Article Title: **State and irrigation: Archaeological and textual evidence of water management in late Bronze Age China**

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Abstract

Ancient China remains an important case to investigate the relationship between statecraft development and 'total power'. While important economic and social developments were achieved in the late Neolithic, it was not until the late Bronze Age (first millennium BC) that state-run irrigation systems began to be built. Construction of large-scale irrigation projects, along with walls and defensive facilities, became vital to regional states who were frequently involved in chaotic warfare and desperate to increase food production to feed the growing population. Some of the irrigation infrastructures were brought into light by recent archaeological surveys. We scrutinise fast accumulating archaeological evidence and review rich historical accounts on late Bronze Age irrigation systems. While the credibility of historical documents is often questioned, with a robust integration with archaeological data, they provide important information to understand functions and maintenance of the irrigation projects. We investigate structure and organisation of large-scale irrigation systems built and run by states and their importance to understanding dynamic trajectories to social power in late Bronze Age China. Cleverly designed based on local environmental and hydrological conditions, these projects fundamentally changed water management and farming patterns, with dramatic ecological consequences in different states. Special bureaucratic divisions were created and laws were made to further enhance the functioning of these large-scale irrigation systems. We argue that they significantly increased productivity by converting previously unoccupied land into fertile ground and pushed population threshold to a new level. A hypothesis that needs to be tested in further archaeological research.

INTRODUCTION

The late Neolithic (ca.3000-2000 cal. BC) witnessed a series of profound changes in societies across China, including the beginning of agricultural intensification to support population growth and the construction of large-scale walls, moats, and hydraulic projects.[1, 2] These changes played a crucial role in the emergence of early states:[3, 4] the organisation of labour and the logistics behind it were central to the evolution of power and social structures. Wittfogel was the first scholar to explicitly link organisation of large-scale irrigation projects with the development of statecraft and 'total power' in his systematic study of ancient hydraulic societies in Asia. [5] However, his theory has been dismissed by many archaeologists and anthropologists. Adams, for instance, has argued that 'irrigation was only one component in a complicated web of factors that stimulated the rise of civilisation'[6] (cited from Ref. 6, p. 18). In Bali, Geertz and Lansing found that complicated irrigation systems, involving careful engineering on a wide range of terrains, were managed by small local communities where temples, rather than state-level organisations, were the centre of coordination.[7-9] Whilst research on the emergence of early states and its relationship with intensifying irrigation practices in Neolithic China is progressing, more scholarly attention is drawn to the discovery of well-organised water system in Bronze Age urban centers such as at the late Shang capital of Anyang.[10] The Bronze Age in China was a period when agriculture was further intensified and states were consolidating and expanding their control over land and resources. Construction of irrigation projects, along with walls and defensive facilities, became vital to the regional states.

This article investigates the relationship between states and their organisations of irrigation systems in late Bronze Age China. The time period concerned is the Warring States period (475-221 BC) when the royal Zhou court was rapidly losing its territorial control with the upsurge of regional economic and military powers, before the Qin State eventually unified the country with their coercive military force and advanced technologies in 221BC.[11] The Warring States in north China also underwent fundamental changes in land ownership and subsequently farming practices, namely from the so-called field-well system to large-scale irrigated farming.[12] The emerging states begun to invest more and more resources in the construction and maintenance of large-scale irrigation projects. This process led to an increasingly closer entanglement between the states and their irrigation systems. Historical accounts suggest that irrigated agriculture provided the economic foundation for the military success of the regional states. However, such an interpretation has yet to be tested against archaeological record. None of the late Bronze Age irrigation infrastructures have been excavated systematically, but surface surveys and test excavations have confirmed their locations, and in some cases, chronologies (see below). Hundreds of historic documents, some of which were written during the Warring States period and transmitted through generations, provide supplementary information to understand the extension, structure, function and social impact of these state-run irrigation projects.[13, 14] However, in a period undermined by warfare such as this one, was state-run irrigation as claimed by Wittfogel and put by Scarborough in his critical review of Wiffogel's theory 'a major condition for centralizing and controlling resources or managers'?[6] (Ref.6, p. 18) Drawing together and cross-checking archaeological and textual evidence (the latter being considered an integral part of the integration if examined scrutinized critically) from the Yellow and the Yangtze Rivers, three main questions arise: (1) what were the social and economic backgrounds for the development of irrigated agriculture? (2) how were large-scale irrigation systems constructed and structured? and (3) what is the role of these irrigation projects in the regional states? We suggest that whilst it is important to examine the construction of these irrigation infrastructures from a top-down perspective as states indeed played a central role in the organisation of construction, it is also vital to emphasise the importance of local knowledge, environmental conditions, and interest conflicts between the states and local regions in the maintenance and functioning of these projects. We conclude that, though these irrigation projects were built at an unprecedentedly large scale, their links to intensified agriculture remain unclear due to the lack of detailed archaeological investigations. Nonetheless, it is clear that the construction and maintenance of these systems pushed up the threshold of not only land capacity but also the means by which the states could deploy resources to build these systems. It was through this process that population growth, warfare, states and their natural environments came intricately closer, foreseeing the development of enormous scale irrigation projects constructed during the early imperial era of Qin and Han (221 BC-220 AD) which had profound impact on the society, landscape and trajectories of economic growth and political discourses.

STATES, POPULATION GROWTH AND AGRICULTURAL DEVELOPMENT

As a fundamental departure from the 'religion-focused' Shang state (ca.1600-1050 BC),[15] the Western Zhou (c.1050 -771 BC) established a feudal system to consolidate their ruling. [16] The Zhou commoners, who were farmers, along with their royal people and armies, were sent to different parts of the state.[17, 18] (Ref. 17, p.575) This radically transformed the political and economic landscapes of many areas. However, a series of internal and external crises and subsequent reforms[19] soon begun to erode this system, which was crumbling in late Western Zhou and was quickly replaced by a multistate system. The emerging regional powers continuously jeopardised the royal Zhou court.[17] Among the seven most powerful in the Warring States period, the regional states of Qin, Zhao, Han, Qi and Chu occupied much of the Wei River, Middle and Lower Yellow River, and the Middle Yangtze River (Figure 1).[2, 17] China became very territorial, notably divided by walls built by warlords.[2] (Ref.2, pp. 276-278) In this period of rapid urbanisation,[20] cities expanded and conglomerated. Compared to limited number of Western-Zhou cities that have been confirmed archaeologically, there was an evident increase of cities dating to the Spring and Autumn (771-476 BC) and Warring States periods. More than 400 cities have been discovered[21] (Ref. 21, p.84) and around 10 of these were capitals of the regional states. They were of large scale and often surrounded by the so-called satellite cities or towns and smaller settlements. The walled area in the Linzi City of the Qi State, for example, was more than 20km^2 in size.[2, 22] (Ref. 2, p. 70; Ref. 22, p.250) While it is hard to determine the precise figure of the population level, Wagner et al.,[23] with limited data, offer a rough assessment of the occupational density during the Eastern Zhou period (ca. 650 BC), showing concentration of settlements not only in the traditionally central area such as the Yellow River valleys but the 'peripheries' such as Inner Mongolia (Note 1).

First, during the Warring States period, land was made freely available to farmers, or more precisely food producers, who paid taxes to landlords. This change in land-tenure had profound socio-economic implications. [2, 17, 24] (Ref. 2, p. 649; Ref. 17, p. 577 for discussion on the percentages of tax paid by peasants) States became more of managerial organisations. They 'fully utilize[d] their economic and human resources' and 'mobilized their population for a variety of infrastructure projects aimed at boosting agricultural production'.[2, 25] (Ref. 2, p. 268; Ref. 25, p. 587) This period also witnessed great agricultural development and with increasing production of iron tools and their gradual application leading to the growth of productivity.[26] Table 1 shows the dramatic increase of iron production sites and quantities of iron products from the Spring-and-Autumn to the Warring States periods. However, the application of iron tools in farming practices was limited in some areas;[27](cf. Ref. 27) but on the other hand, these tools would have been efficient in infrastructure construction.[12] (Ref. 12, p.65) Second, some primary texts most likely composed during the Warring States period suggest that farmers had accumulated good knowledge of farming ecology (Table 2). Particularly advanced was the understanding of water conditions in the field and advantage of irrigation to different crops.

