Historical evolution of urban water conservancy projects in Xi’an, China in the past 3,000 years and its revelations

Wei Zhou, Junrui Chai, Zengguang Xu, Yixuan Wang, Kewu Wei and Yungang Dang

ABSTRACT

Xi’an has a special historical position in ancient China, and it has made great achievements in water conservancy projects in all dynasties. The water network skeleton formed mainly by the ‘Eight Waters’ in the territory, along with the historical changes of Xi’an, has experienced the Lantian ape-man ‘living by the water’, the Western Zhou Fenghao ‘two capitals along the Fenghe River’, and the Qin Xianyang city ‘capital passed by Weihe river’. Developments and changes such as the ‘diversion of water to develop the capital’ in Chang’an in the Western Han Dynasty, the ‘capital be ringed by eight rivers’ in Chang’an in the Sui and Tang Dynasties, ‘reduced water’ from the end of the Tang Dynasty to the Qing Dynasty, and the ‘coordinated supply’ after the founding of the People’s Republic of China. After sorting out the system, it is believed that the ‘Eight Waters’ in the territory are the original driving force for the flourishing Chang’an in history. From ancient times to the present, with the development of industry, there has been a trend that human settlements and rivers are farther away. Urban water supply has shifted from groundwater sources to surface water sources. This article investigates the evolution of water conservancy projects in Xi’an from the Paleolithic Age to the present, and studies the relationship between human production and life and water resources. The changing law and development trend of the water supply structure in Xi’an urban area in modern times are analyzed. We have summarized the enlightenment left to us by the practice of water conservancy projects for thousands of years. This paper provides references for the development and planning of water resources in similar cities.

Key words | drainage, water diversion, water source engineering, water supply, water transfer

HIGHLIGHTS

- Water supply methods and water conservancy facilities over thousands of years are summarized.
- The variation of water supply in Xi’an urban area in recent decades is investigated.
- The development trend of Xi’an’s water supply in the future is analyzed.

INTRODUCTION

Xi’an, known as ‘Chang’an’ and ‘Haojing’ in ancient times, is the capital of Shaanxi Province, one of the world’s four ancient civilizations, and the starting point of the ancient Silk Road. Xi’an is a historical and cultural city with the richest cultural connotations, the most profound cultural heritage, and the most complete preservation of the ancient city system in the world. It has more than 7,000 years of civilization history, more than 3,100 years of history of the city, and more than 1,100 years of history as a capital. Located in

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the middle of the Guanzhong Plain, with Qinling Mountains in the south and Weihe river in the north, the four seasons are distinct. Since ancient times, Xi’an has been known as ‘Eight Waters Around Chang’an’; ‘Eight Waters’ of Jinghe, Weihe, Chanhe, Bahe, Juehe, Haohe, Fenghe and Laohe rivers. In addition, Zaohe and Xiaohe spatially formed the water network skeleton in Xi’an. For thousands of years, the ‘eight waters’ have flowed, not only nourishing and nurturing the people of the ancient city, but also contributing to Xi’an politics, economy, culture, and society. It has had a profound impact in many ways.

With the continuous expansion of ‘Greater Xi’an’ city scale and rapid population increase, at the end of 2017, the total area was 10,752 km², the population was 12 million, and the per capita water consumption was 197.9 m³/person (Shaanxi Provincial Water Resources Bulletin 2017), accounting for 82% of the province’s per capita water consumption and for 45% of the country’s per capita water consumption, which is a typical resource-scarce city. So, where is the water source that helped Chang’an flourish in history? What kind of water source changes did it experience afterwards? What is the enlightenment from the historical evolution of water conservancy projects? What enlightenment can we learn? This article aims to explore these issues and obtain useful enlightenment.

Due to Xi’an’s geographical location and its special historical position as a long-term political, economic, and cultural center in ancient China, all dynasties have made great contributions to water conservancy. Combining its achievements, it can be derived from the ‘living by water’ of Lantian ape-man, ‘Two capitals along the Fenghe river’ by Fenghao in Western Zhou Dynasty, ‘Capital passed by Weihe river’ in Xianyang City of Qin Dynasty, ‘Prosperous capital’ of Chang’an in the Western Han Dynasty; ‘Capital be ringed by eight rivers’ of Chang’an in Sui and Tang Dynasties, ‘Reduced water’ after the abandoned city, and the ‘coordinated supply’ after the founding of the People’s Republic of China.

