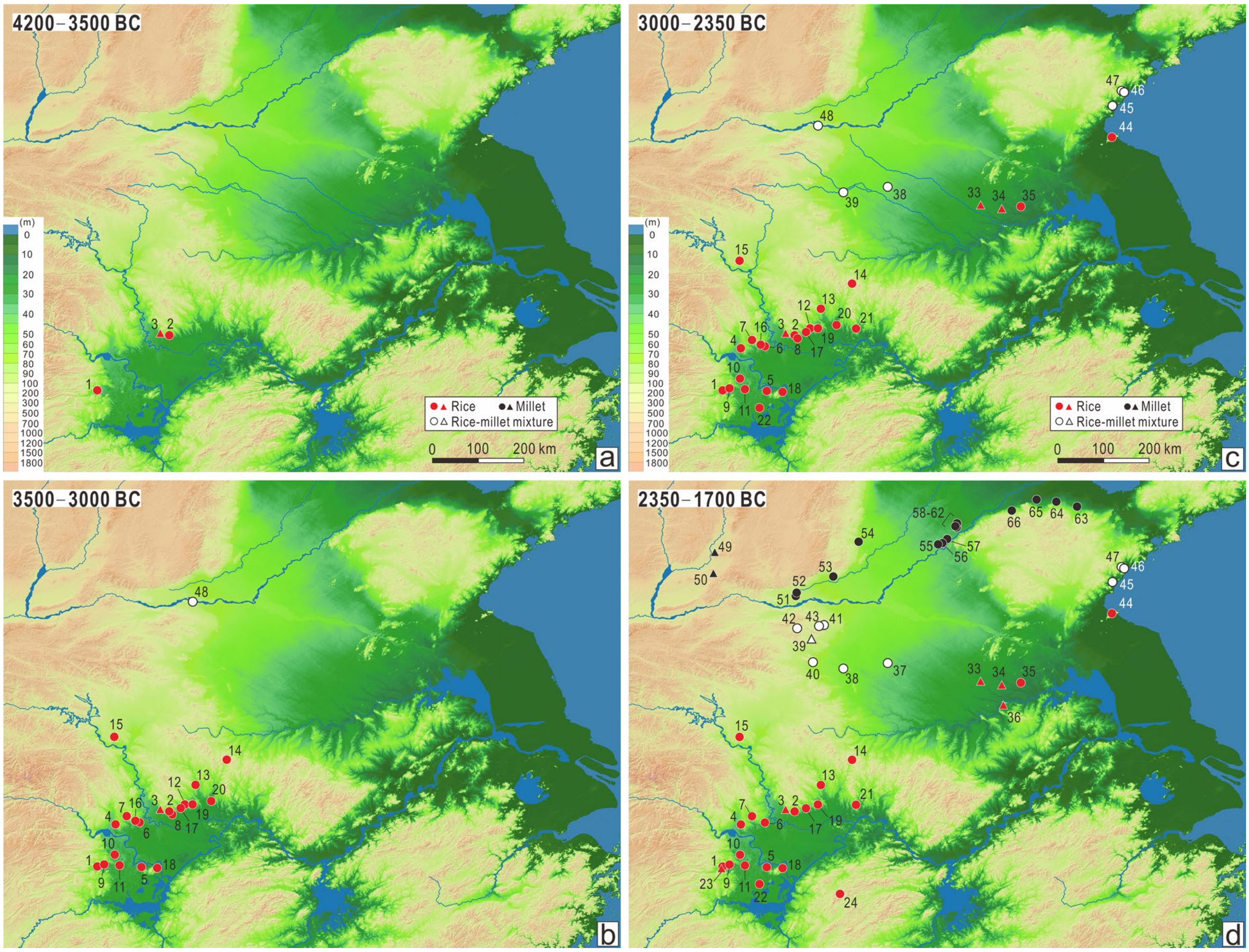

Fig. 10 Locations of the cities and major settlements reviewed in this study (around the Yellow River and the middle-lower course of the Yangtze River)