Third, crops were diversified, with the cultivation of several cereals being gradually intensified. Table 2 summarises the cultivars planted derived from historical records. Multiple cropping systems were established during this time, including the so-called 'five, six or nine grains' of millets, wheat or barley, soybeans, hemp and other crops.[12] (Ref. 12, p.67) For this period, the archaeobotanical record remains limited, partly due to a biased focus on the archaeology of mortuary practices and cities. However, the available data lends support to the crop repertoire recorded in historical sources (Table 3). Several important trends can be drawn from the available archaeobotanical record. Firstly, a variety of crops had spread across much of North China, including nowadays Beijing[28] and Western Liaoning.[29] Archaeobotanical evidence also confirms the widespread existence of multiple cropping systems, although how these systems were practiced (e.g., seasonality and ecology) are still unknown. Secondly, wheat had begun to be cultivated in some areas[30] (Ref. 30, pp.179-184), but its role was less important than millets and other crops (e.g. soybeans). This period saw the continuous intensification of millet farming in many regions especially the Guanzhong Plain, partially confirmed by the predominance of foxtail millet seeds in archaeobotanical assemblages. This was partly due to the deteriorating climate[31] and continuous land degradation,[32, 33] which would make millet a more favourable crop in many regions. Thirdly, cash crops including hemp and mulberry trees (for silk production) were also widely cultivated, though they must have been cultivated in earlier periods too. Well-preserved textiles with elaborate fabrics have been found in many elite burials in waterlogged environments.[22] (Ref. 22, pp.437-440) As to the important role of rice in local subsistence, there are ample historical records[12] (Ref.12, p.73) indicating its expansion in North China, but this has yet to be recorded archaeologically. Limited archaeobotanical discoveries have confirmed the cultivation of rice in the Chu State of the Middle Yangtze River,[34] but the role of rice farming in this area remains unclear. With these developments just described, agriculture became the backbone of state economies in these regional states.[2] Indeed, despite the increasing aridity, regional states were able to feed the growing population and actively involved in frequent warfare by investing more resources into agricultural production, including building large-scale irrigation projects as discussed below.

ENGINEERING THE LANDSCAPE: TECHNOLOGY AND STRUCTURE OF IRRIGATION PROJECTS

In addition to the colossal scale urban landscape transformation,[31] the states were altering their rural, agrarian landscapes by developing more advanced water harnessing technologies and building large-scale irrigation systems. Table 4 gathers information from historical documents on the number and different types of large-scale irrigation projects built during the Warring States period. Surface surveys have confirmed the existence of several important ones,[35] some of which still function today. These projects often were comprised of weirs and reservoirs at the headwaters, main canals across the land that was irrigated, and numerous water outlets and diversion/branching channels connected to fields. Most canals were several hundred kilometres long, flowing through diverse, and sometimes difficult, terrains. Advanced technologies and sophisticated logistics and planning were required to build and maintain these large-scale irrigation projects.

Guanzhong Plain, the heartland of the Qin State, is dominated by semi-arid, loessic landscapes and surrounded by mountains where many rivers were originated. Irrigate became crucial to the sustainable development of agriculture. Surface investigations at the headwater of the Zhengguo canal, located in nowadays Jingyang County, have revealed its grandiose scale and sophisticated structure. The mountainous area of the Jing River before it enters into the Guanzhong Plain (Figure 2) offered an advantageous position to divert water to irrigate the fertile land in Guanzhong. In their surface survey in 1980s, Zhao and colleagues found an east-west weir of 2650m long sitting in front of a relatively narrow gorge in the upper Jing River, of which more than 2000m is still preserved (Figure 3).[35] The weir was built mainly by sand, clay and pebbles (Figure 4). Test excavations at some sections show that the dams were constructed in different periods, not just the Warring States period.[36] The technology of building large-scale weirs was already developed in the Qin State. Archaeological research at Fengxiang, the earlier capital for Qin before they relocated in nowadays Xianyang of the Guanzhong Plain, has discovered a weir, located next to a palaeo-lake outside the capital.[37] However, controversy remains on whether it is plausible to build the weir in this area as the Jing River was heavily silt-laden, and this would have hindered the normal function of it.[38] Other scholars instead suggest that the Jing River water was diverted directly via surface branching channels to the canal in the Guanzhong Plain.[39, 40] The surviving water diversion channel, near the location of the aforementioned weir, is 10-20m in width and around 7m in depth.[41] The height between the bottom of the channel and the water level of the Jing River is around 20m. The former has a sloped bottom, which might accelerate water velocity and thus prevent silting. The extended Zhengguo canal runs for nearly 150km along the foothills area to the north of the Beishan Mountain.[42] The main body of the canal was situated 400m above sea level. This was to maximize the land, especially the swampy and salty fields, it irrigated.

By the Warring States period, much of the nowadays Chengdu Plain was controlled by the Qin State, who began to build irrigation projects to promote agricultural production. The most important one was the Dujiangyan irrigation system, being considered as one of the wonders in ancient China for its clever engineering. An Eastern Han (168 AD) statue of Li Bing, the designer of Dujiangyan, was found in 1974,[43] indicating that Li was indeed related to the original construction of this project, as recorded in historical texts,[44] (Ref.44, pp.1405-1415) and he was still remembered several hundred years later. Sitting on top of the alluvial fan where the Min and Tuo Rivers join, the robust Dujiangyan irrigation system consists of two main parts: the so-called fish mouth and the low barrages, both serving for water diversion.[45] Built by pebbles, bamboo and wooden logs (Figure 5), this simple structure for the first time connects the Chengdu Plain with the two rivers and because of its scientific design that is cleverly tailored to local hydrological conditions, it remains functional since its construction without major repairing. On the gentle slope in the middle of the alluvial fan, the Pi Jiang and Jian Jiang canals were also dug.[46] Together with Dujiangyan, these canals significantly mitigate floods during the rainy seasons, and redistribute water in dry periods.

The Chu State, another super power, occupied vast areas of the Middle Yangtze River. The Chu State was advanced in rice farming and silk production and was also the pioneer in applying iron tools in agricultural practices. Both have been confirmed by the increasing discoveries of rice remains (Table 3), preserved silk products[22](Ref. 22, pp.437-440) and iron tools from archaeological sites.[47] The cultivation of rice and mulberry trees required organised irrigation for guaranteed harvesting, whilst the advanced iron technology increased productivity. Although Chu is well known in historical texts for its early construction of some large scale lake-based irrigation facilities (Table 4), such as the Qisi and the Shao Lakes, none of these has been confirmed archaeologically partly due to the active alluvial processes that cover up these structures, but more importantly, because many of them are still in use today. Bamboo slips discovered at the Baoshan Chu tombs mentioned a special economic area in the Huai River and its fields, possibly close to the Shao Lake repeatedly mentioned in historical documents.[48] The extension, chronology and structure of these lake-based irrigation systems remain unclear. How did the water go into the field? Fortunately, many wells have been excavated from various archaeological contexts, including those located possibly in farming fields. These point to a small-scale, yet robust irrigation system at work. At the Shuangyan site, within an 8000m^2 area, six wells were found during an excavation in 1992. Circles made of bamboo were placed on the walls; abundant plant remains and some pottery sherds were recovered in these wells. Because of the absence of residential features (e.g., houses), the excavators think that they were part of the in-field irrigation system, used to store water before irrigation.[34, 49]

Although the agricultural and technological developments and environmental conditions vary greatly among these regional states, one common tendency was that, due to population pressure, increasing land shortage and rising military conflicts, states became more and more concerned with agricultural productivity. The construction of these large-scale irrigation systems not only fit into this growing concern, but also profoundly changed farming ecology of that time. The session below further discusses the fundamental changes brought about by the state-run irrigation systems on soil conditions, farming patterns and ecological consequences in different states.