HISTORICAL EVOLUTION

Lantian ape-man’s ‘living by water’

The primitive humans ‘lived by the water’; as early as the Paleolithic age, the Lantian ape-men on the terraces of the Bahe River began their cultural creation. According to archaeological research, the Lantian ape-man of Gongwangling Mountain reached 1.1 million years ago (Nianhai & Xianzhi 1996), and this should be one of the earliest active areas of the Chinese nation. In the Stone Age, human beings survived only with the products endowed by the natural environment. They mainly lived by collecting wild fruits, hunting and fishing. Constrained by nature and under the pressure of survival, humans must live near water to solve water sources, food, and even stones.

In the Neolithic period, humans could not dig wells for water, so it was impossible to stay away from rivers. The water in the river fluctuates and the living area is closer to the river, so it is more convenient to get water, but if it is too close to the river, it will inevitably be washed away when the water rises. People in the Neolithic period used the second-level terraces near the river as their residence, which should be a rule of experience gained over a long period of time. The most numerous Neolithic cultural sites have been discovered along the Bahe and Chanhe Rivers. The sites along the Chanhe River are located on the east and west banks, while the Bahe River is limited to the east bank (see Figure 1 for details). In addition, there are also Neolithic cultural sites found near the Weihe, Fenghe, and Laohe river tributaries of the Weihe River that flow down from the Qinling Mountains in downtown Xi’an, as well as the pond and lakes along the river (Nianhai & Xianzhi 1996). Primitive humans ‘living by water’ objectively provided very convenient conditions for frequent contacts and cultural exchanges among settlements in the river network.

Historical evolution of urban water conservancy projects

Xi’an was the ancient capital of 13 dynasties, including the Western Zhou, Qin, Western Han, New Dynasty, Former Zhao, Former Qin, Later Qin, Western Wei, Northern Zhou, Sui Dynasty, Tang Dynasty, Eastern Han Dynasty and Western Jin Dynasty, with a history of 1,140 years. The transformation of the ancient capital in the thirteen dynasties is a history of the evolution of water conservancy projects, among which urban water conservancy projects in the Western Zhou, Qin, Western Han, Sui and Tang dynasties are typical. In addition, the water conservancy projects
after the abandonment of the capital are in the same line as the destiny of the city, and appear weak and unsustainable.

‘Two capitals along the Fenghe River’ by Fenghao in Western Zhou Dynasty

In the 11th century BC, people from the Zhou Dynasty entered the Fenghe River basin on the south bank of the Weihe River in the central part of the Guanzhong from Xiqi. King Wen and King Wu established Fengjing and Haojing on the west and east banks of the Fenghe River respectively, establishing the Western Zhou Dynasty. Since then, Xi’an began its historical structure as the political, economic and cultural center of ancient China, and began its glorious history of building the capital of thirteen emperors (Si 2012).

Fengjing and Haojing in the Western Zhou Dynasty were the earliest twin cities in the world. Facing each
other across the Fenghe River, the two cities are two functional areas of the same city. Fengjing is rich in water resources, and the people of Zhou built the capital in Feng, without the trouble of Weihe River, enjoying the advantages of near by water; it can not only control the water and land transportation from east to west, but also facilitate the development of agricultural production. After Zhou Wu succeeded to the throne, he moved the capital to the east bank of the Fenghe River and established Haojing (Qiliang & Xin 2014) (see Figure 2 for details). Feng and Hao areas are located in the central part of Guanzhong and on the south bank of Weihe River. The terrain is relatively
low and flat, and the fertile fields are endless. It is close to the waters of Fenghe, Weihe, Haohe, Juehe, and Laohe rivers. There are many ponds and rivers. It is ideal for fishing activities. It has superior natural conditions and convenient water resources. Fenghao was not only the political center of the Western Zhou Dynasty, but also one of its main farming areas (Liancheng 1988).