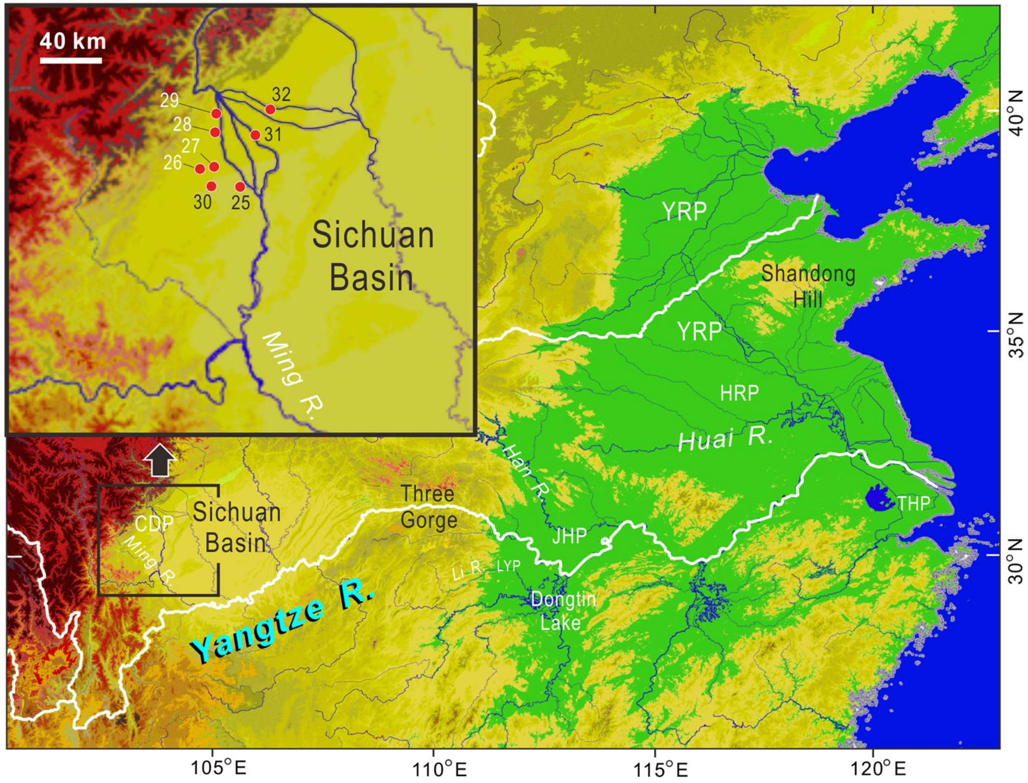

Fig. 11 Locations of the cities and major settlements reviewed in this study (around the Chengdu Plain, Sichuan Basin)

Table 2 Cities and major settlements (4200–1700 BC) reviewed in this study

Name^a	Long. (E)/Lat. (N)	Area (ha)^b	Moat type^c	Culture^d	Age (BC)^e	Staple food	References
Yangtze River (middle)							
1. Chengtoushan	*111.656° /29.693°*	8	A	Daxi to Houshijiahe	**4200**–1800 (n = 10)	Rice	He (2007); Guo (2007); Guo (2010b)
2. Shijiahe I: Dengjiawan and Tanjialing	*113.076° /30.780°*	46	A	Youziling to Qujialing	***4000***–*3000* (n = 3)	Rice	Guo (2010b); Guo and Gorodetskaya (2021); Radiocarbon Dating Laboratory in School of Archaeology and Museology Beijing University (1994); Meng et al. (2017); Hubei Provincial Institute of Cultural Relics and Archaeology, Archaeology and Museology College of Beijing University, and Tianmen Municipal Museum (2017); Wu et al. (2017a); Gorodetskaya et al. (2018b)
2. Shijiahe II	*113.079° /30.775°*	120	A	Late Qujialing to Shijiahe	*3100–2350* (n = 2)	Rice	Guo (2010b); Radiocarbon Dating Laboratory in School of Archaeology and Museology Beijing University (1994); Gorodetskaya et al. (2018b); Gorodetskaya et al. (2019); Radiocarbon Dating Laboratory in School of Archaeology and Museology Beijing University (1996); Report on the investigation of the Shijiahe archaeological sites (1992); Shijiahe Archaeological Team (1994)
2. Shijiahe III: Tucheng	*113.089° /30.778°*	**180**	A	Houshijiahe	*2350–1700*	Rice	Guo (2010b)
3. (Qujialing)	*122.903° /30.835°*	(34)	A	Youziling to Houshijiahe	**3800**–1700 (n = 5)	Rice	Wu et al. (2017a); Hubei Provincial Institute of Cultural Relics and Archaeology, and Jingshan County Museum (2008); Yuan (1997)
4. Yinxiangcheng	*112.021° /30.516°*	**22**	A	Youziling to West Zhou	*3500–780*	Rice	Yuan (1997); Gu (1998a); Gorodetskaya et al. (2018c)
5. Zoumaling	*112.523° /29.676°*	50	A	Youziling to Houshijiahe	***3500***–*1700* (n = 1)	Rice	Guo and Gorodetskaya (2021); Radiocarbon Dating Laboratory in School of Archaeology and Museology Beijing University (1996); Gorodetskaya et al. (2018c); Shan and Yu (2018b)
6. Jingjiacheng	*112.408° /30.588°*	**14**	A	Youziling to Houshijiahe?	*3500–1700?*	Rice	Liu and Cui (1987)
7. Majiayunan	*112.233° /30.683°*	**33**	A	Youziling to Houshijiahe?	*3500–1700?*	Rice	Gu (1998a); Liu and Cui (1987)
8. Longzui	*113.121° /30.723°*	8.2	A	Youziling to Qujialing	**3500**–**2800** (n = 11)	Rice	Guo and Gorodetskaya (2021); Gorodetskaya et al. (2018b); Hubei Provincial Institute of Cultural Relics and Archaeology, and Tianmen Municipal Museu (2015)
9. Jijiaocheng	*111.782° /29.732°*	15	A	Mid. Qujialing to Houshijiahe	*3300–1700*	Rice	Guo 2010b; Hunan Provincial Institute of Cultural Relics and Archaeology 2002)
10. Jimingcheng	*111.986° /29.925°*	18	A	Mid. Qujialing to Houshijiahe?	*3300–1700?*	Rice	Gu (1998b); Jingzhou Municipal Institute of Cultural Relics and Archaeology (2015)
11. Qinghecheng	*112.090° /29.713°*	**7.2**	B	Mid. Qujialing to Houshijiahe?	*3300–1700?*	Rice	Gorodetskaya et al. (2018c); Jingzhou Municipal Institute of Cultural Relics and Archaeology (2015)
12. Taojiahu	*113.376° /30.912°*	**72**	A	Mid. Qujialing to Shijiahe	*3300–2350*	Rice	Guo and Gorodetskaya (2021); Li and Xia (2001); Li et al. (2017)