CHANGING THE FARMING ECOLOGY AND SEASONALITY

Containing rich nutrients for plant growth, such as potassium and phosphate,[50] loess has been the breadbasket for the society since the Neolithic times. But there are ecological constraints associated with loess, especially when the society faces long-term sustainability and population pressure issues. As discussed above, Guanzhong is located in the Southern Loess Plateau, fed by two tributaries of the Yellow River: the Jing and Wei Rivers. First, the temporal distribution of monsoonal rainfall is uneven, with most precipitation being concentrated in the summer and dry spring and winter. Second, in the eastern Guanzhong Plain, due to high groundwater level and high temperature in the summer, salinization has been a major problem especially for continuous large-scale farming. This was described in historical sources as 'white soil' [51] (Ref.51, pp.527-543) and there was already an awareness that introducing silt-laden water might be able to solve this issue.[44, 52] (Ref. 44, p.1409) The Zhengguo Canal would have indeed significantly mitigated both problems. The west-east orientation of the canal and its high elevation meant that it could collect water along the terrains it flowed through before that water was redistributed to the field. This would have therefore fundamentally changed the seasonality and availability of agricultural water in Guanzhong. In addition, the rich sand and silt contained in the river water[53] would not only accelerate the aggrading process of the otherwise swampy lands in low-topography areas, but, more importantly, neutralise the salty soils there. Abundant lands previously unsuitable for farming would have been quickly reclaimed in the Guanzhong Plain.

This process is described by some historians as 'silting irrigation' (*yu guan*),[40] which has resulted in profound changes in land ownership and farming pattern in states such as Qin. Despite the scarcity of archaeological surveys, the so-called field-well farming system prevailed before the Warring States period as recorded in recovered (e.g., oracle bone and bronze inscriptions) and transmitted texts.[54, 55] The character *Tian* field in oracle bones writes as if small ditches were criss-crossing the countryside.[56] (Ref. 56, p.44) Discoveries of some Bronze Age features have been interpreted as the ditches used for temporary irrigation and drainage in the field.[56](e.g., Ref. 56, pp.45-48) Fields under this system were mostly owned by the states and elites and located near their settlements in areas of good drainage. In the *Classic of Poetry*, commonly attributed to the Warring States period and therefore perceived as reflecting situation of the contemporary society, plants growing in wet habitats (e.g., *Niola sp*. and *Sonchus oleraceus L*.) often occurred in farming fields.[57] This system relied predominantly on small-scale irrigation or rainfall and emphasized the importance of drainage. The introduction of large-scale irrigation systems resulted in the breaking down of this system. The Qin State in the Guanzhong Plain was first and foremost involved in this process by (1) expanding farming to lowland areas, (2) constructing the large-scale irrigation systems discussed above, and (3) the radical reform carried out by Sang Yang who encouraged the reclamation of new arable lands and reward agricultural production.[12, 58] (Ref.12, pp.204-205)

The ecological effect of large-scale irrigation systems on farming practices in the Middle Yangtze River is more difficult to assess due to the more pronounced paucity of archaeological evidence. The soil is generally more clayey and does not contain as much nutrient (or nutrient readily to be absorbed by plants) as loess. Thus, the potential nutritional deficit in soils, after long cultivation, could not be compensated by the relatively 'clean' river water. However, on the other hand, such soils have a good degree of water retention, compared with loessic soils, and this is crucial for wet rice cultivation. In addition, how much nutrient is required for rice growth depends on the farming regime of the time, which is presently unclear. It seems though the biggest challenge to sustainable rice farming was the uneven distribution of monsoonal precipitation, pouring down majority of rainfall on the relatively flat alluvial plain in the summer. The combination of lake-based irrigation and well-based water supply in the field would have been a robust system in flood prevention during rainy seasons and irrigation when it was dry.

STATES AND IRRIGATION: MANAGEMENT AND SIGNIFICANCE OF IRRIGATION PROJECTS

The historical anecdote about the construction of the Zhengguo canal was vividly documented in the *Records of the Grand Historian*.[44] Worker *Zhengguo* from the Han State was sent to the Qin State to build the canal as part of Han's plan to exhaust Qin. This conspiracy was unveiled during the construction and *Zhengguo* was to be executed. But the Qin ruler eventually agreed for him to complete the project as this would tremendously benefit agriculture in the Guanzhong Plain and the canal was named after him. The story tells that it did take an enormous amount of resources to construct these large-scale irrigation projects and the states were behind the logistic of such massive undertakings. In this sense, as argued by some scholars, 'construction is a form of social repair',[6] (Ref. 6, pp.92-93) by which the states reinstalled and consolidated their economic order and political power.

Apart from the irrigation projects, many other infrastructure projects such as levees were also organised and constructed by the states. They were often located along major rivers and associated with the irrigation systems. Some recent surface surveys have started to bring these long buried levees along the Lower Yellow River into light. Kidder and colleagues, for example, have located a late Bronze Age levee constructed along the abandoned Yellow River channel in nowadays northern Henan Province, extending for at least several hundred meters. It has been dated to ca. 700-500 BC[59] and was overlain by Han period levees. More information, however, is from historical accounts (Table 4). Majority of levees were located along the Lower Yellow River as the fast sedimentation rate of the river increased frequency of floods,[60] which imposed severe threats to the society.[59] These levees also played an increasingly vital role in the warfare amongst the states. State armies, when attacking their enemies, would often dig ditches and/or build levees around the ditch to change the discourse of river water and circumvent the cities.[61]

Table 5 lists official names associated with water management and their duties, discovered on different types of objects. Some of the duties were very detailed, referring the construction or repairing of specific levees and irrigation projects in local areas, indicative of a clear division within the states on water related affairs. Associated with this mature bureaucracy were water laws and decrees issued by the states. The decree inscribed on the wooden plates discovered in Qingchuan County, Sichuan, mentioned officials who were involved in the construction of irrigation facilities after Qin gained control of the area.[62] How water resource should be utilized and protected were further elaborated in the Qin laws recorded in the Shuihudi bamboo slips found in the Middle Yangtze River. It was prohibited, for instance, to block waterways in February. [63] (Ref. 63, pp.66-94)

It is clear that water management and the maintenance of irrigation systems became closely intertwined with the development of state bureaucracy. But, to what extent then was irrigation related to the formation of state bureaucracy and centralization of power? A deeper understanding of this is fraught with several unsolved issues. First, who came first? It seems that the origin of early state bureaucracy predated the construction of large-scale irrigation projects. Precursors of many of these official divisions and names already occurred in Western Zhou textual records such as bronze vessel inscriptions and oracle bones.[64] This echoes what Scarborough and other scholars have suggested that ‘irrigation schemes’ are not ‘absolutely fundamental to a state’s functioning’.[6] (Ref. 6., p.25) Second, what was the spatial relationship between these irrigation projects and political/social structures? Were boundaries of the irrigation systems and communities of different levels concordant with each other? As aforementioned, the cross-cutting boundary between sabuk, water temple and villages in Bali serves to challenge the top-down view of the relationship between irrigation and evolution of social structure. Different opinions regarding the Western Zhou state organization also exist. Some characterize it as a top-down system created by the states and followed by communities at different levels. A vessel state or rural society would consist of many *yi* settlements and surrounded by arable fields. [64] Others stress the close association between military and farming as a salient feature of early states (e.g., Western Zhou), a system which was inherited later on.[18] Warfare indeed stayed at the center of states in the Warring States period.[65] (cf. Ref. 65) How did such top-down processes influence irrigation systems merits more research.

A more fundamental and theoretic question is to what degree did these aforementioned large-scale irrigation systems contribute to agricultural intensification in the states? Millet farming, which was the main crop in the Middle and Lower Yellow River, is less restricted by water, while rice farming, which was possibly predominant in the Middle Yangtze River (see above, but subject to more archaeobotanical research), is more heavily reliant on timely irrigation and drainage. How did the society legislate a rule that would be followed by production and management units at different levels? A potential challenge or managerial constraint to the Warring States agrarian societies would be coordinating times to release water into fields between the upper and lower streams of the irrigation canals during dry seasons. I would argue that, given the persisting ambiguity on the temporality of irrigation due to the lack of discoveries of related archaeological features for in-field water management, these large-scale irrigation systems did not directly contribute to intensify irrigation practices. Rather, they increased productivity by converting previously unoccupied land into a fertile ground and therefore pushed the population threshold to an unprecedented level. This hypothesis should be tested in several new research directions.

DIRECTIONS FOR FUTURE RESEARCH

Unpacking the ecology of in-field irrigation practices

Transmitted and discovered texts contain copious information regarding water management and its effect on field ecology in late Bronze Age China. Undoubtedly caution should be applied when dealing with such documents, but this does not mean that they should be a hinderance of in-depth inquiries into the ecology of irrigation. The *Classic of Poetry*, for example, mentioned many plants[66], indicative of a variety of habitats, co-existing with different crops in the field. Such information should be used to promote inter-disciplinary reconstruction of field ecology influenced by irrigation. An array of scientific methods such as phytolith analysis and soil chemical and physical analyses should be conducted to address the following questions: 1) how did irrigation change plant (crop and weedy plants) assemblages in the field; 2) long-term impact of irrigation and manuring on the chemical and physical properties of cultivated soils; 3) seasonality of irrigation and farming regimes. Furthermore, investigations should be expanded on a broader scale to, for instance, reconstruct alluvial hydrological regimes and reassess how these contributed (or did not contribute) to sustainable agricultural production in ancient times.