‘Capital passed by Weihe River’ in Xianyang City of Qin Dynasty

In 350 BC, emperor Xiao of Qin Dynasty entered Xianyang from Yong city. Qin Xianyang City is composed of the north bank of Weihe River Qin Xianyang Old City and the south bank of Weihe River Extension. The north part is mainly composed of the palace area in the upper part of Xianyang and the handicraft area, market area and residential area under the original area, including Jique, Xianyang Palace, Lanchi Palace, Wangyi Palace and the ‘Six Kingdoms Palace’. In terms of water supply, in addition to quoting Weihe River water, a large number of wells have been discovered. The known wells are densely arranged with a minimum distance of only about one meter and were specialized water supply organizations at that time (Zhuomin 1994). Changxing Handicraft Industrial Zone is located in the southwest of the North District, near the floodplain on the north bank of the Weihe River. The water intake facilities are wells. As of 1981, a total of 116 such relics have been discovered and 20 have been cleaned and excavated (Juanni 1988).

The south part of Qin Xianyang City is composed of palaces, ancestral temples, markets, residential areas, and handicraft workshops (Xin 2006). Some used natural lakes to build the Shanglin Garden for the emperor’s safari, and there were plans to build the world palace Epang Palace, Zhangtai Palace, Xin Palace and Xingle Palace, which have become another huge palace complex in Qin Xianyang. The Weihe River is the link connecting the north bank and south bank districts of Qin Xianyang City. With Xianyang as the center, the city extends to the Yellow River in the east, Qianhe River in the west, Jiuzong Mountain in the north, and Qinling Mountains in the south. The Xianyang city of the ‘Weihe River Runs Through the Capital’ was under construction, its scope had been expanding, and the center of gravity of the entire city had also moved south. In a sense, Xianyang City, the capital of Qin Dynasty, is a city that has not yet been completed. Details are seen in Figure 3.

‘Prosperous capital’ of Chang’an in the Western Han Dynasty

In more than 200 BC, Liu Bang, the emperor of the Han Dynasty, destroyed the Qin Dynasty, creating the second era of great unification in the history of our country. On the south bank of the Weihe River, the hydrological and geographical environment is superior, with rivers crisscrossing and densely covered with lakes and ponds. A new capital was established on the southern bank of the Weihe River, named ‘Chang’an’, opening up Chang’an, the most prestigious thousand-year-old capital in Chinese history (Figure 4).

The urban water conservancy of Chang’an City in the Western Han Dynasty also reached a development climax. In addition to inheriting Qin Xianyang’s use of natural lakes to build gardens in Shanglin Garden in the suburbs, it also drew Juehe water to supply water to the city, and sculpted a large water storage reservoir, Kunming Lake. A comprehensive water conservancy system with multiple functions including water storage, drainage and drainage combined with water storage and drainage, water supply, gardens, trench protection, and shipping centered on the Juehe water and Kunming Lake had been built, and basically connected into a river network (Lingfu 2002).

The water supply for the moat and suburban living, ecological and production of Han Chang’an City mainly comes from the water of Juehe and its branches. The water branch canal supplies water for the urban gardens and the east city trenches in the city. The main stream of the water mainly serves the Jianzhang Palace area in the western suburbs. The water supply problem and the water supply in the Xicheng trenches, Juehe and its branches solves the ecological and production water use in the north city trenches and northern suburbs. South moat and South ceremonial construction water mainly come from Cao channel and Kunming old channel (Lingfu 2002).

Kunming Lake is the first artificial water storage project in the history of our country (Jianjun 2016). Kunming Lake is the main reservoir of the Han Chang’an City. A weir is set to the south to take the water from the Xiaohua River after the
confluence of the Juehe water and the Haohe water. An artificial water channel was opened on the east and north sides of the pond to directly or indirectly supply water to the Han Chang'an City with Juehe water, and an artificial canal was opened on the west side to open the Feng River to adjust the water level. Kunming Lake has basically the functions of water diversion, water storage and drainage. It is a comprehensive urban water conservancy project with a relatively complex and self-contained system. The area of Kunming Lake is about 10 km², and a water storage capacity of about 50 million m³. Kunming Lake was used to practice water warfare, and, it also played other functions such as supplying the capital's water source and smooth water transportation.