Table 2 (continued)

Name[a]	Long. (E)/Lat. (N)	Area (ha)[b]	Moat type[c]	Culture[d]	Age (BC)[e]	Staple food	References
13. Wangguliu	*113.583° /31.299°*	5	B	Mid. Qujialing to Houshijiahe	*3300–1700*	Rice	Hubei Provincial Institute of Cultural Relics and Archaeology, Xiaogan Municipal Museum, and Anlu Municipal Museum (2015)
14. Tucheng	*114.207° /31.799°*	5	B	Mid. Qujialing to Panlongcheng	*3300–1300*	Rice	Xiaogan Municipal Museum, Dawu County Museum (2015)
15. Fenghuangzui	*111.983° /32.248°*	25	A	Mid. Qujialing to Houshijiahe	*3300–1700*	Rice	Xiang (2019)
16. Chenghe	*112.408° /30.588°*	70	A	Mid. Qujialing to Shijiahe	*3300–2350*	Rice	Peng et al. (2018)
17. Xiaocheng	*113.306° /30.843°*	10	A	Mid. Qujialing to West Zhou	3300–550	Rice	Guo and Gorodetskaya (2021); Hubei Provincial Institute of Cultural Relics and Archaeology, and Tianmen Municipal Museum (2007)
18. Qixingdun	*112.830° /29.660°*	50	A	Late Qujialing to Houshijiahe	***3100***–*1700* (n = 5)	Rice	Wang (2018)
19. Menbanwan	*113.539° /30.914°*	**20**	A	Late Qujialing to Houshijiahe	*3100–1700*	Rice	Wang (2003); Hubei Provincial Institute of Cultural Relics and Archaeology (2015)
20. Yejiamiao	*113.903° /30.977°*	30	A	Late Qujialing to Shijiahe	*3100–2500*	Rice	Liu et al. (2012a); Liu (2016)
21. Zhangxiwan	*114.289° /30.914°*	> 9.8	B	Shijiahe to Houshijiahe	*3000–1800*	Rice	Liu et al. (2012b)
22. Lubaoshan	*112.391° /29.350°*	**9.5**	A	Shijiahe to Houshijiahe	3000–1700	Rice	Qiao (2020)
23. (Sunjiagang)	111.625° */29.663°*	(23)	B	Houshijiahe	**2200**–**1800** (not reported)	Rice	Zhao et al. (2018)
24. Yaojialing	113.965° */29.140°*	5	B	Houshijiahe	***2100***–*1700* (n = 2)	Rice	Li et al. (1983)
Yangtze River (Sichuan Basin)							
25. Baodun	103.746° */30.448°*	60	A	Baodun	***2500***–***1700*** (n = 31)	Rice	Guo and Gorodetskaya (2021); Sino-Japan United Archaeological Team (1998); Chengdu Provincial Institute of Cultural Relics and Archaeology, and Xinjin County Cultural Relics Management Office (2009; Zeng et al. (2016)
26. Yandian	103.510° */30.554°*	15.8	A	Baodun	*2200–2000*	Rice	Chengdu Provincial Institute of Cultural Relics and Archaeology, and Dayi County Cultural Relics Management Office (2013a)
27. Zizhu	103.594° */30.565°*	18.3	B	Baodun	*2200–2000*	Rice	Zhong et al. (2014)
28. Shuanghe	*103.600° /30.768°*	11	A	Baodun	*2200–2000*	Rice	Jiang and Li (2002)
29. Mangcheng	103.607° */30.878°*	10.5	B	Baodun	*2200–2000*	Rice	Yan et al. (1999); Sino-Japan United Archaeological Team (1999a); Sino-Japan United Archaeological Team (1999b)