Spatial analysis of the ecological, social and political boundaries

Past research has focused too much on large-scale irrigation schemes. How to build a bridge, through which the two spectrums, states and local entities, of the irrigation system, could be connected continues to be a fundamental challenge for a coherent understanding of the functions of these irrigation schemes. How exactly did water flow from the reservoir to the field? How did the elites and farmers view water?[6] (Ref. 6, p.97) Were there smaller-scale irrigation schemes? If so, were they parallel with, or used as a supplement to, the state-run irrigation systems? With the fine-grained information concerning field ecology influenced by different irrigation schemes, GIS and spatial analysis could be conducted to examine 1) the spatial relationship between settlements, arable fields, both constrained by diverse physical settings and ecological conditions, and state organisation; and 2) the developmental models of these economic, social and political domains and whether these different trajectories were inter-related to each other.

Early Anthropocene and states

The late Bronze Age China saw intensified modification of landscapes through rapid urbanisation and engineering of countryside for economic production. It was a period when landscape transformation, economic production and socio-political development became intricately intertwined. Though it had not yet reached the tipping point when natural disasters could dramatically change the political discourse of the society, there was a growing awareness of the importance of environmental protection. This was not only recorded in primary texts (also see Table 4), but discussed in great depth by the burgeoning philosophical schools of the time. Their careful observations on salinization, soil management and irrigation practice on a micro level provide us great insights as to how the tension between population, agricultural production and ecological management of the landscape gradually became an issue to the society, ushering in a new era with unprecedented scale of landscape transformation. Future research should synthesize evidence for these developments in different spheres of the society and interrogate how this increasing anthropogenic input represents an important case to the emerging research agenda on early Anthropocene and state development.

Note 1: They also note (1) a decrease of settlement numbers in some areas, for instance, in Shaanxi Province, which could have been the result of settlement reorganisation and conglomeration; and (2) the disappearance of settlements in the Qinghai, which might be due to fundamental shifts in subsistence.

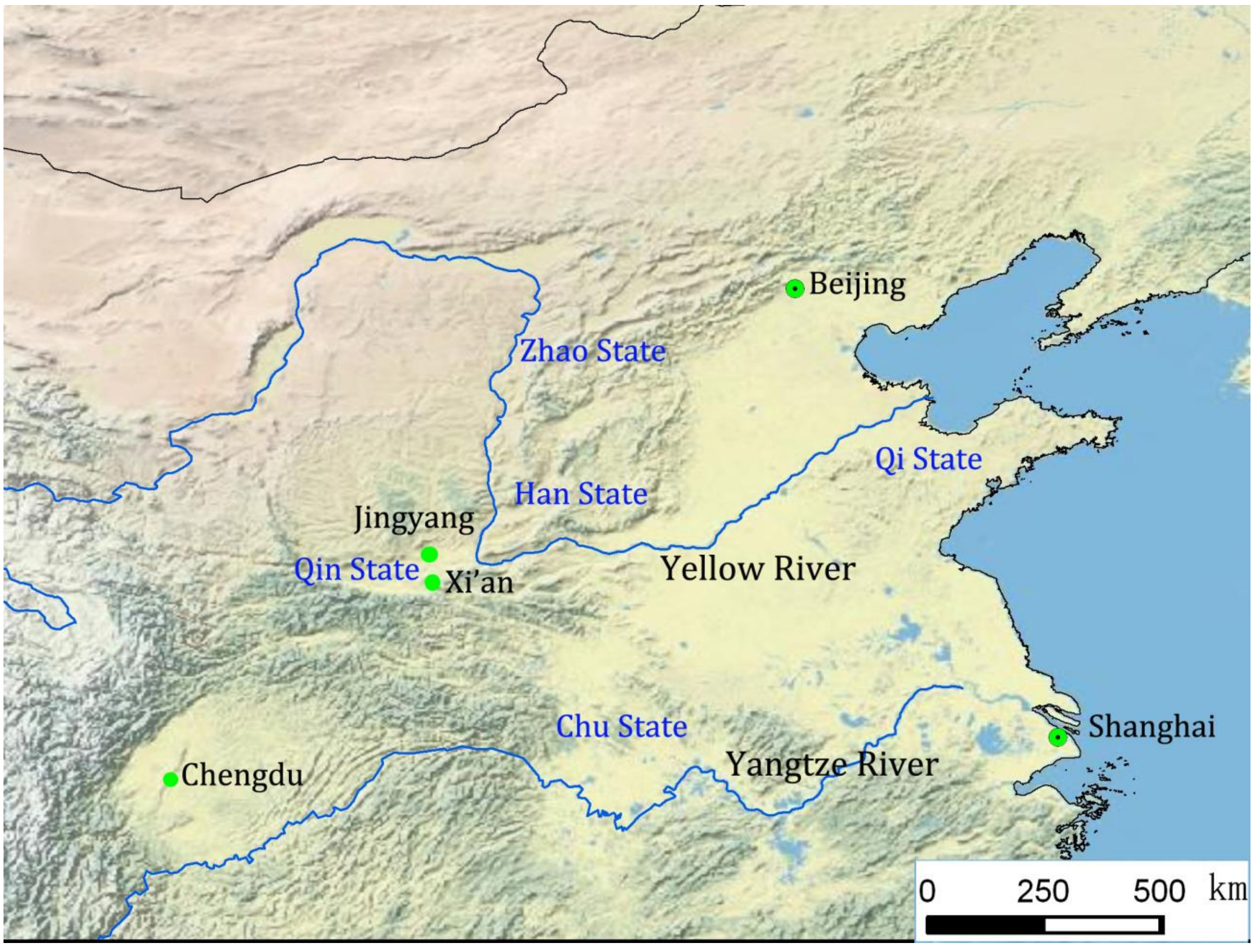

Figure 1: Major rivers, modern cities and Warring States regional powers mentioned in the text.

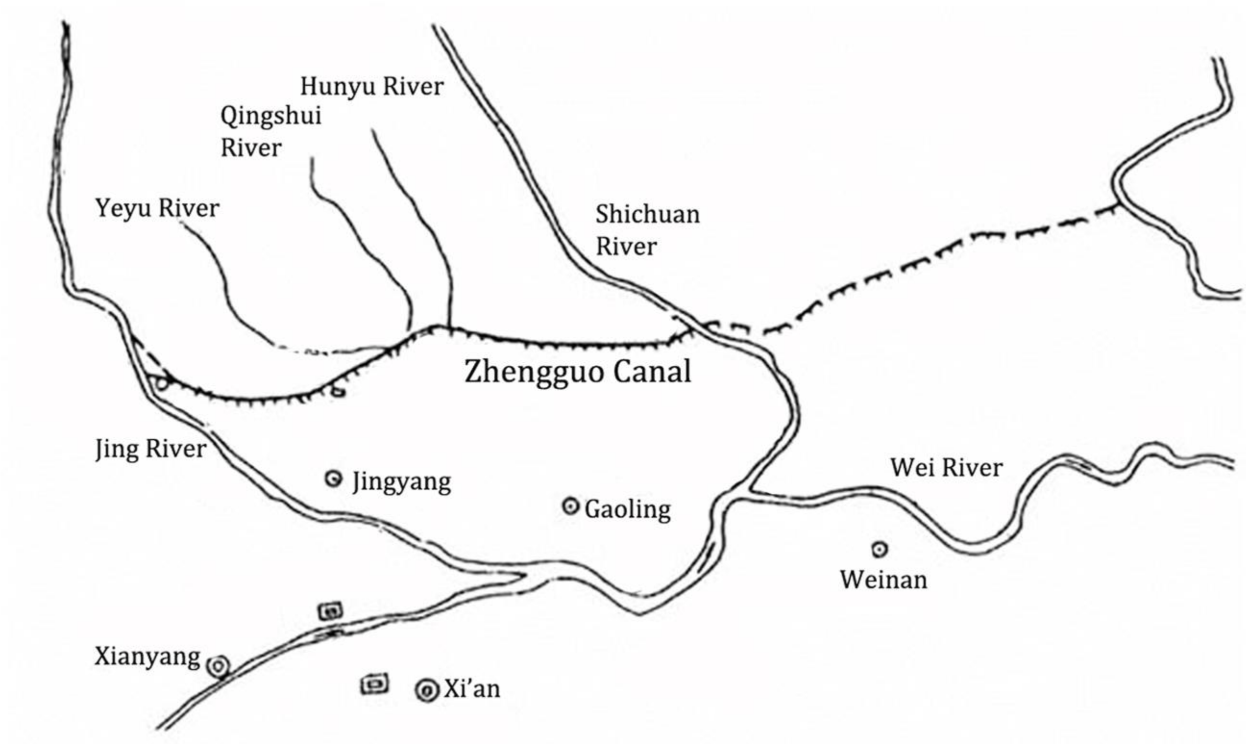

Figure 2: Distribution of the Zhengguo Canal in the Guanzhong Plain, with locations of major and secondary rivers and cities it flows through.