The current part of the Juehe River and the entire Xiaohe River are artificial rivers. They cut off the ancient Haohe river and the ancient Juehe river, making them flow to the west and join the Fenghe River. The Xiaohe River refers to the section from Xiangji Temple to the entrance of Fenghe River after the confluence of Juehe

Figure 3 | Qin Xianyang and Weihe River run through the capital.
and Haohe. The role of the excavation of the Xiaohe River is to intercept the main streams of the two waters, and drain the Feng River to the west, so as to control the water diversion to the Kunming Lake and relieve the threat of water damage to the Han Chang’an City. At the same time, the construction of Shita Weir, a river diversion facility at the interception, can also divert water into the Kunming Lake more stably and maintain the water volume of the Kunming Lake, so that the role of Kunming Lake, the storage reservoir of Han Chang’an City, can be fully utilized for a long time.

In the sixth year of Emperor Wu of the Han Dynasty, an artificial canal parallel to the Weihe River was dug along the northern foot of the Qinling Mountains, starting from Kunming Lake in the southwest of Han Chang’an City in the west, and receiving the Chanhe and Bahe rivers to the east. It is close to the Qinling mountains and the Weihe River, passing through Kunming Lake, the northern suburbs of Xi’an, Xinzhu, Xinfeng, Weinan, and Huaxian to the north of Huayin City into the Weihe River, with a total length of 150 km (93.2 miles) (Jianjun 2016). This was an important water conservancy project in the Han Dynasty and the first artificial canal in Chinese history.

‘Capital be ringed by eight rivers’ of Chang’an in Sui and Tang Dynasties

The Sui Dynasty was established in 581 AD, and the capital still used the old capital of Chang’an City in the Western Han Dynasty. After hundreds of years, the Han Chang’an city was dilapidated, with continuous precipitation of urban sewage and salty groundwater. It is located on the first terrace on the south bank of the Weihe River, with an altitude of 375–390 m; the terrain is low, and it is frequently threatened by floods. In the second year of Emperor Wen of
the Sui Dynasty (AD 590), he began to plan and build the new capital – Daxing City. The new capital is far away from the Weihe River, located at the southern foot of Longshouyuan on the second and third level terraces of the Weihe River, with an altitude of 400–450 m and a relatively high terrain. In 618 AD, Tang established the country and expanded the capital on the basis of Daxing City in the Sui Dynasty (Lihui 2011).

During the Tang Dynasty, Chang’an City was one of the largest cities in the world at that time, with an area of 84 km², 2.4 times that of Han Chang’an City, and a population of more than one million at its peak (Zuobin 2013). The surging of the eight waters nourished Chang’an (Figure 5). The four waters of the Chanhe, Juehe, Xiaohe River after the confluence of the Juehe River and the Haohe River, and the Weihe River are most closely related to Chang’an City in the Sui and Tang Dynasties. The Chan River is in the east, the Juehe River and the Xiaohe River are in the south, the Cao River is a stream of the Juehe River in the west of the city, and the Weihe River lies in

Figure 5 ‘Eight Waters’ surround Tang Chang’an.
the north. The builders of Chang'an City just used these natural rivers and made reasonable arrangements for the use of water sources in Chang'an City (Chaonan 2009). In the early Sui Dynasty, when Daxing city was built, three ditches, Longshou Canal, Qingming Canal, and Yong'an Canal were built to solve the water supply for the city and the palace. At the end of the Sui Dynasty, the Tang Dynasty added Daming Palace and Xingqing Palace on the basis of Daxing City in the Sui Dynasty, and built the Huang Canal, Cao Canal, many ponds, moats, spring wells and other water conservancy facilities, which further improved the urban water supply network. A relatively systematic urban water conservancy network structure has been formed, such as pools for storing water, water diversion canal, trench drainage, trench defense, scattered wells, etc., and there are full-time water conservancy management agencies and relatively complete water conservancy management regulations.

(a) Pools for storing water

The excavation of ponds and lakes was a key project in the water system construction of Chang'an City in the Sui and Tang Dynasties. There are ponds in nearly half of the city's community. There are 57 ponds that can be verified (Zuobin 2013). The ponds are the center, and the canals are used to divert water and build gardens. Kunming Lake in the western suburbs, Qujiang Lake in the southeast of the city, and the imperial garden ponds in the three palaces of Taiji Palace, Daming Palace and Xingqing Palace are the most typical.

(b) Water diversion canal

Chang'an City in the Sui and Tang Dynasties mainly consisted of five main canals, namely Longshou Canal, Yong'an Canal, Qingming Canal, Huang Canal and Cao Canal, which constituted the backbone water diversion network. The five canals and the vertical and horizontal branch canal systems of the community are intertwined with each other, and they are governed by partitions to comprehensively solve the water used for domestic production and pond landscape in Chang'an City (Yabin et al. 2010).