Table 2 (continued)

Name[a]	Long. (E)/Lat. (N)	Area (ha)[b]	Moat type[c]	Culture[d]	Age (BC)[e]	Staple food	References
30. Gaoshan	103.577° *30.453°*	22.4	B	Baodun	*2200–2000*	Rice	Chengdu Provincial Institute of Cultural Relics and Archaeology, and Dayi County Cultural Relics Management Office (2013b)
31. Yufu	103.836° *30.755°*	32	B	Baodun	*2200–2000*	Rice	Jiang et al. (1998)
32. Pixian	103.924° *30.904°*	30.4	B	Baodun	*2200–2000*	Rice	Jiang and Yan (1999)
Huai River (lower)							
33. (Yuchisi)	116.751° */33.352°*	(10)	B	Late Dawenkou to Longshan	**2800**–**2400** (n = 10)	Rice	Institute of Archaeology Chinese Academy of Social Sciences (2001)
34. (Nanchengzi)	117.164° */33.280°*	(15)	B	Late Dawenkou to Longshan	*2800 –2400?*	Rice	Institute of Archaeology Chinese Academy of Social Sciences, and Bangbu Municipal Museum (2013)
35. Gaixia	117.542° */33.319°*	> 15	B	Late Dawenkou to Longshan	*2800–2400*	Rice	Wang (2013)
36. (Yuhuicun)	117.198° /32.884°	(50)	A	Early Longshan	**2300**–**2200** (n = 7)	Rice	Institute of Archaeology Chinese Academy of Social Sciences, and Bangbu Municipal Museum (2013)
Huai River (upper)							
37. Pingliangtai	114.905° */33.715°*	**4.2**	B	Late Dawenkou to Longshan	**2600**–**2000** (n = 16)	Rice; Millet	Institute of Archaeology Chinese Academy of Social Sciences (1992); Cao et al. (2017); Cao and Ma (1983)
38. Haojiatai	114.029° */33.606°*	3.3	B	Shijiahe to Houshijiahe/Wangwan III	**2600**–*2000* (n = 2)	Rice; Millet	Henan Provincial Institute of Cultural Relics and Archaeology (2012)
39. (Wadian)	113.403° */34.190°*	(40)	B	Wangwan III	**2300**–**1800** (n = 10)	Rice; Millet	Wadian (2004); Liu et al. (2018)
40. Puchengdian	113.434° */33.731°*	4.1	B	Mid. to late Wangwan III	*2200–2000*	Rice; Millet	Wei et al. (2008)
41. Guchengzhai	113.650° */34.466°*	**14.6**	B	Mid. to late Wangwan III	*2200–2000*	Rice; Millet	Cai and Ma (2002)
42. Wangchengang	113.125° */34.400°*	34.8	C	Wangwan III	**2170**–**2100** (n = 31)	Rice; Millet	Fang and Liu (2006); Fang (2006b); Liu (2019b)
43. Xinzhai	113.557° */34.443°*	70	B	Wangwan III to Xinzhai	**2100**–**1750** (n = 34)	Rice; Millet	Zhao et al. (2009); Zhao (2004); Liu et al. (2005)
Coastal area bounding the Shandong Hill							
44. Tenghualuo	119.337° */34.687°*	14	C	Late Dawenkou to Mid. Longshan	*2500–1900*	Rice	Wang (2017)
45. Yaowangcheng	119.346° */35.301°*	12	B	Late Dawenkou to Mid. Longshan	*2500–1900*	Rice; Millet	Wang (2017); Liang (2016)
46. Liangcheng	119.573° */35.572°*	No data	B	Late Dawenkou to Mid. Longshan	*2500–1900*	Rice; Millet	Wang (2017); Sino-US Liangcheng Area United Archaeological Team (1997)