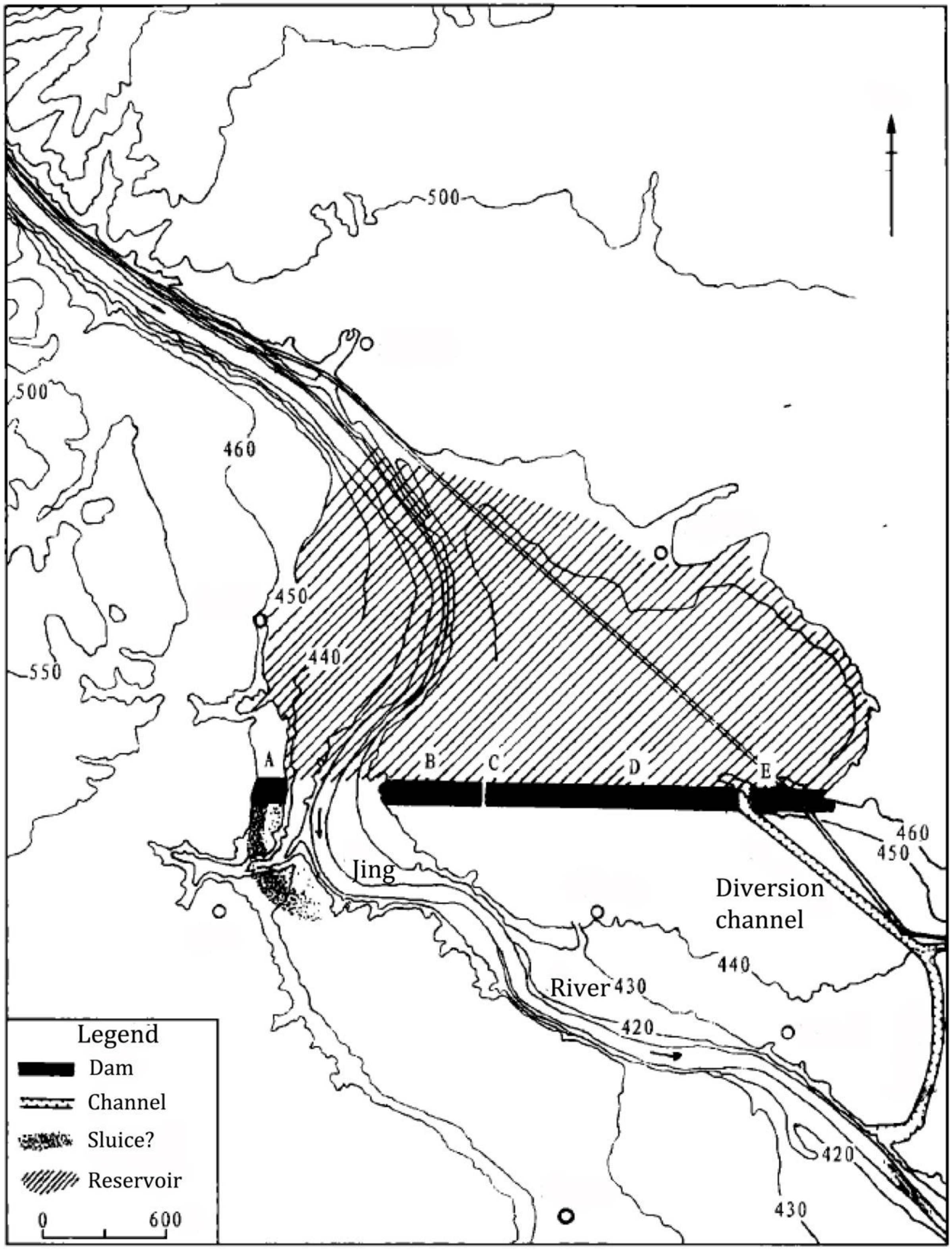

Figure 3: Geographic location and structure of the Zhengguo Canal weir. Modified after Ref. 35.

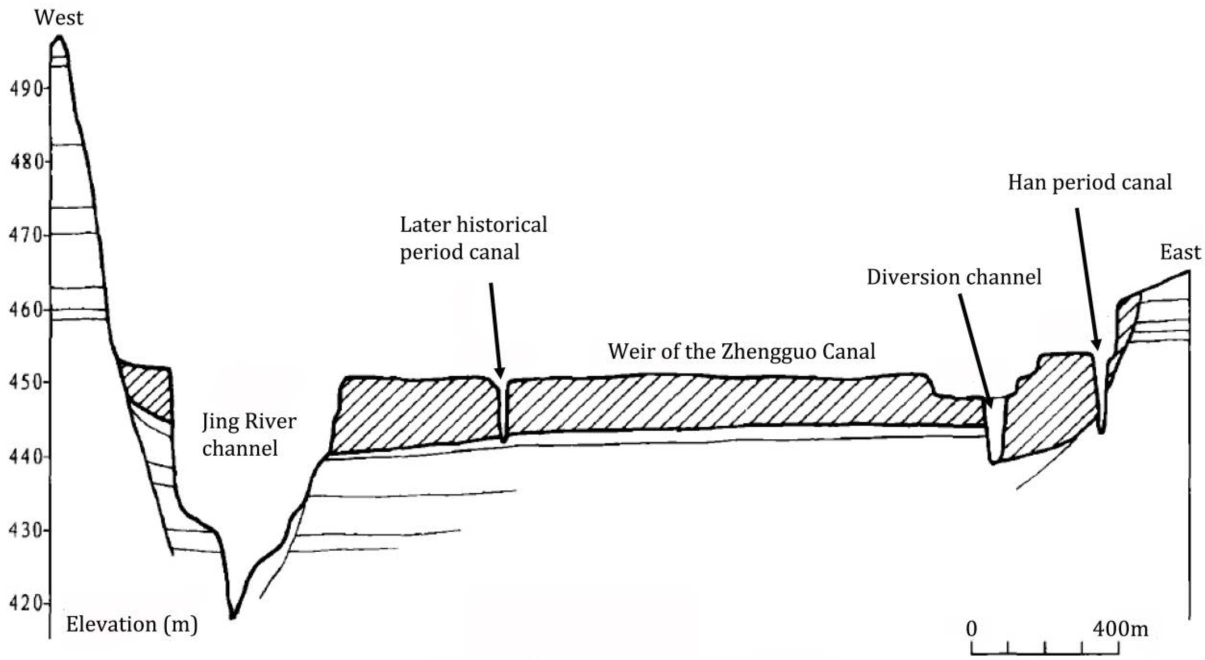

Figure 4: Cross-section of the Zhengguo Canal and its weir; with later period canals also shown in the section. Modified after Ref. 35.