(c) Trench drainage

At that time, the road surface of Chang'an City Road was high in the middle and low on both sides. Drainage ditches were located on both sides of the road, and were significantly lower than the road surface by about one meter. The main water supply channels could also drain stagnant water and relieve the pressure of urban drainage. The ditches became the backbone of urban drainage. Drainage facilities such as drainage pipes and small brick drainage ditches made of ceramic pipe sleeves have been used in the palace. Seepage wells and seepage pits that mainly drain domestic sewage are auxiliary drainage facilities of the city. Ponds and rivers are necessary supplements for urban drainage. Rivers, ditches, ponds, seepage wells, seepage pits, and so on together constitute the urban drainage system. The comprehensive use of multiple drainage methods enhances the urban drainage system's ability to collect, discharge and purify water (Bing 2015).

(d) Trench defense

At the end of Tang Dynasty, due to the need for urban defense, a ring-shaped moat was excavated outside the city wall, and water was conducted from the Longshou Canal into the trench, which played a necessary role in consolidating the city defense (Zuobin 2013).

(e) Scattered wells

Chang'an City is backed by the Longshou plateau form, and the low-lying area in between contains abundant groundwater. The water level is very shallow, with an abundant water volume, refreshing and delicious, and easy to access. Residents’ domestic water mainly relied on groundwater, and more wells were drilled for water, supplemented by surface canal water (Junxia & Yaoping 1994).

(f) Management

In the Tang Dynasty, attention was paid to the development of water conservancy and agriculture was developed. More than a thousand water conservancy projects were built and nearly 10,000 hectares of farmland irrigated. In order to strengthen the unified management of water conservancy, two departments, the Department of Water Department and the Supervision Department, were responsible for the management of water conservancy (Hongbin 1992), and a water law that everyone must abide by ‘Regulations of Water Conservancy Department’ (Yonghou 2007) had been formulated.

In the Sui and Tang Dynasties, Chang'an City was equipped with water conservancy facilities such as water
diversion channels, reservoirs and marshes, drainage ditches, drinking water wells and springs, military defenses, and so on. Equipped with a full-time water conservancy management agency and relatively complete water conservancy management laws and regulations, the city’s surface water resources and groundwater resources had been enriched, and constituted an urban water supply and drainage system that conformed to the natural terrain, had a reasonable layout, and were scientifically dispatched. It satisfied the various functions of urban life, production, water transportation, flood control, drainage, landscape, urban defense, and so on, and was a prerequisite for helping ‘Chang’an Prosperity’.

‘Reduced water’ after the abandoned city

After the fall of the Tang Dynasty, the Central Plains experienced five dynasties and ten kingdoms. Chang’an City underwent major changes such as moving the capital, destroying the city, and shrinking. The reconstructed Chang’an city is called the ‘new city’. The urban area of the new city is 5.4 km², which is only one-sixteenth of the original urban area of 84.1 km², and its scale is no longer the same as that of Tang Chang’an (Shiguang 2003) (see Figure 6). With the loss of the status of Chang’an City as the ruling center of the state capital and the overall contraction, the main canals such as Longshou, Yong’an, Qingming, Huang canal and Cao channel, which crisscrossed the city of Chang’an in the original Tang Dynasty, dried up in the late Tang Dynasty, and the urban water mainly relied on well water. However, from the well system in the early Sui Dynasty, hundreds of years of well water collection and sewage recharge have made most of the groundwater increasingly salty and bitter, and the deterioration of the water environment has greatly degraded the urban living environment.

Until the establishment of the Northern Song Dynasty, Jingzhao Mansion Chang’an City served as the military command center in the northwest. Residents gradually moved in the desolate imperial city and the living environment was restored. Because the well water in the city was mostly salty and bitter, the Longshou West Canal was repaired during the reign of Song Zhenzong and the Chan River was introduced into the city. The water diversion of Longshou Canal and some wells effectively solved the domestic water problem of urban residents in Jingzhao.
prefecture, and the Longshou Canal met the water consumption of Xingqing Pool and the moat (Yuanlin 2001). During the Jin Dynasty destruction of the Northern Song Dynasty, the Longshou Canal continued to live in the city and the water supply of the Xingqing Pool was not cut off. During the war between the Jin and Yuan dynasties, the Longshou Canal was damaged by war and the Xingqing Pool dried up. After the Yuan Dynasty destroyed the Jin, the Jingzhao Mansion was changed to Anxi Mansion and then Fengyuan city. In the early Yuan Dynasty, the Longshou West Canal was repaired on the basis of the Longshou Canal in the Song Dynasty. At the same time, the Longshou East Canal was excavated, which mainly flows through Wangchun Palace and flows into Anxi Palace from the northwest of Changlepo (Shiguang 2003) (Figure 7). After the middle of Yuan Dynasty, Longshou Canal was abandoned again.