Table 2 (continued)

Name^a	Long. (E)/Lat. (N)	Area (ha)^b	Moat type^c	Culture^d	Age (BC)^e	Staple food	References
47. Dantu	119.527° */35.604°*	23	B	Late Dawenkou to Mid. Longshan	*2500–1900*	Rice; Millet	Wang (2017); Zhao (2015)
Yellow River							
48. Xishan	113.528° */34.920°*	**6**	B	Late Dahecun	***~3000*** (n = 33)	Rice; Millet	Yang (1997b); Institute of Archaeology Chinese Academy of Social Sciences (2012)
49. (Taosi)	111.494° */35.891°*	(280)	C	Taosi	**2350**–**1850** (n = 27)	Millet	Gao et al. (2007); Yan and He (2005); Zhao and He (2006)
50. (Zhoujiazhuang)	111.469° */35.486°*	(500)	C	Taosi	**2300**–**1750** (n = 25)	Millet	Dai et al. (2015); Tian and Dai (2018)
51. Xubao	113.092° */35.037°*	20	B	Hougang II	*2200–1800*	Millet	Wu et al. (2007)
52. Xijingcheng	113.112° */35.109°*	30.8	C	Hougang II	*2200–1800*	Millet	Wang and Wang (2010)
53. Mengzhuang	113.832° */35.424°*	12	C	Hougang II	*2200–1800*	Millet	Yuan et al. (2000a)
54. Hougang	114.330° */36.111°*	No data	B	Hougang II	*2200–1800?*	Millet	Ren and Wu (2010)
55. Huangguzhong	115.903° */36.055°*	6	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
56. Jingyanggang	115.982° */36.082°*	35	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
57. Wangjiazhuang	116.079° */36.160°*	4	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
58. Wangjicheng	116.266° */36.390°*	3.8	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
59. Jiaochangpu	116.235° */36.406°*	40	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
60. Daweicheng	116.260° */36.425°*	3	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
61. Lepingpu	116.257° */36.457°*	3	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
62. Shangzhuang	116.272° */36.480°*	3	C	Longshan	*2200–1700*	Rice; Millet	Zhang (1995)
63. Biangxianwang	118.647° */36.803°*	5.5	C	Longshan	*2200–1700*	Rice; Millet	Liu et al. (2015); Du (1995)
64. Tiangwang	118.238° */36.900°*	18	C	Longshan	*2200–1700*	Rice; Millet	Jin et al. (1999)

Table 2 (continued)

Name[a]	Long. (E)/Lat. (N)	Area (ha)[b]	Moat type[c]	Culture[d]	Age (BC)[e]	Staple food	References
65. Dinggong	117.847° */36.945°*	10	C	Longshan to Yueshi	*2200–1500*	Rice; Millet	Luan (1994)
66. Chengziya	117.357° */36.731°*	20	B	Longshan to Yueshi	*2200–1500*	Rice; Millet	Zhu et al. (2019)

[a] Name of cities and major settlement (in bracket). For location see Figs. 10 and 11

[b] Area of city/major settlement in its heyday (1 ha = 10,000 m^2), estimated from the inferred inner parts of moats (for city) or surrounding ditches (for settlement). Area of settlement in bracket. Bold underlined where re-calculated in this study

[c] Types of moat (or ditch). A: moat (ditch) connecting to boatable rivers; B: moat (ditch) connecting to rivers or paleo-rivers that might have been boatable; C: moat (ditch) not connecting to boatable rivers or paleo-rivers

[d] Culture types. See Fig. 1 for their spatial correlation

[e] Age range inferred from cultural characteristics or published ^{14}C dates (underlined), *italic* where re-interpreted in this study. Number of ^{14}C dates in bracket (unreasonable outlier values have been excluded)

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Data availability

Not applicable.

Declarations

Competing interests

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Author details

[1]Department of Anthropology, Sun Yat-Sen University, Guangdong, China. [2]Department of Earth and Environmental Sciences, National Chung Cheng University, 168 University Road, Minhsiung Township, Chiayi County 62102, Taiwan, ROC. [3]Department and Institute of History, National Chung Cheng University, Chiayi, Taiwan. [4]Institute of Global Humanities, Nanjing University, Nanjing, China. [5]Institute of Archaeology, Chinese Academy of History, Beijing, China.

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