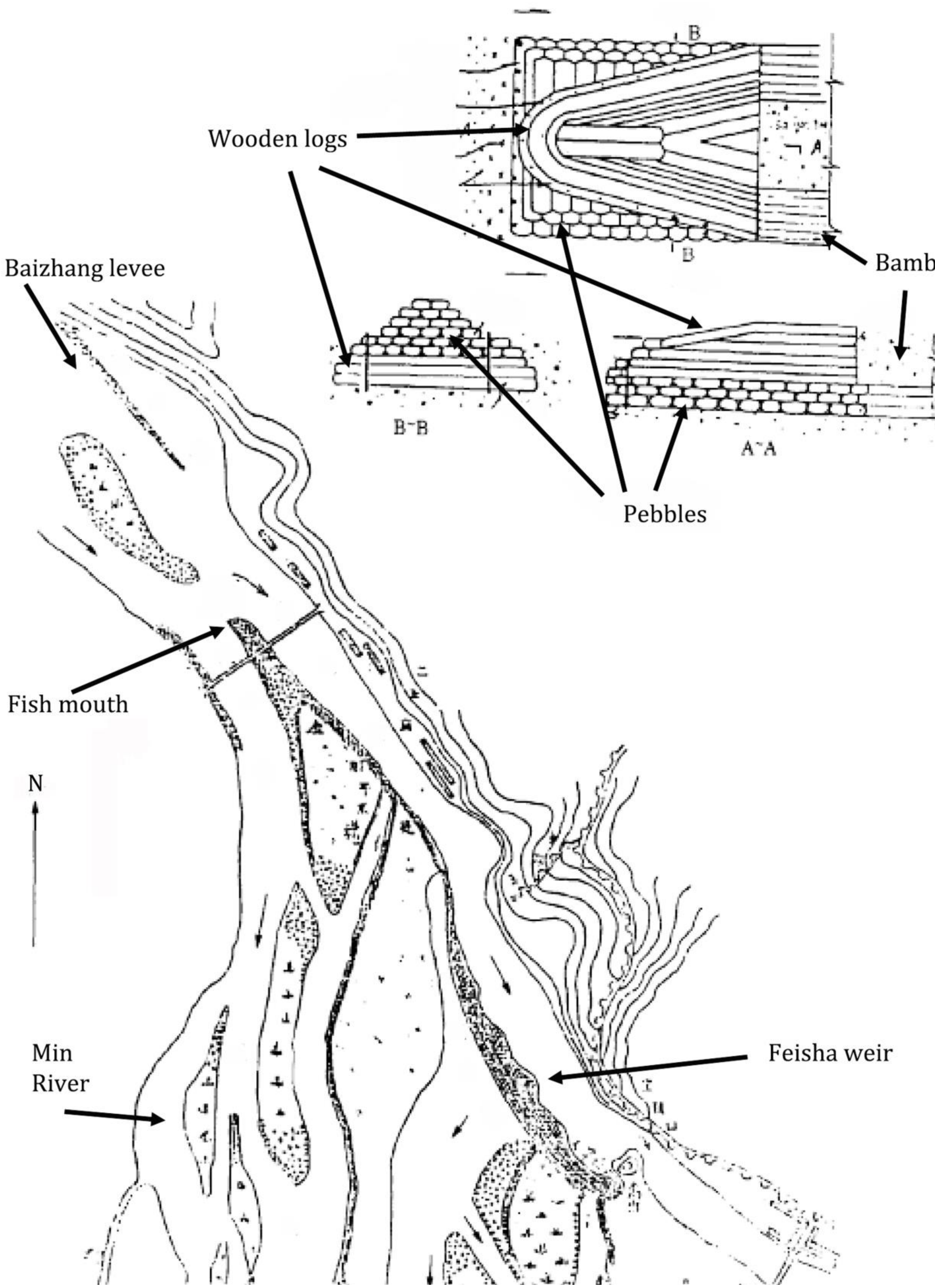

Figure 5: Structure of the Dujiangyan irrigation system. Modified after Ref. 45.

Table 1 Iron casting industry during the Spring and Autumn and Warring States periods. Mainly after Ref. 67

Periods	Numbers of sites	Regions	Quantities	Types
Spring and Autumn	>10	Northwest, Middle and Lower Yellow River, and Middle Yangtze River	All in small quantities	Tools (agricultural and craft production), weapons (knives and swords), and vessels (e.g., cauldron)
Warring States	>350	All over China (e.g., Middle Yangtze River >70 sites; Yan State in nowadays Beijing>40)	Mostly in large quantities	Agricultural tools and weapons

Table 2 Crops, soils, and water conditions in Warring States and Han records

Texts	Soil types and classification	Water conditions and ecology	Crops	Seasonality
Chapters in *Guanzi*: *Dudi* and *Diyuan*	1). 20 categories and 90 types belonging to three classes, based on depth, topography and environment, texture and vegetation, growing conditions for crops, and water quality. 2). Some soil types conducive to farming.	1). 5 types of water across the country, utilized differently. 2). A soil category, '*Wudu*', 5 sub types defined by water retention rate and its effect on soil colour	Millets (foxtail and broomcorn), hemp, soybean, and rice	
Chapters in *Lushi Chunqiu*: *Shangnong, Rendi, Biantu* and *Shenshi*		1). Water, fertilizer, trapped air and temperature essential for crop growth. 2). In high fields, growing crops in furrows not ridges; the other way round for low fields. 3). Using composting and planting different crops to maintain soil fertility	Millet(s), rice, hemp, beans and wheat	1). Inter-cropping systen importance of seasonalit 2). Lunar Jan prepare fo not to initiate 'big affairs farming; March officers countryside and make p irrigation facilities; April time; May and June proc agricultural and sideline farmers pay tribute (crop granaries and encourage farming; Oct and Nov ac store food; Dec select se spring's planting
Chapter in *Shangshu*: *Yugong*	9 categories in 9 states, based on colour, texture, vegetation, salinity and alkalinity, and			

	fertility. 3 classes under each category			
Chapters in *Zhou Li*: *Shiyi*, *Shanfu*, *Dazai*, *Cangren*, and *Zhifang*			Wheat, beans(?), millets, hemp, and mulberry trees	

Table 3 Discovered archaeobotanical remains dated to the Spring and Autumn and Warring States periods

Sites	**Regions**	**Plants/textile remains**	**Dates**	**Sources**
Dingjiawa	Beijing	Foxtail millet; Broomcorn millet; soybean; buckwheat; hemp; legume; etc.		Ref. 28
		Foxtail millet; Broomcorn millet; Cannabis sativa linn.; Glycine max (Linn.) Merr.; and other seeds		Ref. 29
Tudun	Balikun County, Xinjiang	Wheat	c.2800 BP	Ref. 30, p.180
Diaoyutai	Bo County, Anhui	Wheat	Zhou dynasty	Ref. 30, p.182
Fengtai	Qinghai	Wheat, barley, and foxtail millet	Zhou dynasty?	Ref. 78
Houcun city	Shanxi	Soybean	Eastern Zhou	Ref. 30, p.187
Dahaimeng	Yongji County, Jilin	Soybean	ca.2590BP	Ref. 79
Chenjiatai	Hubei (Jinan city of the Chu State)	Rice	Eastern Zhou	Ref. 80
Niuxingshan	Hunan (Chu State tombs)	Foxtail millet?		Ref. 81
Shuangyan	Hunan	Rice		Ref. 34
Zhujiatai	Hunan (Chu State wells)	Rice		Ref. 82
Maoping	Xichuan County, Henan (Chu State tombs)	Millet (placed in containers)		Ref. 83
Yuanjiacun	Xingang County,	Rice		Ref. 84

	Jiangxi (Chu State granary)			

Table 4 Spring-and-Autumn and Warring States period large-scale irrigation systems recorded in historical documents

Names	**Regions**	**Structures and other information**	**Sources**
Shao (Anfeng) Lake	Chu State; nowadays Shou County, Anhui	10,000 hectare fertile land was irrigated; ca.10km in radius and five water outlets	Refs. 85-87
Qisi Lake	Chu State		Ref. 85
12 dikes along the Zhang River	Ye City, Wei State; nowadays Hebei		Ref. 44, pp.1405-1415
Hong Canal	Wei State	Connecting the Yellow River and the Huai River	Refs. 86 and 12
Han Canal	Yangzhou, Jiangsu	Located between the Yangtze River and the Huai River	Ref. 87
Zhengguo canal	Qin	150km long, irrigated 2.8 million hectares	Refs. 44 (pp.1405-1415) and 45 (p. 205)
Dujiangyan irrigation system	Chengdu Plain, Sichuan		Ref. 44
Levees (Rivers)	**Regions**	**Length**	**Sources**
Gu and Luo Rivers	Luoyang, Henan		Ref. 86
Yellow River	Borders between Qi, Zhao and Wei	25km from the Yellow River channel	Ref. 87, p.1692

Table 5 Official names and their duties discovered from archaeological sites.