After the Ming Dynasty collapsed, Fengyuan city was changed to Xi’an city. Since then, ‘Xi’an’ has been named as an administrative division, and the city of Xi’an has also ushered in the resurgence of urban construction since the Tang Dynasty. In the early Ming Dynasty, the city of Xi’an was expanded. Except for the location of the ‘new city’ on the west and south sides, it was expanded by about one-third on the east and north sides, respectively, and the Palace of the King of Qin, the Drum Tower, and the Bell Tower were built. The area of Xi’an city after the new development was about 11.50 km², and the overall layout of Xi’an City has been basically established. The overall structure of the urban domestic water network has been constructed through measures such as the reconstruction of the Longshou Canal and the construction of the Tongji Canal (Figure 8). The two canal systems are intertwined and complemented each other, building a basically complete water supply network in Xi’an City, and also playing an important role in the military defense of the city, garden landscape, and fire protection in the city (Shiguang 2003).

In the Qing Dynasty, due to the deterioration of the ecological environment of the Qinling Mountains, the water volume of the Longshou and Tongji channels was reduced. In addition, the channels collapsed, and the two channels were gradually abandoned (Shiguang 2003) (Figure 9). Therefore, in the late Qing Dynasty, the supply of drinking water in the city mainly relied on the ‘five famous wells’. The urban domestic water network in Xi’an turned to a closed water supply mode that uses groundwater as the main water source and used a large number of wells to achieve urban water supply (Zuobin 2013).

During the Republic of China, project construction activities mainly concentrated on the construction of Xilong Canal and water wells. But the time limit for use of the Xilong Canal was relatively short. The urban water supply mainly relied on underground well water. By the eve of the liberation in 1949, there were 64 public and private motorized wells in Xi’an. The water output of the urban ‘sweet water’ earth wells and motorized wells was not only for industrial water, but also for daily drinking by citizens. ‘Sweet water’ was about 500 m³, and people who drank ‘sweet water’ were about half of the urban population (Hongshuai 2012). At the same time, a group of water conservancy engineers headed by Li Yizhi created the ‘Eight canal in Guanzhong’: Jinghui Canal, Heihui Canal, Fenghui Canal and Laohui Canal Four Canals around Xi’an, which greatly promoted agricultural production in Xi’an.
the surrounding districts and counties of Xi’an (Jianjun & Jianping 2001).

‘Coordinated supply’ after the founding of the People’s Republic

The water supply project in Xi’an began in 1936, but was suspended due to war. After the founding of New China, construction restarted in 1951, and water was officially opened on October 1, 1952, opening the history of modern urban water supply in Xi’an. Before the Shitouhe Reservoir provided water to Xi’an in 1996, the urban water supply was mainly groundwater. A groundwater water supply system composed of riverside groundwater such as Chanhe River, Bahe River, Fenghe River, Zaohe River, Weihe River, and Northwest Suburb.
Water Sources and self-provided wells have been built, but it still cannot meet the increasing demand for water consumption. Especially in the summer of 1995, the surface water source basically stopped supplying water to the city due to dry early days, and the city’s water supply was extremely tight, and the most serious ‘water shortage’ in the history of urban water supply in Xi’an appeared. In 1996, the channel for water supply from the Shitouhe Reservoir to Xi’an was formally completed, and the urban water supply was gradually transformed into surface water sources, forming the main body of the ‘Heihe Water Diversion Project’ (including Shitouhe Reservoir, Heihe Jinpen Reservoir, Shibianyu Reservoir, Fenghe River and Tianyu River) and Lijiahe Reservoir are auxiliary surface water supply systems (Figure 10).