States	**Official names**	**Functions**	**Sources**
Qi	Anyang Shui	Water-related affairs in Anyang	Ref. 88, p.49
Chu	Wuzhu Zheng	Taxman for the water taxation in Wuzhu	Ref. 89
Zhao	Quti Qu	Levee construction (?) and flood prevention	Ref. 90, p. 166
Wei	Chenghe Chen	Water-conservation affairs	Ref. 91
Zheng	Xiakuang Qushui	Water-conservation affairs in Xiakuang	Ref. 92

REFERENCES

1. Liu L, Chen XC. *The Archaeology of China: From the Late Paleolithic to the Early Bronze Age*. Cambridge: Cambridge University Press; 2012.
2. Shelach G. *The Archaeology of Early China: From Prehistory to the Han Dynasty.* Cambridge: Cambridge University Press; 2015.
3. Liu L, Chen XC. *State Formation in Early China*. London: Duckworth; 2003.
4. Liu L. *The Chinese Neolithic: Trajectories to Early States*. Cambridge: Cambridge University Press; 2004.
5. Wittfogel KA. *Oriental Despotism: A Comparative Study of Total Power*. New Haven, CT/London: Yale University Press; 1957.
6. Scarborough VL. *The Flow of Power: Ancient Water Systems and Landscapes*. Santa Fe: SAR Press; 2003.
7. Lansing S, Fox K. Niche construction on Bali: The gods of the countryside. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2011, 366:927-934.
8. Geertz C. The wet and the dry: Traditional irrigation in Bali and Morocco. *Human Ecology* 1972, 1:23-39.
9. Lansing S. *Priests and Programmers: Technologies of Power in the Engineered Landscape of Bali*. New Jersey: Princeton University Press; 2009.
10. Tang J, Yue H, He Y, Niu S, Yue Z, Jing Z. The road system and water network at the Huanbei Shang city and Yinxu (in Chinese with English abstract). *Kaogu Xuebao* 2016 (3):319-342.
11. Bodd D. The state and empire of Ch'in. In: Twitchett D, Loewe M, eds. *The Cambridge History of China: The Ch'in and Han Empires, 221 BC - AD 220*. Cambridge: Cambridge University Press; 1986, 20-102.
12. Yang K. *Warring States History (in Chinese)*. Shanghai: Shanghai People's Press; 2003.
13. Xu Z. Origins of irrigation projects in ancient China (in Chinese). In: Yu ZX, ed. *Essays on History of Economic Developments in China*. Taipei: Lianjing Press; 1980, 825-842.
14. Chi C. *Key Economic Areas in Chinese History, as Revealed in the Development of Public Works for Water-control*. London: G. Allen & Unwin Ltd; 1936.
15. Keightley DN. *The Ancestral Landscape: Time, Space, and Community in Late Shang China, ca.1200-1045 B.C*. Berkeley: University of California, Berkeley; 2000.
16. Li F. *Early China: A Social and Cultural History*. Cambridge: Cambridge University Press; 2013.

17. Hsu CY. The Spring and Autumn period. In: Loewe M, Shaughnessy E, eds. *The Cambridge History of Ancient China: From the Origins of Civilization to 221 BC*. Cambridge: Cambridge University Press; 1999, 545-586.

18. Li K. He gui and the Shang-zhou military system (in Chinese with English abstract). *Kaogu yu Wenwu* 2015 (4):46-48.

19. Falkenhausen L. *Chinese Society in the Age of Confucius (1000-250 BC): The Archaeological Evidence*. Los Angeles: Cotsen Institute of Archaeology; 2006.

20. Shen C. Early urbanization in the Eastern Zhou in China (770-221 BC): An archaeological view. *Antiquity* 1994, 68:724-744.

21. Xu H. *Archaeology of Pre-Qin Cities (in Chinese)*. Beijing: Yanshan Press; 2000.

22. Institute of Archaeology, Chinese Academy of Social Sciences. *Archaeology of China: The Western and Eastern Zhou Volume (in Chinese)*. Beijing: Chinese Social Science Press; 2004.

23. Wagner M, Tarasov P, Hosner D, Fleck A, Ehrich R, Chen XC, Leipe C. Mapping of the spatial and temporal distribution of archaeological sites of northern China during the Neolithic and Bronze Age. *Quaternary International* 2013, 290–291:344-357.

24. Falkenhausen L. The waning of the Bronze Age: Material culture and social developments, 770–481 B.C. In: Loewe M, Shaughnessy E, eds. *The Cambridge History of Ancient China: From the Origins of Civilization to 221 BC*. Cambridge: Cambridge University Press; 1999, 450-544.

25. Lewis M. Warring States political history. In: Loewe M, Shaughnessy EL, eds. *The Cambridge History of Ancient China: From the Origins of Civilization to 221 B.C.* Cambridge: Cambridge University Press; 1999, 587-650.

26. Xiang A. Chu state agriculture during the Spring and Autumn and Warring States periods I (in Chinese). *Agricultural Archaeology* 1997 (3):125-130.

27. Zhuang Y, Lee H, Kidder TR. The cradle for the Heaven-Human Induction idealism: Agricultural intensification, environmental consequences and social responses in Han China and Three-Kingdoms Korea. *World Archaeology*; in press.

28. Zhao ZJ. Flotation report at the Jingjiawa site, Fangshan, Beijing (in Chinese). In: Beijing Institute of Cultural Relics, ed. *Archaeological Reports of the Excavations in Beijing.* Beijing: Science Press; 2008.

29. Jia X, Sun Y, Wang L, Sun W, Zhao ZJ, Lee HF, Huang W, Wu S, Lu H. The transition of human subsistence strategies in relation to climate change during the Bronze Age in the West Liao River Basin, Northeast China. *The Holocene* 2016, 26:781-789.

30. Liu CJ, Jin GY, Kong Z. *Archaeobotany: Studies of Seeds and Fruits (in Chinese)*. Beijing: Science Press; 2008.

31. Dong JG, Wang YJ, Cheng H, Hardt B, Edwards R, Kong XG, Wu JY, Chen ST, Liu DB, Jiang XY, et al. A high-resolution stalagmite record of the Holocene East Asian monsoon from Mt Shennongjia, central China. *The Holocene* 2010, 20:257-264.

32. Huang C. Resource degradation and human-environment relationship in the Wei River valley 3100 BP (in Chinese with English abstract). *Geographical Science* 2001, 21:30-35.

33. Huang CC, Pang JL, Chen BQ, Zhou QY, Mao LJ, Li PH. Land degradation and its social impact in the Weihe River drainage basin during the predynastic Zhou and Western Zhou periods (in Chinese with English abstract). *Quaternary Sciences* 2003, 23:404-414.

34. Xiang A, Zhang WX, Cao Y, Liu GF. Ancient rice unearthed from wells of the Eastern Zhou Dynasty ruins at Daping Shuangyan of Li County in Hunan Pronvince (in Chinese with English abstract and title). *Acta Agronomica Sinica* 2012, 38:1943-1947.

35. Qin JM, Yang Z, Zhao R. Investigation of the dam in the head of the Zhengguo canal of the Qin State, Jingyang, Shaanxi Province (in Chinese). *Kaogu* 2006 (4):12-21.

36. Zheng H. Engineering and scientific technology of the Qin period Zhengguo Canal and Han period Bai and Longshou Canals (in Chinese). *Kaogu yu Wenwu* 1996 (3):61-63.

37. Shaanxi Provincial Institute of Archaeology. The water landscape of the Qin captial: Archaeology at the Yong Qin city (in Chinese). Available at: http://www.kaogu.cn/cn/kaoguyuandi/kaogusuibi/2015/0728/50977.html.

38. Du B, Zuo Z. Irrigation projects along the Jing River and related steles (in Chinese). *Agricultural Archaeology* 1992 (3):195-201.

39. Ye YC, Zhang H. Function and history of the Zhengguo Canal and surviving relics (in Chinese). *Wenbo* 1990 (3):74-84.

40. Li LF. Water diversion methods of the Zhengguo Canal of the Qin State (in Chinese). *Chinese Historical Geography* 2001 (2):10-18.

41. Zhu SH. *Utilization of Water Resources in the Qin State (in Chinese)*. PhD dissertation. Zhengzhou: Zhengzhou University; 2006.

42. Sun DR. Distribution and evolution of the Zhengguo canal (in Chinese). In: Huang LZ, Wei QR, eds. *Research of the Zhou, Qin, Han and Tang Cultures (1)*. Xi'an: Sanqin Press; 2002, 3-34.