As the urban layout structure of Xi’an develops from a single center to a peripheral group of towns, the scope of the city has expanded and the urban population has increased sharply. Water resources in the basin are no longer sufficient to support the sustainable development of the city. The ongoing water diversion project from Han River to Weihe River basin is expected to become the main force in solving the problem of water resources in Xi’an. It will cause the city’s water supply to be divided into two parts: local water sources and inter-basin water transfer. After the implementation of the Han-to-Wei River Diversion Project, the total water supply capacity of the Guanzhong area will reach 7.5 billion cubic meters. The per capita water resources in the Guanzhong area of the Weihe River Basin will increase.
from about 370 cubic meters to about 450 cubic meters, and the per capita water consumption will increase from about 200 cubic meters. Increased to about 300 cubic meters, the newly-added urban industrial production available water is nearly 1.4 billion cubic meters.

**INFLUENCE**

From ancient times to the present, the construction of water conservancy projects has been closely related to people’s livelihood, and it has also greatly affected and restricted the development of cities. Since Lantian ape-man’s human water collection to the current large-scale water conservancy project delivery and distribution, human water collection has undergone a long period of development. Table 1 summarizes the development of water intake in Xi’an. It can be seen from Table 1 that the relationship between human settlements and water sources has gone from near to far. During the Lantian Ape Man and Western Zhou Dynasty, the residence was relatively close to the water source, which was convenient for life, fish farming and farming. With the development of industry, the distance between residential areas and water has gradually become

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longer. Humans have built water conservancy projects for different purposes, from simple digging of wells for water, to relatively complex large-scale artificial reservoirs and artificial rivers and other integrated water conservancy systems, to complex systems of urban water network facilities, and to today’s more technologically-content solutions. Surface water supply systems and cross-basin water transfer systems have gradually increased water intake and gradually improved water supply systems. It provides a convenient way for humans to take water. Figure 11 shows the distance between the urban water source (water intake or dam site) and the urban center in different periods. With the advancement of science and technology, the distance between the water source and the city shows a trend of growing farther and farther. With the development of society and the increasing demand for water by human beings, we should realize the importance of rational development of water resources. Therefore, the development of water resources should adhere to green and sustainable development, and steadily establish a new harmonious supply pattern.

As shown in Figure 12, we have analyzed in detail the water supply in Xi’an in recent years (1980–2019), including surface water supply in the river basin, surface water supply across river basins, groundwater supply, other unconventional water sources, and total water supply. Through analysis, the following laws were found:

(1) The city’s total water supply increases along with the city’s development. There was a partial downward trend from 2000 to 2009, mainly because the amount of water supplied to agriculture decreased significantly before and after the implementation of water-saving measures. In 2000, the total water supply was 1.787 billion m$^3$, of which the water supply for agriculture was 964 million m$^3$ (Xi’an Water Authority), accounting for 53.95% of the total water supply. After 2000, with the promotion and use of agricultural water-saving measures, the total water supply volume in 2009 was 1.555 billion m$^3$, a decrease of 232 million m$^3$ compared with 2000; the amount of water supplied to agriculture was 694 million m$^3$ (Xi’an Water Authority), a decrease of 270 million m$^3$ from 2000, with the water supplied to agriculture accounting for 44.63% of the total water supply.

(2) The water supply of surface water in the basin reaches its peak before the completion of the inter-basin water transfer project. It is expected that after the completion of the inter-basin water transfer project, it will show a downward trend. The amount of water reduced before the completion of the cross-basin water transfer project will gradually be converted into the amount of water that can ensure and improve the ecological environment in the region.

(3) The city’s groundwater supply reached its peak in 2000. With the successful completion of surface water source projects in the basin, there is a downward trend. It is expected that after the completion of the inter-basin water transfer project (estimated in 2024), the amount of groundwater supply will further decline.

(4) With the advancement of technology and the strengthening of water resources management, the amount of
unconventional water supply such as rainwater utilization and sewage treatment and reuse has shown an increasing trend.

The changes in temperature, precipitation, runoff and human activities in the past 7,000 years have had an important impact on cities and water conservancy projects. For example, the rise of the Himalayas blocked the warm and humid air currents in the Indian Ocean, drought and reduced rainfall; coupled with the increase in population, the construction of cities, the construction of civil engineering projects, the destruction of the ecological environment, and the destruction of cities by war, have made the problem of human water use increasingly prominent. Therefore, it is necessary to continuously develop water supply, flood control, drainage, and landscape water conservancy projects, and use surface water and groundwater to alleviate human demand for water supply.

ENLIGHTENMENT

For thousands of years, the people of the ancient city have lived with water, diverting water to promote agriculture. Water is the original driving force for Xi'an's prosperity. Thousands of years of practice have left us many enlightenments, which are as follows:

(1) The impact of urban sewage on groundwater pollution lasts for hundreds of years. The capitals of the Sui and Tang Dynasties were far away from the capital of the Han Dynasty, Chang'an, because of the continuous precipitation of urban sewage in the city of Chang'an in the Han Dynasty and groundwater is bitter and salty. One of the reasons that Tang Dynasty chose to build Luoyang as the accompanying capital was that hundreds of years of well water collection and sewage recharge had seriously polluted groundwater, and the deterioration of the water environment had greatly degraded the urban living environment. The impact of sewage recharge on groundwater quality is long-lasting, growing for hundreds of years.

(2) The urban water supply model based on groundwater has a significant impact on the urban geological environment. From the founding of the People's Republic of China to 2000, due to the excessive pumping of groundwater in the suburbs of the city, the confined water level dropped drastically, forming a large-area falling funnel, causing ground subsidence and aggravating the vertical activity of ground fissures. After 2000, the mode of water supply in the suburbs of the city was changed to surface water sources. The groundwater level is gradually rising, environmental geological problems are effectively contained, and the ecological environment is being gradually restored.

(3) Water is one of the most important natural factors determining the location and development of a city. From living with water in the ancient times to the later construction of cities across rivers, first-level terraces on rivers, second and third-level terraces on rivers, urban single-center development, and pan-central town cluster development, it is shown that in the urban construction and development of Xi'an, water safety factors such as water sources, flood control, drainage, and water supply are important conditions to ensure urban safety.

(4) We should respect, protect, use, and live in harmony with nature. Xi'an city is surrounded by the 'Eight Waters', with its water resources and water environment experiencing many times of destruction, pollution and natural restoration. The construction of the city is determined by water. Historical experience warns us that human life and urban development need to follow the laws of nature and ecology, and insist on giving priority to water conservation and green development.

Summarize past water conservancy projects, including urban flood control and drainage, urban water supply, and urban water landscape. Urban flood control and drainage means that the city will be built on the second and third level terraces of the river to avoid floods and build pools for drainage. Urban water supply, that is, the construction of canals to divert water to the city, the combined supply of surface water and groundwater, and water transfer projects. The urban water landscape, the 'Eight Water Ring Capital', has inspired modern Chang'an. These water conservancy projects have played an important role. Some buildings have been preserved to this day. Among them, Duijiangyan was built around 256 BC, more than 2,000 years ago, and Zhengguoqu in the Qin Dynasty. Therefore, water conservancy projects are not a one-time construction,
but a career for generations to come. Ecological protection and sustainable development must be considered.

CONCLUSION

In the evolution of Xi’an for more than 7,000 years, it has always been accompanied by the historical changes of water source projects. Starting from how to use water sources, people have gradually understood the truth of living by water and a prospering capital by water. Water source projects have been basically synchronized with the rise and fall of Xi’an capital and played an important role. For thousands of years, the ‘Eight rivers’ in the region have nourished and nurtured the people of the ancient city, and had a profound impact on Xi’an politics, economy, culture, society and other aspects. It was the original driving force for the flourishing Changan in history. With the loss of the function of the capital city of Chang’an, the water potential gradually decreased; since the founding of New China, the urban water supply has undergone a transformation from groundwater sources to surface water sources, and the ‘Heihe Water Diversion Project’ has become a key water source project in Xi’an. The urban layout of Xi’an is further developing, and the inter-basin water diversion project from Han to Weihe River will help the sustainable and healthy development of Greater Xi’an.

AUTHOR CONTRIBUTIONS

Conceptualization, W.Z., JR.C., ZG.X., YX.W., KW.W. and YG.D.; methodology, W.Z., ZG.X. and JR.C.; investigation, W.Z., KW.W. and YG.D.; writing – original draft preparation, W.Z.; writing – review and editing, JR.C., ZG.X., and YX.W.; visualization, W.Z., and YX.W. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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