43. Cultural Bureau of Guan County. The Eastern Han stone statute of Li Bing discovered in Dujiangyan (in Chinese). *Wenwu* 1974 (7):27-28.

44. Sima Q. *Records of the Grand Historian (in Chinese)*. Beijing: Zhonghua Book Company; 1959.

45. Zhou KY. *History of Science and Technology in China: Water Conservancy Volume (in Chinese)*. Beijing: Science Press; 2002.

46. Okawa Y. Zhengguo canal and Dujiangyan: Development of the Qin alluvial fans (in Chinese). In: Association of Pre-Qin History of China, ed. *Research of the Zhou and Qin Society and Culture*. Xi'an: Shaanxi Normal University Press; 2002, 237-248.

47. Xiang A. Chu state agriculture during the Spring and Autumn and Warring States periods II (in Chinese). *Agricultural Archaeology* 2000 (3):100-109.

48. Chen LZ. The construction and geographic location of the Shao lake in light of discovered Chu bamboo slips (in Chinese). *Journal of Anhui Normal University (Social Sciences)* 2012 (4):441-449.

49. Xiang A. Agricultural remains discovered at the Eastern Zhou site at Shuangyan, Li County, Hunan (in Chinese). *Agricultural Archaeology* 1992 (1):123-126.

50. Zhuang Y, Bao WB, French C. Loess and early land use: Geoarchaeological investigation at the early Neolithic site of Guobei, Southern Chinese Loess Plateau. *Catena* 2016, 144:151-162.

51. Gu JG, Liu QY. *Interpretation of the Book of Classic (in Chinese)*. Beijing: Zhonghua Book Company; 2005.

52. Xu W. *Interpretation of Lushi Chunqiu (in Chinese)*. Beijing: Zhonghua Book Company; 2009.

53. Han JW. On the water quality of the Jing and Wei River water (in Chinese). *Journal of Northwest University (Natural Science)* 2003 (3):341-343 and 348.

54. Yu ZX, Bao CS. A complementary note to the field-well system (in Chinese). *Agricultural History of China* 2001 (1):11-15.

55. Zhou KY. In-field water management in ancient China (in Chinese). *Agricultural Archaeology* 1986 (1):175-183.

56. Wang JL, Zhang F. *History of Water Conservancy and Farming Fields of China (in Chinese)*. Beijing: Agricultural Press; 1990.

57. Li GP. The ditch-based agriculture in the Pre-Qin period (in Chinese). *Chinese Economic History* 1986 (1):1-11.

58. Chen CY. A discussion on Shang Yang's 'Land Reclamation' activities (in Chinese). *Agricultural Archaeology* 1986 (1):46-53.

59. Zhuang YJ, Kidder TR. Archaeology of the Anthropocene in the Yellow River region, China, 8000–2000 cal. BP. *The Holocene* 2014, 24:1602-1623.

60. Chen YZ, Syvitski JPM, Gao S, Overeem I, Kettner AJ. Socio-economic impacts on flooding: A 4000-year history of the Yellow River, China. *AMBIO* 2012, 41:682-698.

61. Cui XD. Using water in the attacks in the Spring and Autumn and Warring States period (in Chinese with English abstract). *Journal of Peking University (Social Sciences)* 2012 (5):79-85.

62. Li ZH, Mo HG, Yu CQ. The Qin inscribed wooden plates at Qingchuan: Excavation of the Warring States tomb (in Chinese). *Wenwu* 1982 (1):1-21.

63. Xu FC. *Study of the Shuihudi Qin Bamboo Slips (in Chinese)*. Taibei: Literature, History and Philosophy Press; 2010.

64. Li F. *Bureaucracy and the State in Early China: Governing the Western Zhou*. Cambridge: Cambridge University Press; 2008.

65. Kiser E, Cai Y. War and bureaucratization in Qin China: Exploring an anomalous case. *American Sociological Review* 2003, 68:511-539.

66. Fu J, Sheng Y. *Atlas of Plants in the Classic of Poetry (in Chinese)*. Shanghai: Shanghai Bookshop; 2003.

67. Bai YX. *Archaeological Research of Iron Objects from the Pre-Qin and Western and Eastern Han Periods (in Chinese with English abstract)*. Beijing: Science Press; 2005

68. Zhou HY. Beginning of soil ecological theory: Preliminary of the Diyuan chapter of Guanzi (in Chinese). *Studies of Guanzi* 2016, (1): 10-18.

69. Cao HF. Preliminary study of the soil classification in Guanzi (in Chinese). In: Association for Guanzi Studies, ed. P*roceedings of the 8th Annual for Guanzi Studies*. Hefei: Association for Guanzi Studies; 2013, 122-125.

70. Li S. *Interpretation of Guanzi (in Chinese)*. Beijing: Zhonghua Book Company; 2009.

71. He HZ, Hui FP. Study of the ecological relationship between soils and plants during the Pre-Qin period (in Chinese). *Agricultural Archaeology* 2010, (1): 200-204.

72. Zhang J. A comparison between the Shangnong and other three chapters in the Lushi Chunqiu and the De Agri Cultura (in Chinese). *Agricultural History of China* 2012, (3): 122-131.

73. Hou H. Preliminary investigation of the agricultural management theory in Lushi Chunqiu (in Chinese). *Agricultural Archaeology* 2015, (1): 114-117.

74. Xu WY. *Intrepretation of Lushi Chunqiu (in Chinese)*. Beijing: Zhonghua Book Company; 2009.

75. Wang YS. Brief introduction of soil classification in ancient China (in Chinese). *Acta Pedologica Sinica* 1979, (1): 3-10.

76. Mu P. *Interpretation of Book of Classics (in Chinese)*. Beijing: Zhonghua Book Company; 2009.

77. Xu ZY, Chang PY. *Interpretation of Rites of Zhou (in Chinese)*. Beijing: Zhonghua Book Company; 2014.

78. Zhao ZJ, Wang W, Xu XG, Niu SS, Cai LH, Song JN, Xiao YM, Zhang CS, Yang JG. Report of the archaeobotanical research at the Kayue culture site of Fengtai, Huzhu county, Qinghai (in Chinese). *Kaogu yu Wenwu* 2004, (2): 85-91.

79. Liu SM, Shu SZ, Li FS. Preliminary identification of the carbonised soybean seeds discovered in Yongji County, Jilin (in Chinese). *Kaogu* 1987, (4): 365-369.

80. Hubei Museum. The survey and excavation at the Chu State Jinan city (in Chinese). *Kaogu Xuebao* 1982, (4): 477-507.

81. Hunan Museum. The numbers 1 and 2 Warring States wooden-coffined tombs at Niuxingshan, Xiangxiang county, Hunan (in Chinese). *Wenwu Ziliao Congkan* 1980, (3): 98-112.

82. Institute of Cultural Relics Management of Sangzhi County. Report of the excavation of Warring States kiln and well at Zhujiatai, Sangzhi county, Hunan (in Chinese). *Jianghan Kaogu* 1994, (2): 15-26.

83. Huang YF. Excavation report of the Chu tomb at Maoping, Xichuan county (in Chinese). *Zhongyuan Wenwu* 1982, (1): 46-50.

84. Jiangxi Museum. The Warring States period granary discovered in Xingan county (in Chinese). *Wenwu Gongzuo Ziliao* 1976, (62): 1-2.

85. Gu Q. *Interpretation of Huan Nan Zi (in Chinese)*. Beijing: Zhonghua Book Company; 2009.

86. Chen QY. *Interpretation of Shuijing Zhu (Annotated Classic of the Waterways) (in Chinese)*. Beijing: Zhonghua Book Company; 2009.

87. Ban G. *Book of Han (in Chinese)*. Beijing: Zhonghua Book Company; 1964.

88. Chen GT. *Regional Study of the Warring States Seals (in Chinese)*. Changsha: The Yuelu Book Company; 2009.

89. Zheng C. Study of the Chu State official seals (in Chinese). *Study of Cultural Relics* 1986, (2):87-95.

90. Cao JY. *Introduction to Ancient Seals (in Chinese)*. Shanghai: Shanghai Book and Painting Press; 1995.

91. Li XQ. Introduction to Warring States inscriptions: II (in Chinese). *Wenwu* 1959, (8): 60-64.

92. Li LC. Preliminary interpretation of the 'Xiakuang Qushui' seal. *Wenbo* 2000, (4): 31-32.